Chapter 6
Why Legacies Matter: Merits of a Long-Term Perspective

Verena Winiwarter, Martin Schmid, Helmut Haberl and Simron J. Singh

Abstract Long-term approaches are an important concern of Social Ecology and Environmental History. This chapter outlines approaches developed within the Vienna School of Social Ecology to analyze society-nature interactions over long periods in a manner that combines the Humanities, the Social Sciences and the Natural Sciences. It discusses the interrelations between Environmental History and the novel research strand of Long-Term Socioecological Research (LTSER) that expands the Natural Science-based Long-Term Ecological Research (LTER) approach. The chapter also relates sociometabolic approaches to the concept of socio-natural sites (SNSs) as a specific configuration of 'practices' and 'arrangements', both conceived of as socionatural hybrids. Using the 'fossil-energy-driven carbon sink' in Austria's agrarian-industrial transition and colonial mining in Central and South America as research examples, it analyses the importance of long-term legacies for the course of human history as well as our current predicament, thereby demonstrating the strength of a truly interdisciplinary socioecological approach to contribute to a better understanding of current sustainability issues.

Keywords Carbon sink · Fossil energy · Mercury mining · Silver mining · Mexico · Huancavelica/Peru · Deforestation · Organic machine · Eternity costs · Environmental legacies · Socio-natural sites (SNSs)

V. Winiwarter (✉) · M. Schmid · H. Haberl
Institute of Social Ecology (SEC), Alpen-Adria University,
Schottenfeldgasse 29, 1070 Vienna, Austria
e-mail: verena.winiwarter@aau.at

M. Schmid
e-mail: martin.schmid@aau.at

H. Haberl
e-mail: helmut.haberl@aau.at

S.J. Singh
Faculty of Environment, University of Waterloo,
200 University Avenue West, Waterloo, Ontario N2L 3G1, Canada
e-mail: simron.singh@uwaterloo.ca

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6.1 Introduction: Long-Term and Historical Approaches to Social Ecology

The interdisciplinary field of Social Ecology studies the relationship between society and nature. The investigation of this relationship and its transformation over longer periods, incorporating contributions from the Historical Sciences, is a distinguishing feature of Viennese Social Ecology. From the beginning, long-term and historical approaches have been and continue to be a constitutive element of Viennese Social Ecology. Important terms such as 'socioecological regimes' and 'energetic transition' (see Chaps. 2 and 3) were formulated in (universal) historical works (Sieferle 1997). They acquire meaning through a perspective that incorporates the common history of society and nature over centuries and millennia.

This long-term approach takes its inspiration not least from the conviction that the particularities of contemporary relationships between society and nature can only be properly understood if contrasted with the conditions of the past. The US environmental historian McNeill (2000) employed numerous, primarily quantitative parameters to show that in the 20th century, humanity altered ecosystems worldwide to a more profound and wide-ranging degree than ever before. Research fields such as 'Global and Climate Change' base their argumentation on a historical approach. They formulate statements regarding contemporary situations and characterize and evaluate these situations by means of comparison with situations from the past. The debate in Environmental Science around the definition of the 'Anthropocene' (Crutzen and Stoermer 2000) as a distinct epoch in Earth's history and its appropriate chronological boundaries is a case in point for a long-term approach. However, the historical approach in these research fields usually remains implicit. Thoroughly researched contributions from Historical Sciences are rare. 'Long-term' and 'historical' are not, after all, identical. Whereas the former refers to a consideration of longer time frames (independent of any concrete epistemological interest), historical research aims at the source-based reconstruction of human-influenced events, actions and structures in the past. Environmental History regards these actions, events and structures as the expression of a constantly changing relationship between society and nature.

Social Ecology as an interdisciplinary research field combines approaches from Natural and Social Sciences and the Humanities. By creating terms such as 'colonization of natural systems' and further developing others, such as 'social metabolism' (see Chaps. 1–3), Social Ecology has succeeded in conceptualizing the relationship between society and nature in a way that is not hegemonic and, in so doing, has avoided determinism in all its forms (such as biologism or culturalism).

