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Pesticides, soil removal, and fire for the restoration of ecosystems? A call for ethical standards in ecosystem restoration

Pestizide, Bodenabtrag und Feuer zur Renaturierung von Ökosystemen? Ein Plädoyer für ethische Standards bei der Ökosystemrenaturierung

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Abstract

The restoration of degraded ecosystems has become a challenge for our societies in the 21st century. In order to assist the recovery of degraded, damaged, or destroyed ecosystems towards the enhanced provision of ecosystem services, a broad set of measures are nowadays applied, which range from doing nothing up to a heavy impact with technological measures. With the application of those measures that, in other cases, strongly contributed and contribute to ecosystem degradation worldwide (e.g. the application of pesticides) it seems as if the restoration targets have absolute priority, no matter what measure applied to achieve them. Accordingly, we want to critically debate the application of certain measures by focusing on pesticide application, topsoil removal, and prescribed burning. We hereby assessed the ecological impact as well as the impact on humans by means of environmental ethics. It turns out that measures for the restoration of ecosystems have to undergo not only an ecological and socio-economic assessment but also have to be grounded on ethical considerations. Approaches such as, e.g. multi-criteria decision or ecological impact assessment provide tools for theory and practice of restoration. Based on our critical reflection, we suggest an implementation of environmental ethics into the definition and guiding objectives of ecosystem restoration.

Keywords: *environmental pragmatism; prescribed burning; resource protection; restoration measures; strong sustainability; topsoil removal*

Zusammenfassung

Die Renaturierung degradierter Ökosysteme ist eine Herausforderung des 21. Jahrhunderts. Um die Ökosystem(dienst)leistungen degradierter, beschädigter oder zerstörter Ökosysteme wiederherzustellen, werden sehr verschiedene Maßnahmen angewendet, die vom Nichtstun bis hin zu umfangreichen technologischen Maßnahmen reichen. Mit der Anwendung solcher Maßnahmen, die weltweit zu einer Degradation von Ökosystemen beigetragen haben (z.B. Ausbringung von Pestiziden), scheint es, als hätten die Renaturierungsziele absolute Priorität, unabhängig davon, welche Maßnahmen zu ihrer Erreichung angewendet wurden. Wir stellen hier deshalb die Anwendung bestimmter Renaturierungsmaßnahmen auf den Prüfstand und fokussieren hierbei auf Pestizide, den Oberbodenabtrag und kontrolliertes Brennen. Wir beleuchten einerseits die ökologischen Auswirkungen dieser Maßnahmen aus der Sicht der Naturwissenschaften und andererseits bewerten wir diese aus der Sicht der Umweltethik. Wir heben hervor, dass Maßnahmen zur Renaturierung von Ökosystemen nicht nur einer ökologischen und sozioökonomischen Bewertung unterzogen werden müssen, sondern auch auf ethischen Erwägungen beruhen müssen. Ansätze wie z.B. Multikriterienanalyse oder die ökologische Folgenabschätzung bieten Werkzeuge für Theorie und Praxis der Renaturierungsökologie bzw. Ökosystemrenaturierung. Basierend auf unserer kritischen Reflexion schlagen wir eine Implementierung ethischer Erwägungen in der Definition und den Zielen der Ökosystemrenaturierung vor.

Schlüsselwörter: Umweltpragmatismus; kontrolliertes Brennen; Ressourcenschutz; Renaturierungsmaßnahmen; starke Nachhaltigkeit; Oberbodenabtrag

1 Introduction

1.1 Ecosystem restoration on the world's environmental agenda

Worldwide, natural and cultural environments have been degraded by strong and unsustainable human interferences. This means that the degree of human impacts has increased up to grades that impair ecosystem functions from which humans and non-human organisms benefit via ecosystem services (provisioning, regulating, cultural). Therefore, the restoration of degraded ecosystems has become a challenge for our societies in the 21st century in order to restore ecosystem services. Ecosystem services to restore comprise, in accordance with the Millennium Ecosystem Assessment (MEA 2005), production (e.g. timber, crops, non-timber products), regulation (e.g. water, soil fertility, carbon sequestration, erosion protection), and cultural services (e.g. for recreation, tourism, environmental education). Restoration is one guideline in the field of nature conservation that deserves close societal and political interest. Walder (2018: p1) rightly states that it is "one of the most important steps we can take to ensure that people can continue to survive, and thrive, on Planet Earth". The UN recently declared the next Decade on Ecosystem Restoration (2021–2030). Among global restoration initiatives stated by Gann et al. (2019) are the United Nations Sustainable Development Goals (DSDG 2020), the Convention on Biological Diversity (CBD 2016), the United Nations Convention to Combat Desertification (Orr et al. 2017), and the Bonn Challenge, launched by the Government of Germany and the International Union for Conservation of Nature (IUCN 2011).

1.2 Restoration ecology: concepts, aims, approaches

Restoration ecology is considered to take ground as a discipline of ecology since the 1930ies with the "restoration" of the Curtis Prairie at the University of Wisconsin-Madison Arboretum (Wegener et al. 2008), although it was not carried out on a reproducible scientific basis (Anderson 2009) and has more the character of a foundation myth (Jordan III & Lubick 2011, p. 75). Since then, restoration ecology has rapidly emerged and has been continuously developed with its concepts, approaches, and measures on the international level (e.g. SER 2004; Andel & Aronson 2012; Zerbe 2019). A large number of ecosystem restoration projects on the local up to the landscape level have been carried out (e.g. for river restoration projects in the USA, see Bernhardt et al. 2005). Experiences in practical restoration throughout the past decades have been gathered for many terrestrial ecosystems, including lakes and wetlands as well as rivers with their floodplains. Additionally, there is growing interest in the urgently needed restoration of marine ecosystems (e.g. Böhm & Ott 2019). Besides the numerous single projects which were documented in scientific journals and through other dissemination sources (e.g. Fagúndez 2013 for the restoration of heathland), a high number of textbooks and comprehensive general overviews of restoration ecology or focusing on specific ecosystems or land-use types, respectively, have been published since the 1980ies, one of the first ones by Bradshaw & Chadwick (1980).

