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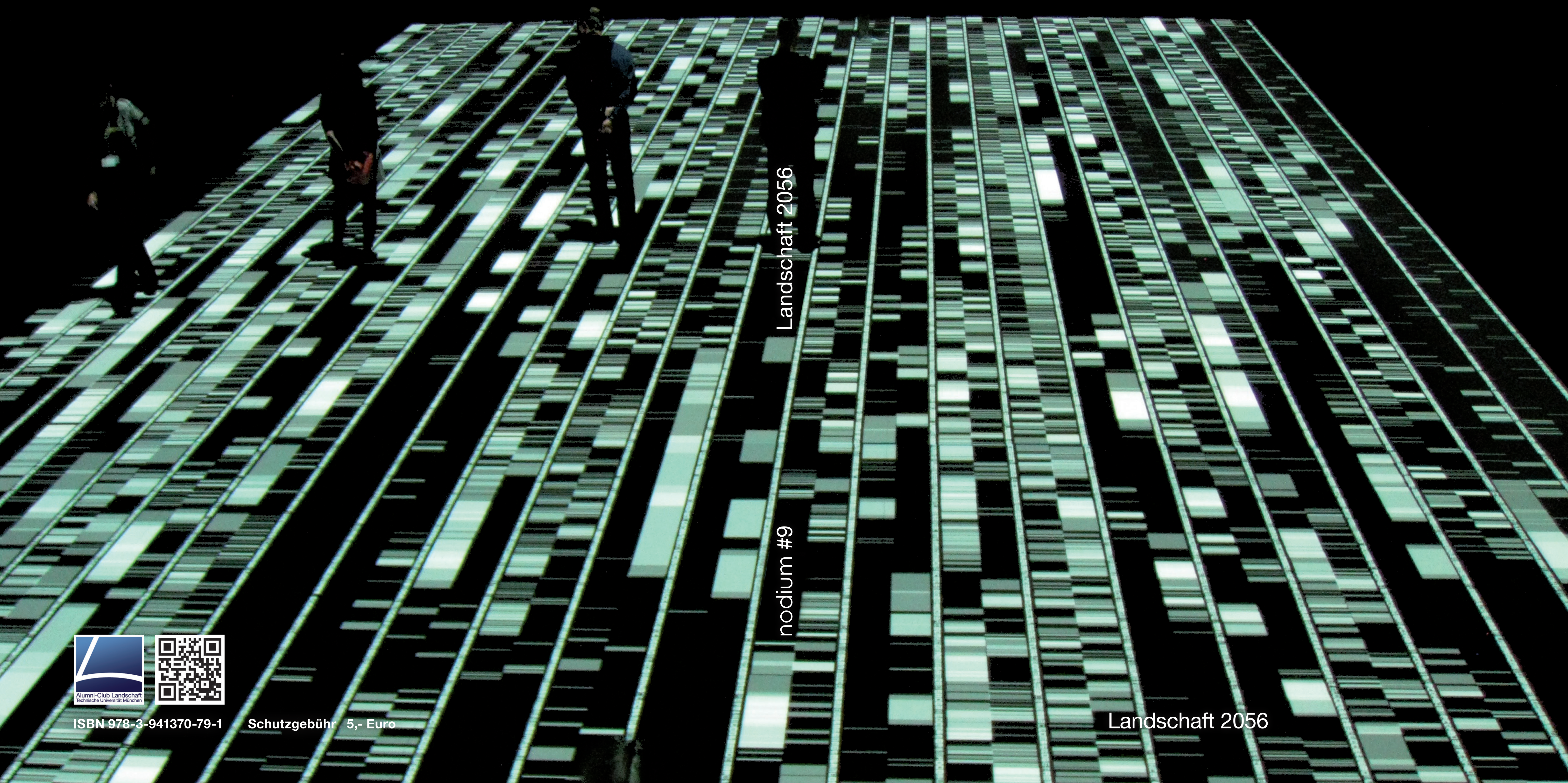