These conceptual foundations of Social Ecology emerged 20 years ago through critical analysis of other disciplines and their 'blind spots'. Sociology, to give but one example, continues to adhere to Durkheim's dictum that social facts can only be explained in terms of other social facts (see Chap. 2). It thereby constrains its own capacity to contribute to current environmental debate. Regardless of whether one sees this as a good thing, this debate is fundamentally characterized by the

Natural Sciences and rests on their results. The interdisciplinary research field of Social Ecology is an irritation for such older and better-established research fields. Its interdisciplinary approach calls into question decisions constitutive of other sciences. Explaining social facts by means of social facts is, after all, only one option among others. There are similar issues regarding the relationship between historical research and interdisciplinary Environmental History.

Establishing the relationship between society and nature as a subject of scholarly research relies on the critical analysis of different disciplines, but it equally requires involving these other disciplines in this debate and motivating them to make their own contributions to it—and this is where the communicative challenge of interdisciplinary research lies. Communicative connections need to be encouraged, and appropriate terms and concepts need to be introduced to develop Social Ecology's own connectivity to other disciplines. Socioecological research over long periods must consider two interfaces in particular: the Historical Sciences (which today see themselves primarily as part of the Humanities) and the Ecological Sciences. Viennese Social Ecology established two different approaches: Environmental History and Long-Term Socioecological Research (LTSER). The two are similar in terms of their scientific interest in the relationship between society and nature and its transformation over longer periods. They also share the conviction that concentrating solely on either sociocultural or natural aspects is unhelpful and results in an inadequately narrow explanatory approach.

Just as Environmental History and LTSER communicate with different scientific communities, they also necessarily differ in terms of their conceptual basis. Environmental History's sphere of intervention is the field of history. Its task is to communicate to other historians the plausibility of a scientific perspective that sees 'Nature' as an influencing force within history. Its message to the Historical Sciences is that 'Nature' is more than stage scenery and is not merely the relatively static background to historical events. It is also more than the '*longue durée*' (Braudel 1977, 2001) and more than the very gradually evolving spatial setting for human existence. 'Nature' is the coauthor of history; as already mentioned, however, an environmental program can only be put into practice with the cooperation of the Natural Sciences. 'Socio-natural sites' (SNSs) provide an appropriate conceptual basis (Winiwarter and Schmid 2008; Winiwarter et al. 2013; see also Chap. 23). Social Ecology's analytical differentiation between society and nature is abandoned in favor of a hybrid (Fischer-Kowalski and Weisz 1999) and, indeed, socionatural approach. The analytical and systemic differentiation between society and nature has proven to be less easily applicable to the actor-centered approaches of the Social Sciences and Cultural Studies (see Chap. 5).

LTSER explores the blind spot of another scientific field, that of Ecology. This research aims to show that society has exerted and continues to exert an influence on nature (and by no means only in the form of) 'anthropogenic disturbance'. Ultimately, LTSER aims to convince ecologists that we can hardly continue to engage with 'natural ecosystems' but should instead be discussing 'socio-ecological', 'coupled socio-ecological' or 'human-environmental systems' (regarding these terms, see Singh et al. 2013a). Whereas a systemic approach of this kind has proven to be a barrier to communication between the Environmental and Historical Sciences, it has proven useful in the communication between the LTSER community and Ecology. Consequently, the conceptual basis for LTSER is systems theory. Interactions between society and nature are addressed as a question of socioecological metabolism (Haberl et al. 2013a) and land-use change.

This chapter illustrates both variants of long-term and historical research in Social Ecology by means of two examples. At first sight, the examples appear to address very different phenomena in the common history of nature and society: on the one hand, we discuss carbon flows and stocks as a focus of LTSER, and on the other hand, we provide a colonial environmental history of the long-term consequences of historical mining activities. However, both examples show that the conceptual 'lenses' through which we view the past have tangible political consequences. Human relationships with nature, even those of several centuries back, continue to have an impact today. The conditions of possibility for our relationship with nature were already determined in the past. We will discuss this insight in detail in the conclusions.