The international Society for Ecological Restoration (SER) defines ecological restoration as "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (Clewell et al. 2002; Gann et al. 2019). This rather broad and unspecific definition was specified by Zerbe et al. (2009) with focusing on the restoration of ecosystem services and structure against the background of the current ecological and socio-economic conditions. "Degradation" is a term which is used in manifold different contexts, defined very differently by various sources, and often ambivalent. Lund (2009), for example, compiled more than 50 different definitions for "forest degradation". The WHO (2017) relates land degradation to the loss of ecosystem services. Accordingly, the large-scale use of synthetic pesticides in agriculture leads to the loss of biodiversity and might negatively affect human health (see chapter 2). Hereby, degradation can be measured with indicators such as, e.g. number of plant and animal species, functional groups of plants, Red-List species, etc. From an ethical perspective, the term "degradation" has evaluative connotations, as it suggests a loss of naturalness. If restoration ecology is about "ecological upgrading" it intends a reversal of former degradation. Such terms strongly indicate the interface between ecology and ethics. Concepts as degradation point to the epistemic problem that some crucial concepts in restoration ecology are so-called hybrids within which factual and evaluative meaning blend. Hybrids are nothing special to restoration ecology but occur in other disciplines as well (as "health" in medicine). We propose an analytical attitude to hybrid concepts. Such attitude commits not to confuse facts and values but to clarify meaning. The concept of damage is at its core evaluative and implies some normativity. A damage should, if possible, be fixed, repaired or compensated. The concept of degradation denotes a deviation from a desirable state which serves as benchmark. Benchmark concepts as "integrity", "naturalness", "health", and "wilderness" are, however, contested (Kirchhoff 2016). The benchmark, against which a degradation is stated, should be scientifically credible. Franke et al. (2020) propose, for instance, a credible interpretation of "ocean health". In any case, the existence of hybrids positively indicates that ethics is inherent to a discipline.

In order to assist this recovery of degraded, damaged, or destroyed ecosystems or land-use systems, a broad set of measures are nowadays applied (Tab. 1), which range from doing nothing (= passive restoration; e.g. Prach & Hobbs 2008) up to a heavy impact with technological measures, often adapted from ecological engineering, for example for restoring natural river or coast dynamics by opening or removing dykes (e.g. Roman & Burdick 2012) or changing the hydro-morphology of rivers (e.g. Darby & Sear 2008). Restoration measures also comprise well-known agricultural practice (e.g. mowing, grazing) as well as the practice of habitat management for nature conservation purposes. As Table 1 indicates, restoration often is a rather interventionistic and "hands-on" strategy full of ambivalences which should be reflected from the perspective of environmental ethics. Given this interventionistic dimension, it does not surprise that restoration has found both supporters as well as critics among environmental ethicists (Katz 1996; Elliot 1997). Irrespectively of this ethical controversy, it seems beyond doubt that restoration ecology has an ethical dimension since it never can be completely value-free (Cairns 2003, Egan et al. 2011).

1.3 Are all restoration measures justified?

Studies and practical restoration projects are carried out in which measures are applied which have led and still lead in other cases to ecosystem degradation. Thus, for example, pesticides are applied in various ecosystems such as, e.g. forests, grasslands, and wetlands in order to get rid of certain invasive plant species or influence the species assemblages according to certain restoration objectives. Glyphosate, for instance, as one of the synthetic pesticides applied (Cornish & Burgin 2005) is highly contested within the legal bodies of the EU because of severe concerns about health risks

Tab 1: Measures of ecosystem restoration according to the restoration objectives with examples of ecosystems and land-use types, respectively (compiled from Zerbe 2019).

Tab 1: *Maßnahmen, die entsprechend der gesetzten Ziele in der Ökosystemrenaturierung Anwendung finden, mit Beispielen von Lebensräumen bzw. Landnutzungstypen (Zusammenstellung nach Zerbe 2019).*

Restoration measures	Objectives	Examples of restored ecosystems and land-use types
Doing nothing (passive restoration)	Ecosystem restoration without any further direct anthropogenic impact (protection of ecological processes; e.g. in national parks)	Near-natural forests, former open-cast mining sites as well as near-natural peatland, rivers, coastal marshes
Mowing	Re-opening of anthropogenic grassland by removing perennial herbs and shrubs, removal of nutrients by continuously removing biomass	Wet, dry, and mesophytic meadows, heathland, traditional agroforestry systems
Grazing	Re-opening of anthropogenic grassland, development of traditional grassland-forest-mosaics, nutrient extraction, zoochorous diaspore transfer, re-introduction of traditional livestock species	Dry, wet, or calcarous grassland, pastures, heathland, forest pasture, silvo-pastoral agroforestry systems, coastal salt grassland, sub-alpine and alpine grassland
Artificial diaspore transfer with seeds, hay, etc.	Restoration of target plant communities, enhancing biodiversity, re-introduction of threatened or key plant species, protection against erosion, accelerate vegetation development	Dry, wet, or calcarous grassland, pastures, heathland, former mining sites, waste deposits
Re-introduction of certain animal species with reproductive individuals	Re-introduction of extinct species into the local or regional species pool or stabilization of populations of threatened, key or umbrella species, enhancing biodiversity	On principle, all terrestrial, limnic or marine ecosystem; also, land-use types in the cultural landscapes
Cultivation of certain plant species (crops)	Nutrient extraction after eutrophication or extraction or de-mobilization of pollutants (phytoremediation)	Arable land, nutrient-poor grassland, waste or mining deposits, urban-industrial sites
Topsoil removal	Nutrient removal after eutrophication or contamination	Arable land, nutrient-poor grassland, heathland, lowland mires, waste or mining deposits, urban-industrial sites
Topsoil coating	Transfer of humus with diaspores and mycorrhiza spores or fungi, transfer of nutrient-poor topsoil on eutrophicated soil	Dry sandy grassland, sub-alpine and alpine grassland, waste or mining deposits, urban-industrial sites
Ploughing or topsoil inversion	Nutrient reduction in the topsoil on eutrophicated sites, creation of safe sites for the germination of target species	Arable land, dry sandy grassland
Controlled burning	Prevention of succession towards woody vegetation, nutrient reduction in the topsoil, reduction of deadwood in forests	Heathland, forests, grassland
Extraction of sediment or sludge, respectively, from water bottoms	Extraction of nutrients or pollutants	Lakes, coastal areas (e.g. harbors)
Applying precipitants such as, e.g. Fe or Al salts	Reduction of, in particular, phosphorous in the water body through artificial sedimentation	Lakes
Liming	Increasing the pH value in heavily acidic open waters (e.g. after after brown coal open-cast mining)	Lakes
Re-wetting, including opening or removal of dykes	Restoration of the natural water dynamics or balance, respectively	Peatland, wet meadows, traditional urban sewage fields, coastal or inland salt grassland