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Outcomes and perspectives of ecological restoration

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A powerful approach to countering the negative impacts of environmental degradation is ecological restoration. Restoration actions are increasingly being implemented in response to the global biodiversity crisis, and are supported by agreements such as the global Convention for Biological Diversity – a major target of its strategic plan for 2020 is restoring at least 15% of degraded ecosystems, the EU Council's conclusions on biodiversity post-2010, e.g. "halting the loss of biodiversity and the degradation of ecosystem services in the EU by 2020, and restoring them in so far as feasible", and the Agenda 2030 – Sustainable Development Goal no. 15 is "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss". In this short paper, I will (1) provide evidence of the increasing global ecological footprint, (2) report quantitative outcomes of ecological restoration based on published meta-analyses, and (3) comment on future perspectives of ecological restoration.

There is scientific evidence that human ecological footprint is still expanding and causing loss of biodiversity and ecosystem function at the global level. For instance, Venter et al. (2016)[1] have estimated an increase of the global ecological footprint by 9% in the 1993-2009 period; a recently published analysis of the PREDICTS[2] database has shown that human-driven land use caused a loss of 13.6% of local biodiversity worldwide as compared to natural ecosystems by 2005; and the last Living Planet Report (2016)[3] shows a reduction of the Living Planet Index by 58% since 1970. Newbold et al. (2016)[4] estimated that "land use and related pressures have already reduced local biodiversity intactness – the average proportion of natural biodiversity remaining in local ecosystems – beyond its recently proposed planetary boundary (i.e., 80%) across 58.1% of the world's land surface, where 71.4% of the human population live".

As ecological restoration aims to recover the biodiversity and function of degraded or destroyed ecosystems to benefit humans, assessing the outcomes it delivers is critical for both scientists and practitioners. I propose to measure these outcomes as the recovery progress or the recovery completeness of ecological integrity in the restored state against the degraded or reference states, respectively. However, measuring ecological integrity is not an easy and straighforward task as it is underpinned by multiple structural components (both abiotic and biotic, including the multiple forms of biodiversity) and processes. Thus, for practical reasons, people usually measure a limited set of indicators that are related to these components and processes. As illustrated in Figure 1, it is predictibly more difficult to recover ecological integrity – a concept implicit to the "official" definition of ecological restoration (SERI 2004)[5] – than recovering particular components and processes, e.g. carbon sequestration.

Rey Benayas et al. (2017)[6] reported a synthesis of outcomes of ecological restoration according to various published global meta-analyses, which are summarized in Table 1. For all ecosystem types, recovery progress or enhancement of biodiversity and ecosystem services (ES) by ecological restoration averaged 58 and 99%, respectively; however, values

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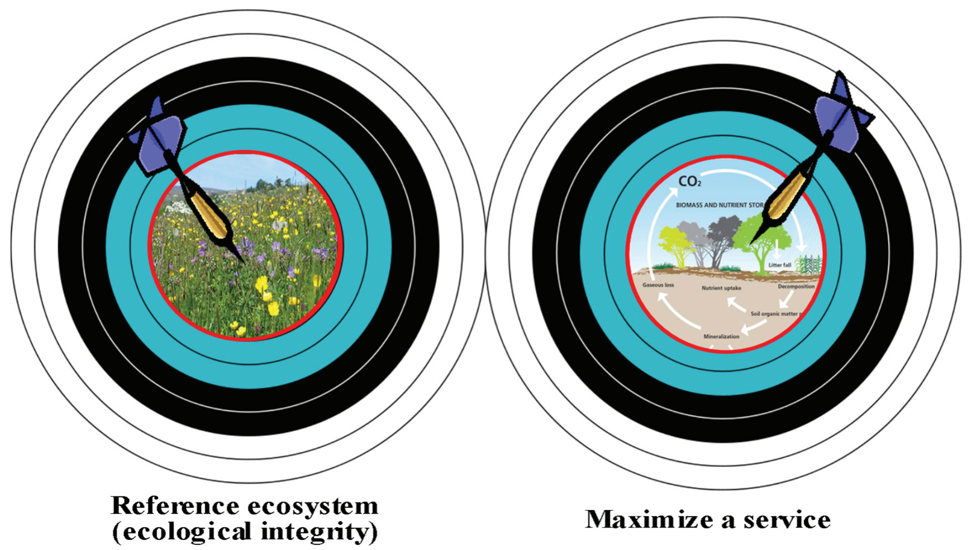