6.2 Including the Social Dimension in Ecology: From LTER to LTSER

In recent decades, vast resources have been invested in the worldwide establishment of institutions for the monitoring and documentation of and research into changes in ecosystems over longer periods. The often-used acronym 'LTER' stands for 'Long-Term Ecological Research' (http://www.ilternet.edu/). LTER sites are equipped for long-term monitoring with the instruments, data storage capacity and comparative spatiotemporal measurement protocols for a range of ecosystem parameters. LTER undertakes the documentation and analysis of changes in patterns and processes in ecosystems over longer periods and thereby contributes to a better understanding of global change. The key goals of LTER include identifying the effects of global change as early as possible and understanding its consequences (Redman et al. 2004).

At the inception of LTER, natural or near-natural ecosystems were the focus—in line with the aim of identifying possible effects of global change, which also depends upon the ability to distinguish these effects from changes resulting from direct human intervention. This is easier to achieve in the case of little-utilized (ecologists often use the term 'undisturbed') ecosystems because fewer causes of change need to be identified. The disadvantages of this approach, however, lie in the fact that natural or near-natural ecosystems are becoming progressively less important while the significance of ecosystems that are more or less intensively utilized by humans continues to increase. Thus, a focus on ecosystems that are utilized little, if at all, by humans cannot provide much relevant insight into how ecosystems might be sustainably managed within the context of global change (Haberl et al. 2006).

Efforts have been underway for some time now to expand the original concept of LTER to include economic and institutional dimensions (Collins et al. 2011; Redman et al. 2004; Singh et al. 2010). However, this entails a significant increase in the complexity of research designs, moving from an empirical/analytical/model-oriented approach to the inter- and transdisciplinary concept of LTSER, 'Long-Term Socioecological Research' (Collins et al. 2011; Haberl et al. 2006; Singh et al. 2013b). This requires not only an expansion of the inventory of empirical methods to include historical and socioeconomic data collection procedures but also far-reaching changes to research processes through the expansion of expertise to include the Social and Economic Sciences, the Humanities and Cultural Studies and, ultimately, the inclusion of stakeholders. These changes entail the need to develop interdisciplinary terminology, concepts, models and syntheses.

The effort, however, results in a significant benefit because this expansion of the research perspective allows results to be obtained that are directly relevant in a social and therefore political and economic context. Only through the widening of the research approach does it become possible to arrive at conclusions with direct relevance for sustainability. LTSER allows the recognition of the feedback loops incurred in social and economic processes and thereby provides crucial insights into phenomena important for global change.

6.2.1 The Fossil Fuel-Driven Carbon Sink

In the following section, we aim to illustrate LTSER's possibilities to elucidate global change through the example of changes in socioecological carbon flows and stocks in Austria from 1830 to the present. Carbon is important for a number of reasons. First, a large proportion of the human impact on the global climate can be ascribed to changes in the global stocks and flows of carbon: the extraction of coal, oil and gas as well as the energetic utilization of these material resources leads to the release of carbon dioxide (CO_2) into the Earth's atmosphere. CO_2 is one of the most important greenhouse gases (GHGs) that cause global warming. Humanity also impacts carbon stocks and flows through changes made to ecosystems, such as the clearing of forests and the cultivation of pastures and agricultural land. The absorption of CO_2 by terrestrial ecosystems, the so-called 'terrestrial carbon sink', is a key process because of its capacity to decrease the velocity of climate change. It is also accounted for (albeit not comprehensively) in climate change agreements such as the *Kyoto Protocol*.