Change of the hydro-morphology of rivers	Restoration of the natural water dynamics and thus the respective species assemblages and water retention capacity	Rivers and their floodplains, oxbow lakes
Revegetating of open soil by the transplantation of sods	Protection against erosion, enhancing natural succession	Open-cast mining sites, waste and mining deposits, degraded skipistes, slopes and river banks
Pesticides	Removal of certain non-target organisms	Meadows, forests, wetlands, lakes

(Myers et al. 2016). Additionally, topsoil removal is nowadays widely accepted as a restoration measure in order to remove nutrients from the restoration site (e. g. Gilhaus et al. 2015). It has been applied in recent years more and more also on peatland sites with the removal of a shallow layer of the upper peat (Klimkowska et al. 2015). In particular, for the conservation and restoration of traditional land-use types in Europe and other parts of the world, intentional burning is recommended as a restoration measure (Page & Goldammer 2004). Controlled burning, also, is increasingly discussed for forest management and restoration (Artmann et al. 2001; Agee & Skinner 2005). Although, forest fires can be part of the natural ecosystem dynamics (e. g. in the Mediterranean region), those fires have to be considered as extreme events by which a high damage on wildlife occurs. Thus, intentional burning is ambivalent at best.

With the application of those kinds of measures which also strongly contributed and contribute to ecosystem degradation worldwide, it seems as if the restoration targets have absolute priority, no matter what measure being applied to achieve them. In fact, the definition of the SER (see above) sets no constraints on measures being taken, thus blurring the boundaries of ecosystem restoration and ecological engineering or even conventional agriculture by applying pesticides. These measures run counter to intuitions and convictions of conservationists and ordinary lay persons. How can one justify the use of glyphosate in ecosystem restoration if it should be banned in agriculture? One may answer this specific question in terms of human food security, but the underlying generic question about means-end relations and ends deserves close attention. These worrisome means-end relations in restoration ecology has never been analyzed.

Accordingly, we want to critically discuss the application of certain measures, thus contributing to the debate of sustainability and nature conservation. Our leading questions is whether ends justify all means. Consequently, we address the overall relation of means, ends, side-effects, and risks. Mean-end-relations are often not purely technical but entail ethical questions. Clearly, the selection of ends is also based on value-judgements. The article supposes that ends of restoration projects are *ceteris paribus* acceptable as they reverse degradation. We focus on the mean-end-relation. The general problem is this: If means look morally repugnant (or nasty), some people may drop the end while others may accept the mean for the sake of the end. Debates about such contested mean-end-relations are ethical, not technical.

We base our analysis of restoration measures on the practice and theoretical work done so far in restoration ecology and ecosystem restoration by focusing on pesticide application, topsoil removal, and prescribed burning as measures applied in order to reach the restoration objective. Ethical considerations are derived from general basics of ethics as well as, in particular, environmental ethics. For our argumentation and the recommendations derived for theory and practice of ecosystem restoration, we cite the most relevant literature. Accordingly, merging ecology with environmental ethics our approach has to be considered inter- and transdisciplinary (cp. Scholz & Steiner 2015). Practical implications for the selection of those restoration measures which meet the objectives of sustainability and are grounded on ethical considerations are discussed. As we shall see in detail, devices as multi-criteria decision analysis (MCDA) and environmental impact assessment (EIA) are grounded in environmental ethics.

2 Critical assessment of restoration measures

2.1 Pesticides

Pesticides for the restoration of ecosystems have been applied so far in forests (Baer & Groninger 2004; Nakamura et al. 2008), wetlands and open water bodies (Cheshier et al. 2012; Martin & Blossey 2013; Hazelton et al. 2014), heathland (Snow & Marrs 1997) and grassland (Lulow et al. 2007; Young & Claassen 2008; Rokich et al. 2009). Applied are, for example, the pesticides glyphosate (Cornish & Burgin 2005), metsulfuron-methyl (Baer & Groninger 2004), rotenone (Finlayson et al. 2000), fluazifop-P-butyl (Rokich et al. 2009) and tebuthiuron (Olson & Withson 2002). The application of pesticides in ecosystem restoration refers often to unwanted species which should be suppressed or eradicated. These unwanted species, for example, are non-native species which should be removed in favor of native species. In the US, wetlands with a European genotype of reed (*Phragmites australis*), which is considered invasive, are treated with the herbicide glyphosate and imazapyr (Cheshier et al. 2012; Hazelton et al. 2014). This has to be reflected against the background that wetlands with a dominance of reed, in other parts of the world such as, e. g. Central Europe, are considered as very important with regard to the manifold ecosystem services they provide (e. g. Köbbing et al. 2013/2014). Accordingly, the same ecosystem (*Phragmites* reed) is valuated positively for their ecosystem services it provides and negatively for their ecosystem disservices (for the concept of “ecosystem disservices”, see e. g. Lyytimäki 2015), both referring to different evaluation schemes.