Figure 1. Success of anything depends on the planned objetives. As this figure shows, it is different to restore the ecological integrity of a reference ecosystem (left) than a particular component or process/function (e.g. carbon sequestration, right). This figure was produced by James M. Bullock.

Ecosystem type	Biodiversity		All ES		Supporting ES		Regulation ES		Provisioning ES		Source
All	**38**	**-14**	**25**	**-20**	**28**	**-18**	**20**	**-44**	-24	23	Rey Benayas *et al.* 2009
Wetlands	**19**	-2	**43**	**-13**	**40**	**-16**	**47**	**-22**	**80**	-7	Meli *et al.* 2017
Agroecosystems	**68**	-3	NA	NA	**42**	-18	**120**	22	NA	NA	Barral *et al.* 2015
Forests	**106**	**-21**	**228**	9	NA	NA	**131**	-5	NA	NA	Meli *et al.* (under review)
Mean ± sd	**58 ± 38**	**-10 ± 9**	**99 ± 112**	**-8 ± 15**	**37 ± 8**	**-17 ± 1**	**79 ± 54**	**-12 ± 28**	**28 ± 74**	**8 ± 21**	

Table 1. Recovery progress (comparison of restored and degraded ecosystems, gray columns) and recovery completeness (comparison of restored and reference ecosystems, white columns) after four global meta-analysis of restoration of biodiversity and ecosystem services (ES). The numbers are percentages; note that, for recovery completeness, a positive number means that it is larger than complete or 100% recovery. Numbers in bold indicate statistically significant differences in the levels of biodiversity and ES in restored and degraded, or reference ecosystems (this does not apply to the last row of means and standard deviations); NA means insufficient data for analyses. Cultural ES were only analyzed in wetlands resulting in similar levels in restored and degraded or

of both remained lower in restored versus intact reference ecosystems (recovery completeness averaged -10 and -8%, respectively). Levels of recovery varied among ecosystem types. Restored wetlands showed 19 and 43% higher levels of biodiversity and ES, respectively, than did degraded wetlands; however, their levels of ES were lower (-13%) than in reference wetlands. Restoration increased biodiversity and levels of supporting ES and regulating ES by an average of 68, 42, and 120%, respectively, relative to levels in the pre-restoration agroecosystem, and restored agroecosystems showed levels of biodiversity and these ES similar to those of reference ecosystems. In forests, recovery was complete for all ES, whereas biodiversity, although it increased by 106% after restoration, was 21% lower than in reference forests. There is a gap related to quantitative assessment of cultural ES provided by restored ecosystems in the scientific literature. Biodiversity and ES response ratios are positively correlated in comparisons of restored and degraded ecosystems in all individual meta-analysis. The major conclusion of this study is that ecological restoration markedly enhances biodiversity and ES supply, but the attained levels are lower than those in the reference ecosystems and effectiveness is context-dependent to a large extent.

Whereas ecological restoration has demonstrated a high potential to reverse ecological degradation due to causes such as habitat fragmentation, it is very limited to cope with the impacts of e.g. climate change and biological invasions. Rey Benayas & Bullock (2015)[7] proposed strategic revegetation to enhance wildlife and particular services such as habitat provision and seed dispersal in agricultural landscapes. Strategic revegetation consists on highly specific planting (and sometimes seeding) actions that are characterized as occupying a tiny fraction of the landscape, and may take advantage of the linear elements in the landscapes (ways, roads, field boundaries and others). In actively farmed fields, these actions can include planting woodland islets, hedgerows and isolated trees. They have the potential to enhance wildlife, agricultural production, and other services at the field and landscape scales since they hardly compete for farmland use, and can be considered a form of rewilding per se.