With a purely ecological approach such as LTER, an analysis of ecological carbon flows and stocks in Austria would lead to the following conclusion. The quantity of biomass produced annually by ecosystems through photosynthesis—essentially, what is termed 'net primary production', or NPP—increased in the last 170 years by approximately one-third. Despite a massive (+70 %!) increase in human harvesting of biomass, the biomass stocks in ecosystems increased as well. The stocks of

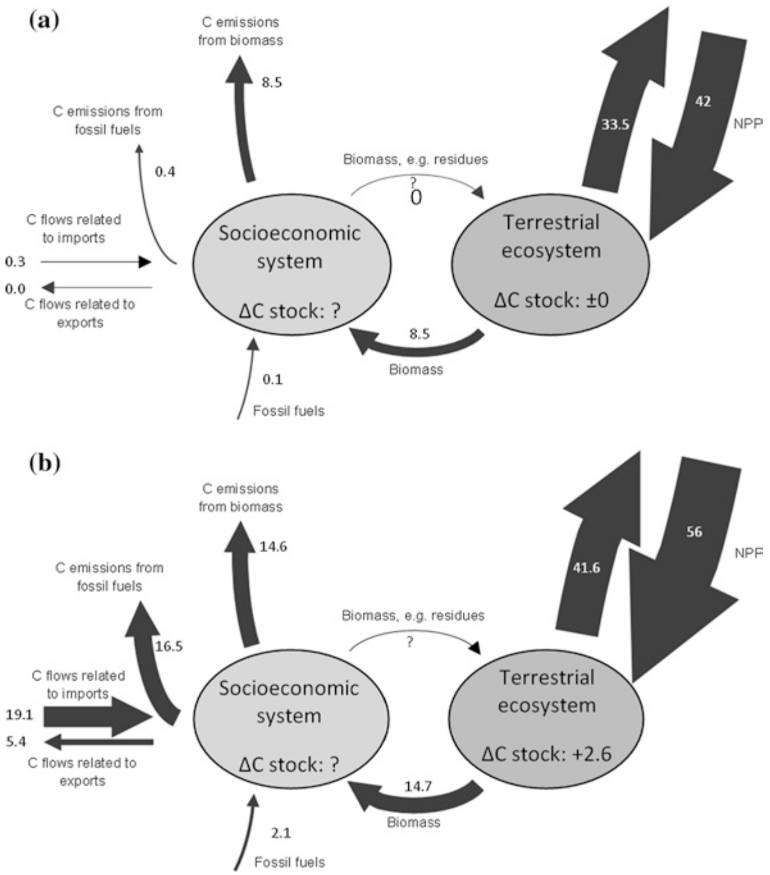

Fig. 6.1 Average yearly flows of carbon (MtC year^{-1}) in Austria in the periods **a** 1830–1880 and **b** 1986–2000. *Arrow sizes* are drawn proportionally to the magnitude of the carbon flow (except those that are unknown, marked with '?'). Imports and exports include carbon in fossil fuel products and biomass products. Biomass transfers from the socioeconomic system to the terrestrial ecosystems are unknown, as are carbon stock changes in the socioeconomic system. (*NPP* Net primary production). (Reprinted with permission from Haberl et al. 2013b)

carbon in soils and vegetation grew from approximately 1.04 GtC[1] in 1880 to ca. 1.23 GtC in 2000, i.e., by approximately 18 % (Erb et al. 2008; Gingrich et al. 2007). This means that the ecosystems in Austria store significant quantities of carbon each year—approximately 2.6 MtC/year (megatons of carbon per annum[2]) by the end of the 20th century (Fig. 6.1b). This corresponds to approximately 16 % of

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[1] 1 GtC = 10^9 tC = 1 billion tons of carbon; one ton of carbon is approximately equivalent to 2 tons of dry-matter biomass.

[2] 1 MtC = 10^6 tC = 1 million tons of carbon.

the CO_2 emissions produced through the combustion of fossil fuels in Austria, indeed a significant amount.

What are the reasons for this development? It was caused primarily by the expansion of forested area as well as by increased planting density and, therefore, the quantity of carbon stored in soils, trees and other vegetation per unit area. The increase in carbon storage can be attributed to a reduction in overuse of woodland, partly because of decreasing demand for fuel wood but also because of greatly reduced nutrient removal via forest grazing or litter use[3] (Erb et al. 2008; Gingrich et al. 2007; Haberl et al. 2013a, b). In a purely ecological approach, one may attempt to explain these phenomena through processes such as increased nutrient input (e.g., in the form of nitrogen from combustion gases) or the so-called CO_2-fertilization effect (increased plant growth as a result of higher atmospheric concentrations of CO_2).