Despite the fact of many studies which point to the negative impact of many synthetic pesticides on plants and animals (e. g. Scholz et al. 2012; Brühl et al. 2013; Goulson 2014) as well as on human health (e. g. Bassil et al. 2007; Mnif et al. 2011; Nicolopoulou-Stamati et al. 2016), there is hardly any critical reflection on the application of pesticides in ecosystem restoration. Wagner & Nelson (2014), for example, state a negative impact of the pesticides aminopyralid and picloram applied for the restoration of grassland on the diaspore soil seedbank of target species. KNAPP & MATTHEWS (1998) point on the lethal effect of rotenone on amphibians, zooplankton and invertebrates of the benthos when applied for the management of the fish populations in North American lakes. On the short term, rotenone has, in general, a negative impact on the overall water quality (CDFG 1994).

In many regions of the world, an increase of the application of pesticides is observed (WILSON & TISDELL 2001; FAO 2002; ALAVANJA 2009). The negative impact of synthetic pesticides on environmental resources (soil, water), biodiversity and certain target species or species groups, respectively, has been well proofed in the past decades (GEIGER et al. 2010; BEKETOV et al. 2013; GOULSON 2013). Cynically speaking, this may count as collateral damage. From an environmental ethics perspective, however, lethal effects on plants and animals count morally. Given such lethal collateral damage, the burden of proof falls upon the persons who wish to perform such restoration activities. Ethical questions emerge: Is there an obligation to reach the end or might the end be just nice to have? The difference matters since obligations, but not wishes may legitimate specific means. If neobiota are combated, a series of value questions emerge. What's so awfully wrong with non-native species (cp. SIMBERLOFF 2015)? What counts as invasiveness? What kind of damage does a specific species cause? In any case, it seems mandatory to address the overall relation of means, ends, side-effects, and risks. If so, an environmental impact analysis of restoration projects might be needed.

2.2 Topsoil removal

There is a general agreement in many countries worldwide to treat heavily contaminated soils and restore unpolluted sites in order to protect human health, in particular in urban-industrial areas and on mining sites. In the European Union, for example, sites contaminated with heavy metals are monitored (for lead, see TÓTH et al. 2016) and environmental policy defines thresholds, which call for action if the thresholds are exceeded (e. g. for Germany, UBA 2003). In order to restore those sites, they can be treated by phytoremediation (PULFORD & WATSON 2003; GOMES 2012; DADEA et al. 2017) or topsoil is removed, cleaned (e. g. by means of biodegradation) or stored as hazardous waste.

However, topsoil removal is often applied in ecosystem restoration as a measure to reduce nutrients on strongly eutrophicated sites in a fast and efficient way. In particular, topsoil is removed on grassland, heaths, peatland, and arable land in order to significantly reduce nitrogen and phosphorous (e. g. KLIMKOWSKA et al. 2007; GILHAUS et al. 2015). In the broadest sense, the extraction of sediments or sludge from the bottom of open waters also has to be considered as a kind of topsoil removal (DEMARS et al. 1995; BJÖRK 2014). Not only because the year 2015 was declared by the UN as the "International Year of Soils" there are considerations which have to be critically taken into account when applying topsoil removal as a measure to reduce soil nutrient loads:

Tab. 2: Approximate displacement of soil organisms caused by erosion; as soil erosion is usually measured in tons per hectare and year, values were converted to take the approximate abundance of soil organisms displaced within 1 ton of soil (right column); for this conversion, a mean bulk density value of 1.5 g/cm was assumed (adapted from ORGIAZZI & PANAGOS 2018).

Tab. 2: *Geschätzter Verlust von Bodenorganismen durch Erosion. Da die Bodenerosion üblicherweise in Tonnen pro Hektar und Jahr angegeben wird, wurden die Werte entsprechend umgerechnet, um die ungefähre Häufigkeit von Bodenorganismen aufzuzeigen, die mit einer Tonne Boden abgetragen werden (rechte Spalte); hierfür wurde eine mittlere Lagerungsdichte des Bodens von 1,5 g pro cm angenommen (Daten nach Orgiazzi & Panagos 2018).*

Soil organisms	**Approximate abundance**	
	Estimated in untouched soil[1]	**Estimated to be displaced by runoff of 1 ton of soil**
Prokaryotes (cells)	4–20 × 10^9/cm^3	2.7–13.3 × 10^{15}
Fungi (metres of hyphae)	100/g	100 × 10^6
Arbuscular mycorrhizal fungi (metres of hyphae)	81–111/cm^3	5.4–7.4 × 10^7
Protists (individuals)	10^4–10^7/m^2	6.7 × 10^9–10^{12}
Nematodes (individuals)	2–90 × 10^5/m^2	1.3–60 × $1,0^{11}$
Enchytraeids (individuals)	12–31.1 × 10^3/m^2	8–20.7 × 10^5
Collembola (individuals)	1–5 × 10^4/m^2	6.7–33.3 × 10^5
Mites (Oribatida – individuals)	1–10 × 10^4/m^2	6.7–66.7 × 10^5
Isopoda (individuals)	10/m^2	667
Diplopoda (individuals)	110/m^2	7,330
Earthworms (Oligochaeta – individuals)	300/m^2	20,000

[1] estimated according to BARDGETT & VAN DER PUTTEN (2014)

- With the removal of the topsoil and thus often the complete organic layer, nearly the whole soil seed bank is removed. KISS et al. (2017), for example, quantifies the amount of seeds in the upper 10 cm of the soil on dry grassland on 1 m^2 with up to more than 50.000, KLIMKOWSKA et al. (2010) and VALKÓ et al. (2011) on wet grassland even up to more than 90.000 seeds.