To illustrate the uncertainty related to perspectives of ecological restoration, I use here the hope related to technological progress, which is expected to reduce human footprint by e.g. more efficient use of resources (water, energy, and others)

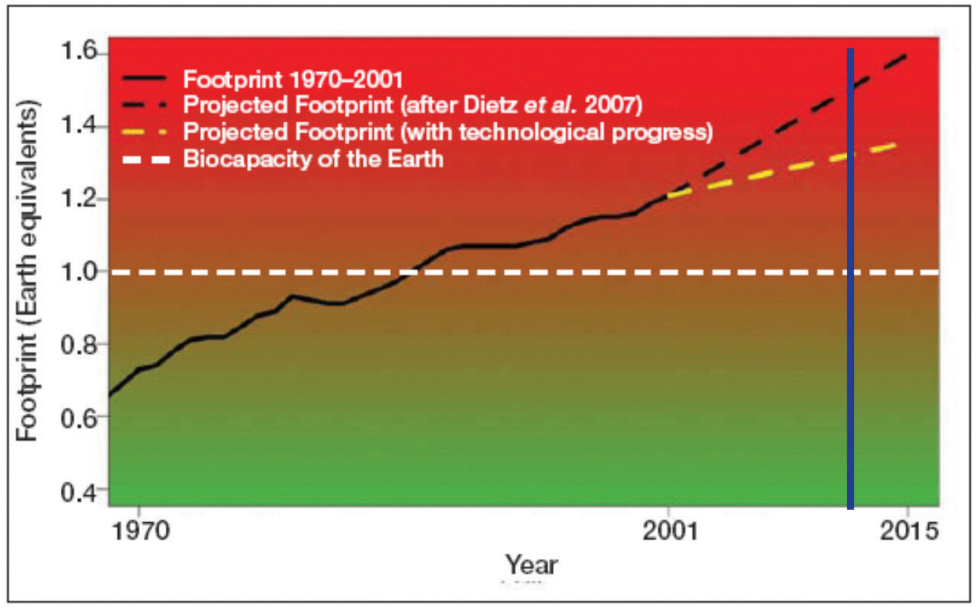

Figure 2. Measured (by 2001, continuous black line) and projected global ecological footprint with technological progress (dashed yellow line) and without technological progress (dashed black line) according to the studies of Hockley et al. (2008)[11] and Dietz et al. (2007)[12], respectively. The blue vertical line shows the measure of global ecological footprint in 2012 according to the Living Planet Report (2016).

and less pollution from industry processes. I compared the projected global ecological footprint with and without technological progress according to two earlier studies (Hockley et al. 2008[8] and Dietz et al. 2007[9], respectively) with the last measure of this footprint according to the Living Planet Report (2016)[10], that was estimated in circa 1.6 Earth equivalents by 2012 (Figure 2). This comparison shows that the global ecological footprint has overshot even the most pesimitic predicted scenario in absence of technological progress. Part of the reason is that technological progress is producing cheaper goods and services and hence they are more accesible to people, ultimately resulting in higher consumption of resources. Nevertheless, technological progress and scientific knowledge will favour more efficient restoration actions; two examples of these are ”assisted evolution“ and ”de-extinction of species“.

To conclude, further research is always needed but ecological restoration actions in the real world are desperately needed to reverse loss of biodiversity and ecosystem services due to environmental degradation. Conserving natural habitats is crucial for human well-being as outcomes of ecological restoration are limited, at least in the short to middle run. Ecological restoration should be a relevant component of the transition to a green economy.

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