Only a comprehensive socioecological analysis can show further potential causes of the phenomena observed (Fig. 6.1). In the last 170 years, a socioecological transition has taken place in Austria from an agrarian to an industrial society. The energy system has fundamentally changed from a biomass-based agrarian energy system to the fossil fuel-based energy system of industrial societies. This led not only to a decrease in the demand for fuel wood, which was largely replaced by coal, oil and gas, but also to profound changes in agriculture. Yields per area unit per year for major cereal crops increased by factors between four and seven. Thus, despite a clear reduction in agricultural land area, significantly more agricultural biomass could be produced. Additionally, draught animals were replaced by tractors, which also reduced the requirement for agricultural land (Krausmann and Haberl 2007). Imports and exports grew exponentially but remained largely balanced. The spectacular increase in the supply of food and other agricultural raw materials, including fibers and bioenergy, became possible through increases in domestic productivity, accompanied by ever-greater integration into the global market.

On a systemic level, we can therefore speak of a ‘fossil-energy-driven carbon sink’. Only fossil energy has made it possible to increase agricultural yields at such a high rate by means of synthetic fertilizers and tractors. The replacement of wood as a fuel source by fossil energy carriers must also be considered (Haberl et al. 2013b). What proportion of the increase in NPP is attributable to direct interventions such as the increased use of fertilizers and irrigation or the return of forested land (‘forest transition’, see Chap. 20), and what role is played by climatic and biogeochemical feedbacks (such as changes in precipitation and temperature or higher CO_2 concentrations in the atmosphere)? At present, such questions can only be addressed through modeling. A recent study (Erb et al. 2013) presents strong indirect evidence that historical legacy effects and subtle changes in management that are not captured by widely used land-use/carbon models play a

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[3] The use of foliage and young branches as bedding for livestock.

substantial role. These findings question the validity of conventional approaches to attribute changes in the carbon balance of biota and soils to either human activities or global change feedbacks—a hugely important task required to gauge humanity's impact on the global carbon cycle (Le Quéré et al. 2012). The example shows that linking socioeconomic with ecological approaches is also very fruitful on the level of basic research. Only through an LTSER approach can direct (land use) and indirect (climate change) drivers of important biophysical processes, such as carbon emissions and carbon sequestration, be recognized and interpreted correctly. Solid LTSER will be required to adequately address these highly complex but hugely important questions.

LTSER, we have attempted to show, offers a link between ecological processes and the societal drivers that are not included in merely ecological research. LTSER thus embraces socioecological approaches. We have also seen the value of a long-term perspective. Historians can contribute to this broader agenda of LTSER by offering long-term data on society. In turn, historical research could benefit from including ecological perspectives.

6.3 How Does 'Nature' Feature in History? From History to Environmental History

Nature plays an important role in history, whether 'nature' refers to the inner nature of people or to the outer nature surrounding them. Without accounting for biophysical, material phenomena, historical developments cannot be explained; consequently, neither can the present, which is always the result of earlier structures and events.

Because power depends upon (among other things) access to resources, even political history cannot be told immaterially. However, the greater part of the Historical Sciences continues to focus on the immaterial. Great men are no longer the mainstay of study, the importance of economic, social and political structures have long been recognized, but the natural conditions of these structures continue to be underestimated. The long-term consequences of interventions in nature are rarely examined.

6.3.1 Colonial Mining in South and Central America

Like the above description of LTSER, this section at least partly addresses forests and wood. We shall show that the current situation in some regions of Mexico cannot be understood without recourse to history. As even the standard narrative of the Historical Sciences would hold, the economic and political power of Spain from the 16th century onward relied on the exploitation of its colonies (see, e.g., Waszkis 1993). North and South America established their hegemony on the global silver market from approximately 1570 until the 20th century (Nriagu 1994). People and nature paid the price for this hegemony. Rich silver mines were located in 'Virreinato de Nueva España', the 'Viceroyalty of New Spain', which existed from 1535 until 1822 in what is now Mexico. In the 'Virreinato del Perú' and the 'Virreinato de Nueva Castillia' (from 1542), an essential agent for the extraction of silver could be found, the highly toxic liquid metal mercury.