- Together with the soil seed bank, all organisms in the topsoil are removed. Although, the variety of abiotic conditions of soils with respect to water, soil texture, pH, nutrients, etc. influences the species assemblages very differently, the amounts of soil organisms on 1 m^2 of the upper 30 cm layer of an unspecified Central European soil stated by JEDICKE (1989) give an impression of how many soil animals and microorganisms might be removed from the site with topsoil removal, i. e. 10^{12} bacteria, 10^{11} flagellates, one million nematodes, 300 quadrupeds, 80 earthworms, and 50 snails, besides numerous other soil organisms. More specifically and with regard to the worldwide problem of soil erosion, ORGIAZZI & PANAGOS (2018) estimate similarly high figures of organisms removed from the respective site (Tab. 2).

- As an interaction of chemical, physical, and biological processes, the rate of soil development has to be considered as a very slow process. JONES et al. (2012) quantify it for permanent grassland under Central European temperate climate with only 1–2 cm per 100 years, thus considering soil as a non-renewable natural resource. Adding the yearly loss of soil due to erosion, which amounts in Europe yearly for 10 t per ha (JONES et al. 2012), topsoil removal for the restoration of ecosystems becomes even more doubtful.

- As the removed soil has to be transported to deposits or to sites where it is used for other purposes, high costs arise for the whole process of removal, transport, and deposition (e. g. TÖRÖK et al. 2011; KLIMKOWSKA et al. 2010). HARNISCH et al. (2014) assess a restoration scenario for 1 ha and 50 cm topsoil removal which would account to about 6,000 m^3 soil; this means about 225 tours of a 40-tons truck for the transport.

- Together with all other ecosystem compartments such as, e. g. vegetation and roots, soil as a natural capital contributes to the provision of ecosystem services. If the soil is removed certain ecosystem services get lost, e. g. the provision of habitats for antagonists for pests in agriculture and forestry, a production site for biomass, a carbon sink, an archive for landscape history as well as an objective for research and environmental education (DAILY et al. 1997; DOMINATI et al. 2010; ROBINSON et al. 2012; ADHIKARI & HARTEMINK 2016).

2.3 Prescribed burning

Since humans became able to control fire, burning has become common practice as a land-use measure all over the world. Still today, slash-and-burn farming is commonly practiced in the tropics, even increasing in some regions in order to gain permanent grassland (TINKER et al. 1996; GAYDES-COMBES et al. 2017). In particular in Europe, prescribed burning is suggested and practiced for the management and restoration of open cultural landscapes and traditional land-use types. Under focus of this measure are heaths (KEIENBURG et al. 2004), grassland (MOOG et al. 2002; PAGE & GOLDAMMER 2004), dunes (VOGELS 2009), former military training areas (GOLDAMMER et al. 2012) and traditional vineyards (BYLEBYL 2009). Thus, succession to shrubs and forests is pushed back, a dense and tamping litter layer is removed, and the site conditions for the germination and establishment of target species is favored. Also, for the restoration of forests in the temperate and boreal climate zone prescribed burning is considered (KUULUVAINEN et al. 2002; STANTURF et al. 2014; BERNES et al. 2015). Besides the often documented failures of this landscape and ecosystem management measure (see overview by VALKÓ et al. 2014), there are many reasons which should be considered before practicing prescribed burning as a restoration or habitat management measure:

- In comparison to climates where fire is a natural and frequent element of vegetation and landscape dynamics such as the Mediterranean, sub-tropical, and tropical regions (BOOYSEN & TAINTON 1984; MYERS 2006), in temperate zones fires are exceptional events. Most fires today, and even in the Mediterranean region with its frequent natural fires (e. g. Secretariat of the Convention on Biological Diversity 2001), are man-made, accidentally or intended. In Germany, for example, in the year 2015 proofed man-made fires accounted to 44 % and only 5 % had natural causes e. g. by lightning (UBA 2016; for Europe, see EC 2017). Based on a literature survey, THOMAS et al. (2017) estimated the economic burden of wildfire for the United States considering (1) intervention costs, (2) prevention/preparedness, mitigation, suppression, and crosscutting, (3), and into direct and indirect wildfire related losses. Accordingly, the annualized economic burden from wildfire is estimated to be between 71.1 to 347.8 billion US Dollars ($2016 US).

- Man-made fires and the related damages for the environment and socio-economy belong to the most important environmental problems in the world with regard to biodiversity, release of greenhouse gasses and in particular CO_2, as well as human health. WERF et al. (2010) quantify the global carbon emissions by fire in the period 1997–2009 with 2 gigatons (= 1,000,000,000,000 kg) per year, fires on grassland and savannas contributing to this with 44 %, forest fires in the tropics with 36 %, forest fires outside the tropics with 15 %, and the burning of agricultural waste and peat fires, respectively with 3 % (GOLDAMMER et al. 2009). Global warming with longer drought periods and extraordinary weather events will increase the probability of fires in many regions of the world (STOCKS et al. 1998; WESTERLING et al. 2006; MORITZ et al. 2012). Burning as a nature conservation and restoration measure contributes to the greenhouse gas release and is counterproductive, in particular, on those ecosystems and land-use systems, respectively, which can contribute significantly to climate change mitigation as a carbon sink such as, e. g. heathland (EVANS et al. 2006; VRIES et al. 2009).

- Worldwide and throughout the various climate zones, the burning of agricultural and municipal waste has been practiced for centuries and still nowadays is common practice (BOWMAN & JOHNSTON 2005; GOLDAMMER et al. 2009; JOHNSTON et al. 2012; BOWMAN et al. 2013; Reddington et al. 2015). On a global level, 8-11 % of fires are related to agricultural land-use (Korontzi et al. 2006). Goldammer et al. (2009) review the character, magnitude, and role of pyrogenic gaseous and particle emissions from vegetation fire emissions on human health and lay special emphasis on radioactive emissions generated by fires, burning in peatlands and on terrain contaminated by radionuclides. The smoke from vegetation fires may contain respiratory irritants, asphyxiants, carcinogens, mutagens, and systemic toxins as toxic compounds. Accordingly, Goldammer et al. (2009) call for the development of international policies to address the underlying causes for avoiding excessive fire application, and to establish sound fire and smoke management practices and protocols of cooperation in wildland fire management.