Both types of mines ruined the landscape. Pollutants such as sulfur dioxide (SO_2), mercury and salt entered the biosphere in large quantities. Previously undisturbed areas were settled and deforested, and the lungs of those working in the mines were filled with dust, which caused silicosis. Mining accidents regularly caused the deaths of hundreds of mine workers. The exploitation of nature went hand in hand with the exploitation of indigenous peoples. The mercury mine in the Peruvian town of Huancavelica was fittingly called a 'public slaughterhouse', or *mina de la muerte*, a mine of death. All those who worked in the service of the Spanish throne's insatiable desire for precious metals were more or less chronically poisoned with mercury.

Silver was extracted from the middle of the 16th century onward by means of amalgamation. In shallow-walled, open enclosures known as *patios*, finely ground silver ore was mixed with water, salt, mercury, iron and other substances and then regularly stirred over a period of weeks or months depending on the temperature. Either donkeys or workers who treaded barefoot in the knee-deep toxic sludge performed the mixing. Amalgamation reduced the amount of fuel wood and improved the yield of precious metals so that mercury became an essential processing material, particularly once the richest ores had been removed and the remainder was extracted from less-concentrated material. There were only three mercury mines worldwide: Almadén in Spain, Idrija in today's Slovenia and Huancavelica in Peru.

The Santa Bárbara mercury mine was situated above the town on the eastern slopes of the Western Cordillera at an altitude of ca. 4000 m a.s.l. The Spaniards had begun their activities there at the end of the 16th century, initially with opencast mining. During the winter, the mine often flooded, and miners had to work while standing knee-deep in ice-cold water. For those involved in smelting, lung infections brought about by the temperature change between the hot mercury kilns and the icy conditions were a common cause of death (Brown 2001). One of the earliest sources informing about the horrible working conditions was written by Felipe Waman Puma de Ayal (*1534 or ca. 1550, †1615) at the beginning of the 17th century. His major work *Nueva Corónica y buen gobierno* ('New Chronicle and Good Government') is a depiction of the life of the Incas and a profound critique of the Spanish conquerors. It includes a view of Huancavelica (known then as *La Villa Rica de Oropesa*). As can be seen in Fig. 6.2, the town (referred to as *uilla*) is in the center. Above left, the image probably shows the mercury mine (*socabón*); above right, the silver mines of Potosí (*Guayna Potocí, minas de plata*); below in the foreground, smelting kilns, possibly the enclosures known as '*patios*' and other arrangements required for smelting the metals. The title makes clear reference to the working conditions: *LA VILLA RICA DE OROpesa*