- Fire may have positive effects on certain target organisms for the restoration of ecosystems, however, has negative effects on other organisms. For example, after prescribed burning on heathland in NW Germany many bryophytes and most lichens (mainly the genus *Cladonia*) were damaged or vanished completely (Keienburg et al. 2004), among them Red-List species such as, e.g. *Cetraria aculeata*, *Cladonia ciliata*, and *Ptilidium ciliare* (Fottner et al. 2004). This negative effect of prescribed burning on heathland is also documented for animal populations such as, e.g. the butterfly *Coleophora juncicolella* which nearly completely vanished (Schmidt & Melber 2004). In particular on isolated habitats, a natural re-population by animal species with a low colonization capacity is improbable. Accordingly, the question arises which should be the „winner“ and which the „looser organisms“ (cp. Moretti et al. 2004)?
- Through fire, a high amount of nitrogen from vegetation and soil might be released and end up in the groundwater (Pilkington et al. 2007). On heathland in NW Germany, for example, 80–90 % of the nitrogen in the above-ground vegetation was released after a prescribed burning event (Keienburg et al. 2004). Chapman (1967) quantified the release of about 170 kg nitrogen per ha with the burning of heathland in Southern England. Against the background of the high eutrophication and its related negative impact on ecosystems and the socio-economy in many industrialized regions of the world (for Europe, see EEA 2016), these additional amounts through the “restoration” of ecosystems have to be considered very critical.

Given all these side-effects and collateral damages, the burden of proof shifts, as in the case of the above discussed restoration measures. If forest fires *prima facie* count as disservice and if intentionally causing a forest fire (e.g. Campbell 2017) should be punished as a criminal act, it seems perfectly fair to shift the burden. It might be argued, that periodical forest fires are necessary to renew specific tree species and that this renewal outweighs the collateral damage.

To sum up: Our three cases at hand, i.e. pesticide application, topsoil removal, and intentional burning point to underlying patterns of environmental reasoning. By describing these cases, we already identified some topics of such reasoning, as mean-end-relations, burdens of proof, standards of justification, assessment of collateral damage, service-disservice ambivalencies, and ethical ideas about the practice of ecosystem restoration. We wish to address these topics in the next section in a systematic way. By doing so, we wish to stimulate debates rather than criticizing persons who engage in specific restoration activities.

3 Principles, means, and ends in environmental ethics

As our cases of pesticide application, topsoil removal, and prescribed burning strongly indicate, the mean-end-relationships within ecosystem restoration are highly contested. Perhaps, this controversy goes, on reflection, as deep as attitudes towards restoration as such. Therefore, one should not address the sophistications of mean-end-relationships in restoration ecology simply case by case without having an ethically informed understanding of the very practice of ecosystem restoration as such. Any substantial human practice rests on some ethical ideas (MacIntyre 1984). This generic truth also holds for restoration. Therefore, we wish to frame our case studies with a comprehensive view on the ethics of ecosystem restoration. Restoration has a more scientific (“restoration ecology”) and a more practical side (“ecological restoration”). Both sides are united under some axiological (= value-oriented) suppositions.

Restoration supposes that it is possible to act *on behalf of nature*. Acting on behalf of nature via restoration means to give assistance and support to (semi)-natural systems (or single species) to recover from degradation and damage. In principle, restoration might be regarded as a type of action which can be performed out of care or even out of respect to nature even if it interferes within nature. Means should be in accordance with this type of action. Note, that the “re” within “restoration”, “recovery” or other “re”-words does not mean that restoration shall “re-turn” to a previous state of affairs. The meaning of “re” is rather a “re-gaining” of some valuable features and items of nature which have been lost in the past (cp. Zerbe 2019). Humans restore, nature recovers, and humans (and animals) regain some benefits which might be spelled out in terms of ecosystem services. “Acting on behalf of nature” is the basic idea within the practice of ecological restoration. This idea leaves it open whether such acting on behalf of nature ultimately is performed in the interests of humans only. Humans can act on behalf of nature for the sake of humans, either for themselves or for other humans. They can also act on behalf of nature for the sake of natural beings. The very idea of restoration as such does not commit anyone to a specific solution of the demarcation problem (Ott 2008). Thus, the term “for the sake of” points to the beneficiaries of restoration. Now, we can give the formal agency structure of restoration practices as “*acting against a benchmark within a mean-end-relation on behalf of nature for the sake of human and/or non-human beneficiaries*”. This structure implies that the beneficiaries either are entitled to or deserve such actions. Restoring on behalf of nature and for the sake of beneficiaries, however, may not allow any means. One can discard means because they are a) ineffective, b) too costly, or c) forbidden on legal or moral grounds. In interhuman ethics, there are many cases in which it is prohibited to act on behalf of X for the sake of Y if such actions violate other obligations, impose harm upon others, or may impair the self-esteem of the agent. Given such cases, we have to apply the problem onto man-nature interferences. The mean-end-relation will be differently perceived according to underlying general ethical theories. Kantians (deontologists) are far more reluctant against nasty means than consequentialists and teleological ethics who are focusing on desirable end states. Would you kill an innocent person in order to save five endangered lives (so-called Trolley-problem)? Kantians would say No. If one counts lives by numbers, however, the sacrifice of one life might be legitimated by five survivals. There are hundreds of such "hard cases" in the ethical literature. It is safe to argue that most ethicists deny that valuable ends justify all means. Without further debate, we adopt a moderate Kantian approach suggesting that means and ends should be arranged in such ways that means are in accordance (in moral equilibrium) with ends and the ethical idea upon which a practice rests. One can modify means-end relations in many different ways to reach such equilibrium. The idea of ecological restoration is now specified to this Kantian equilibrium approach: Acting against a benchmark on behalf of nature for the sake of beneficiaries in an equilibrium of means and ends. Equilibria require accordance between the topics of our formal agency structure (as benchmark, sake of nature, motives, and beneficiaries) and the overall ethical background.