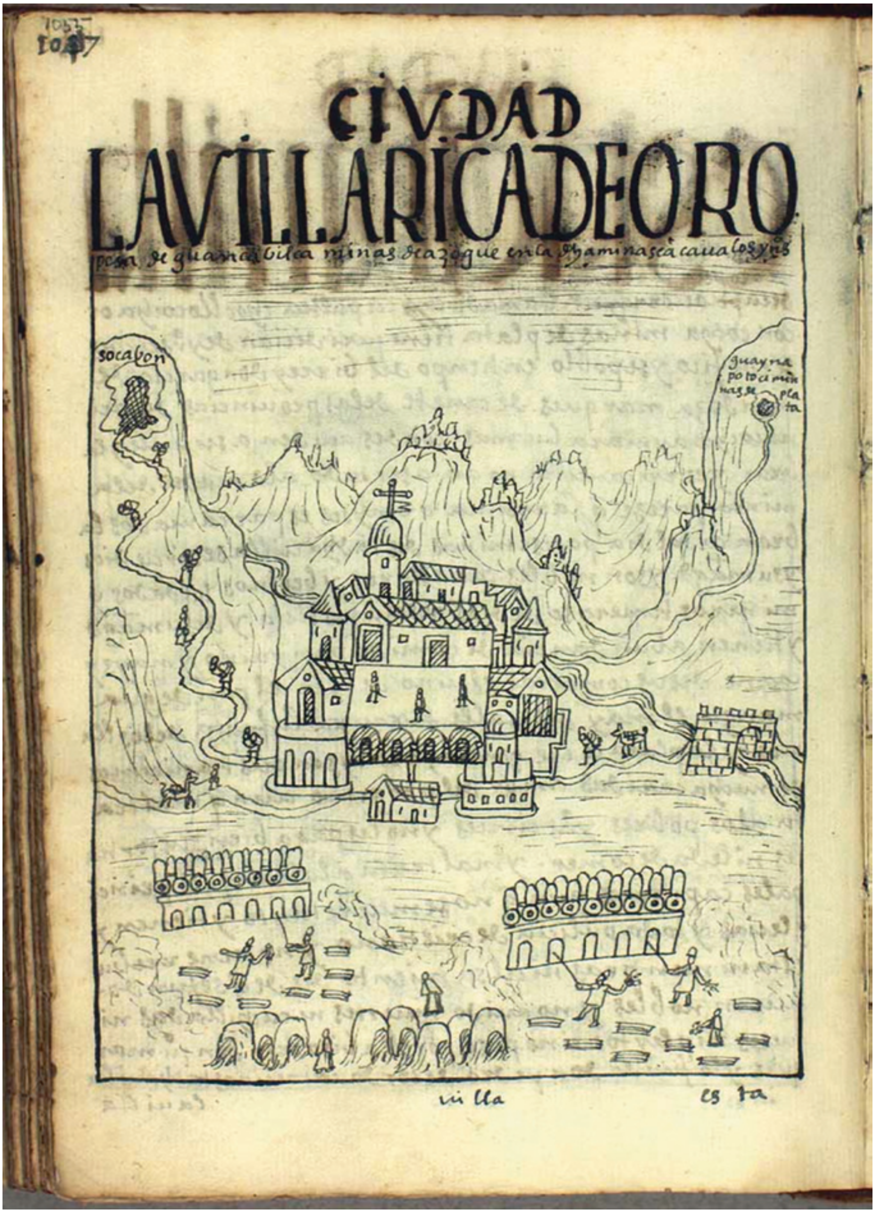

Fig. 6.2 Front page of a 17th-century treatise showing the town of Huancavelica with mines in the mountains and smelters in the foreground. (Reprinted from Poma de Ayala 1615/1616)

de Guancabilca, minas de azogue. En la dicha mina se acaua los yndios—'… Huancavelica, mercury mines. In this mine the Indios perish'.

When the walls of the open-cast mine threatened to collapse, the mine's operators resorted to tunnel construction. Conditions during the first half of the 17th century were particularly grim. The *mita*, the colonial system of forced labor carried out by the indigenous population, supplied the mines with cheap labor. Labor was so cheap that neither machinery to transport the ore above ground nor any form of safety system were put in place. The indigenous workers knew the dangers and sometimes went to desperate measures to avoid forced labor. The Spanish Viceroy reported to the King in 1630 that native Indian mothers were mutilating their sons to save them from a painful death as a result of mercury poisoning (Brown 2001).

Chronic mercury poisoning leads to tremors, pallor, discoloration and inflammation of the gums, loosening of teeth, abnormal salivation, anemia, difficulties in speaking, loss of appetite and a loss of muscular control. Even at low doses, poisoning causes personality changes. The medical literature records irritability, impatience, hypercritical or unsociable behavior, depression, anxiety, memory loss, obsessive-compulsive behavior and concentration problems. The toxic metal transgresses the placenta, causing miscarriage and stillbirth or defects in the embryo. Such effects are commonly recorded for miners and their wives and children, who often accompanied them at work, whether in the mercury mine or during the amalgamation process at the silver smelting works (Robins 2011).

Whereas the *mita* labor period at the silver mines in Potosí (today part of Bolivia) lasted one year, it was limited to two months at the mercury mine because the Spanish colonial masters knew that the symptoms of mercury poisoning improved over time. By limiting exposure to two months, the workers could be brought back periodically. In any case, a report from 1604 suggests that the graves of deceased mining and smelting works laborers contained puddles of mercury where the bodies had decayed (Robins 2011).