Our framework in environmental ethics is discourse-oriented environmental pragmatism (Norton 2005). The idea of acting on behalf of nature for the sake of beneficiaries in an equilibrium (accordance) of means and ends can be embedded in the paradigm of environmental pragmatism. Environmental pragmatism wishes to get an in-depth understanding of the values being implicitly present in different man-nature relations (as farming, hunting, shipping, pet keeping, hiking, diving, restoring etc.). From the lens of environmental pragmatism, one has to ask for the many values and attitudes by which persons are actually motivated to engage in restorative activities. To pragmatism, it is clearly possible to restore nature out of joy as a kind of a commonly shared "focal practice" (Higgs et al. 2000; Jordan 2006; Spencer 2007). Restoration, then, is rather interaction with nature than interference. This approach can integrate symbols, works of art, rituals, and festivities (Barau et al. 2016). Restoration as focal practice not only modifies nature, but it also shapes humans in terms of attitudes, virtue, and character. Some means, as spraying pesticides, may negatively affect or even corrupt the "spirit" out of which a focal practice is performed. Pragmatism can apply the approach to single cases not in a schematic, but in a learning way. Ecological restoration can learn case by case how to reach an equilibrium of means and ends under the idea to act on behalf of nature for the sake of beneficiaries.

Pragmatism can adopt the prominent ecosystem service approach distinguishing providing, regulating, and cultural services (MEA 2005). All of these values can, in principle, be enhanced by restoration, but in reality there are often trade-offs. Total economic value of nature (TEV) includes existence value and bequest value (Randall 1987). The mere existence of a species or a landscape might be delightful. If one regrets the loss of an ecosystem type and opts for restoration, one often supposes existence value. If one wishes to restore in order to bequeath specific ecosystems to future generations, one supposes bequest value. Cultural services and existence value belong to a specific category of environmental values which have been called eudemonic values ("eudaimonia" = good and flourishing life; see Ott 2016). This category is internally complex, including transformative value (Norton 1987), the ethics of place (Berthold-Bond 2000), natural beauty (Seel 1998), cultural heritage (Knights 2014), environmental virtue ethics (Cafaro 2001), and biophilia (Kellert & Wilson 1993). Recognition of the plurality of non-exclusive eudemonic values, virtues, and focal interactions with nature result in "deep" anthropocentrism (Hargrove 1992; Ott 2016). Given this, the mean-end-relationship of restoration activities must be compatible with deep anthropocentrism, including focal practices (Borgmann 1984). A focal attitude to restoration sees restoration as an intrinsically valuable practice being performed for its own sake. Acting on behalf of nature is performed rather out of joy than out of duty. If acting on behalf of nature is seen as focal practice one might be reluctant to use specific means. In such cases, the agents who perform restoration activities are *ipso facto* among the beneficiaries.

If one sees deep anthropocentrism as one source of normativity that underlies the ethical idea of sustainability, a reasonable choice can be made in favor of strong sustainability (Daly 1996; Norton 2005; Ott 2014). Strong sustainability emphasizes a constant natural capital rule. Within this set of rules, there holds a so-called investment or restoration rule: If stocks and living or non-living funds of natural capitals have been depleted, degraded, and damaged in the past (for whatever reasons), there is a *prima-facie* duty for present and future generations to invest prudently in such stocks and funds. Thus, strong sustainability adds a rule that there should be ecological restoration in order to regain stocks and services of natural capital. Given the depletion and degradation of natural systems in past and present times, it becomes mandatory to act on behalf of nature up to a specific benchmark being determined in terms of natural capital.

What counts as investment in economic parlance, turns out to become restoration in practice. This generic restoration rule (RR) substantiates the practice of restoration but, in isolation, it leaves much leeway of how to perform restoration activities and projects, and requires open debates which measures, tools, and devices (not) to choose if one wishes to act on behalf of nature. If one, however, does not wish to split environmental ethics into isolated slices, RR should be followed in ways which are coherent with other environmental values and virtues. If so, there are obligations to follow a rule to act on behalf of nature looking for an equilibrium of means and ends in order to regain stocks and services of natural capital. Restorationists are free to follow the rule in a focal attitude.

Environmental pragmatism and strong sustainability can harbor Aldo Leopold's (1949) famous guideline how to act with respect to land and its biotic communities: "A thing is right if it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong if it tends otherwise" (Leopold 1949, p. 224-225). This guideline is not a supreme moral principle but belongs to the rules of strong sustainability. It is a corollary to the constant natural capital rule. We also wish to resolve the guideline from Leopold's convictions about "sick" and "healthy" land because the concept of health can't be literally applied to ecosystems (see Franke et al. 2020). Leopold's guideline, however, needs a conceptual update because its ecological background has shifted since the days of Clements and Tansley (Golley 1993). Following Neumann et al. (2017), we propose the following statement: "Use land (and sea) in ways only which preserve or enhance the fertility (productivity), resilience, and diversity (richness) of bio-geocoenoses. Don't act otherwise. If fertility, resilience, and diversity have been impaired in the past, try to restore them fully." This guideline is in line with Leopold's personal attempt to restore prairies. It remains doubtful, whether spraying pesticides or burning in ecosystem restoration is in accordance with Leopold's updated guideline. The following result emerges: Following the restoration rule in a Leopoldian spirit of acting on behalf of nature for the sake of beneficiaries in a Kantian equilibrium (accordance) of means and ends. By specifying the very idea, we have determined a "spirit" of restoration which is willing to learn from case studies how to reach the equilibrium and which is open for focal practices. At the level of personal attitudes, an idea becomes a spirit. Such "spirit" can be made explicit also from an environmental virtue ethical perspective. A nasty mean might be detrimental to such "spirit" of restoration.

Environmental ethics is, however, not restricted to anthropocentrism. The idea of ecological restoration leaves the demarcation problem (Sober 1995; Ott 2008) so far open. The topic "for the sake of beneficiaries" and the mean-end-relation can be specified accordingly. An analysis of how the agency structure must be interpreted from sentientism, biocentrism, ecocentrism, and holism is beyond the scope of this article. It must suffice to note that restorative means shouldn't be lethal, harmful and disrespectful to any member of an enlarged moral community. Sentientism and biocentrism would be prohibitive against aggressive means because they cause much collateral damages among members of the moral community.

To wrap up the ethical analysis: Ethics has provided some outlooks for orientation within restoration ecology. It gives a formal agency structure open for further analysis, it demands an accordance between means and ends, it embeds restoration within a strong sustainability paradigm, it proposes a Leopoldian principle, and it points at a spirit, out of which restoration should be performed. If so, there is a remarkable convergence against the use of pesticides between a deep Kantian equilibrium approach, a pragmatic reading of Leopold, and strong sustainability on the one hand, and sentientism and biocentrism on the other hand. Such practical convergence generally counts as strong rationale in applied ethics. This sets the bars higher for meeting the burden of proof. All rules only hold "*prima facie*" and can be trumped by reasons why an exception should be made in a specific case. The use of pesticides, topsoil removal, and burning in ecosystem restoration requires substantial reasons.

4 Discussion

In the recently published "International principles and standards for the practice of ecological restoration", Gann et al. (2019: p.3) state that ecological restoration when combined with conservation and sustainable use, "is the link needed to move local, regional, and global environmental conditions from a state of continued degradation, to one of net positive improvement". Interestingly, they do not address a limitation of practical measures or even a critical assessment of measures applied for ecosystem restoration. Taking the example of pesticide application in ecosystem restoration, topsoil removal, and prescribed burning we have shown that negative environmental and socio-economic trade-offs might not justify the end.

This brings us finally back to the mean-end-relationship, asking which tools, measures, and devices are in accordance with respectful and healing restoration or not. Our ethical approach as outlined in the previous section does not categorically ban specific means. It rather stimulates discourse about specific mean-end-relations within the broader agency structure.

From our ethical perspective, pesticide application, topsoil removal, and prescribed burning are quite drastic measures. If so, the burden of proof fairly falls upon agents who propose such harsh measures. Such initial burden can be met by demonstrating that one faces an specific or even exceptional situation. Topsoil removal in order to combat eutrophication is a strategy to reach the goal quickly (however, often only with short-term effects) but topsoil loss counts as environmental damage. There are, of course, strategies which reduce eutrophication rather slowly from an ecosystem. Choices in favor of a "quick fix" have alternatives. Why can't one try to reduce eutrophication slow by slow via reducing intakes, biomass yields, and grazing? Why there must be a fire that always has collateral damages? This clearly is a plea for standards that favor "soft" measures. According to Dudley (2011: p.177, Table 8.1), "soft" measures may include cutting some trees in order to ensure a mixed age stand, introduce grazing animals to regain patchy structures in agroforestry, create new corridors in order to make species trespass, restore natural flow regimes in coastal zones, and the like. The virtue of patience might play a much stronger role in restoration. Such virtue might also result in "wait and see" -strategies. Acting on behalf of nature includes omissions. Restoration by combinations out of actions and omissions might be a topic for another article.

For theory and practice of interdisciplinary restoration ecology and ecosystem restoration, respectively, tools are available for a careful decision of measures which are in accordance with sustainability and are based on ethical ground. Applied for design and monitoring of restoration projects for example by Convertino et al. (2013), multi-criteria decision analysis (MCDA) can also be used for the assessment of restoration measures. MCDA is a decision-making analysis based on decision science theory (Keeney & Raiffa 1976) that can evaluate alternatives with respect to defined criteria and the relative importance of those criteria (Linkov & Moberg 2011). MCDA is open to define criteria which are important to find solutions in nature conservation, restoration, and land-use development (e.g. Fontana et al. 2013; Esmail & Geneletti 2017). MCDA can also assist decision making by clarifying trade-offs (Corsair et al. 2009). Criteria stem from principles or rules. It would require another article to derive criteria from our ethical approach, but MCDA should incorporate ethical reflections of how criteria are generated and weighed.

Environmental impact assessment (EIA) assesses the impacts of a planned activity on the environment in advance, thereby allowing for alternative measures to be taken following the paradigm "prevention is better than cure" (Ott et al. 2011; Glasson et al. 2012). Formally established in the USA in 1969, it entered environmental policy and practice on the international level in Europe with the EC Directive on EIA in 1985 (EC 2011). EIA has been applied for restoration projects in river systems (Negrei et al. 2017), is recommended before re-introducing species within restoration projects (Buisson et al. 2018), and can support the assessment of the effectiveness of ecological restoration efforts when performed before and after a restoration project (Zhu et al. 2017). Accordingly, ecosystem restoration can be the consequence of EIA, for example through mitigating a strong environmental impact but can also be object of EIA before deciding and implementing a restoration project with its measures and objectives. The interdisciplinary team for the EIA suggested by Burger (2008) should also integrate the social sciences, e. g. environmental ethics. We suggest to perform EIA within ecological restoration under an ethical perspective as outlined in this article. Given the contest over means and ends, EIA should become part of restoration projects. By doing so, the topics, principles, and proposals being made in this article may become critically refined.

Consequently, we suggest to integrate ethics into the definition of ecosystem restoration which is of relevance to the debate on principles and standards in ecological restoration as well as for practical ecosystem restoration (Box 1).

Box 1: Proposal of an updated definition of ecosystem restoration

> Ecosystem restoration assists, with ethically acceptable measures and by activating or re-activating natural processes, the development of an anthropogenically degraded ecosystem or land-use type towards a state which provides the target ecosystem services (provisioning, regulating, cultural) based on a functioning ecosystem, thus enhancing natural capital against the background of strong sustainability. It takes into account the transformative dimension of restoration seen as human-nature interaction. Ecosystem restoration gives priority to the conservation of certain desired species and and habitats at selected sites as well as resource protection and/or the conservation of the cultural landscape.

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