In 1680, the 13 mercury kilns operating in Huancavelica and producing a relatively high output of 594 t of mercury (not including the smuggled portion, which was a continuous factor) emitted 69 t of mercury. The entire population of the town, not merely the laborers from the mines and kilns, was exposed to 30–100 times the current maximum safe exposure levels, and near the smelting kilns, the air pollution likely exceeded 1000 times the current safe level for inhalation (Robins et al. 2012).

If one assumes that during mercury extraction roughly 25 % of this highly volatile metal vaporizes, then ca. 17,000 t of mercury would have entered the atmosphere here between 1564 and 1810. Worldwide, more than 236,000 t of mercury vapor were released into the atmosphere between 1550 and 1930 as a result of silver and gold extraction. The lower the concentrations of silver were in the ore, the more mercury was required. Whereas roughly 1.5 kg of mercury was needed per kilogram of silver in 1740, by the end of the colonial regime between 1790 and 1810, 2.4–2.9 kg of mercury was used per kilogram of silver (Nriagu 1994; Robins and Hagan 2012).

The Huancavelica mine closed in 1974 because yields had dwindled. Soil studies published in 2012 show that the current inhabitants of Huancavelica (population 40,000) are exposed to mercury concentrations that are among the highest worldwide, posing a significant risk to their health. The soil in the locality contains up to 35,000 times as much mercury as unpolluted areas (Robins and Hagan 2012). Even today, mercury is used for amalgamation processes. Estimates suggest that each year, 350 t of mercury enter the atmosphere as a result.

The sites of the mercury and silver mines were linked by colonial rule. Mercury also poisoned the workers in the silver mines and was an agent of environmental change in silver mining regions. Silver mining history and the associated environmental change has been researched by Studnicki-Gizbert and Schecter (2010). From the beginning of the 16th century to the beginning of the 19th century, more than 50,000 t of silver and nearly 800 t of gold were shipped to Spain from Mexico alone.

To produce a single kilogram of silver, the Mexican mines needed the wood resources of more than 6000 m^2 of forest. In total, more than 315,000 km^2 of forest was destroyed, an area nearly four times the size of Austria. However, this figure does not even include the deforestation resulting from the miners' independent silver production. They received a part of their payment in the form of ore. The miners did not have mercury for their small and inefficient kilns—it was reserved for the large 'Haciendas de Beneficio'—so their use of wood for silver production was higher. Roughly 76,000 km^2 of deforestation can be attributed to their activities. Between 1558 and 1804, 20 % of the land area of Mexico was deforested in the pursuit of silver production (Studnicki-Gizbert and Schecter 2010)—more than the entire land area of modern Germany.

As Studnicki-Gizbert and Schecter show, the valley in which the silver mine of San Luis Potosí, a city at an altitude of ca. 1850 m a.s.l. in central Mexico, is located is a good example of the rapidity with which mining-related deforestation took place. In 1614, only 20 years after mining activities began, charcoal had to be transported to the mines over distances as great as 120 km. By the mid-17th century, travellers to the region encountered a treeless, denuded landscape in which only an occasional yucca palm had survived. The forests had fallen victim to charcoal production. The demise of a leguminous species, the Mesquite tree (from the *nahuatl* name *mizquitl*) that was one source of charcoal, proved particularly detrimental. In the subtropical heat, the shade provided by trees is a decisive ecological factor for forests. However, the Mesquite provides more than this: only leguminous plants can use atmospheric nitrogen directly as a nutrient source. This benefits other plants as well because they grow on the enriched soils. Numerous animals depend upon the protein-rich bean pods of the Mesquite tree as a food source. As soon as the tree stock on the mountains around the silver mines had been cleared, desertification processes began. Even today, reforestation of the area remains impossible.

Deforestation also proved to be an effective weapon against the indigenous population. The Guachichites lived as hunter-gatherers, cultivating only a little maize. As excellent archers, they had managed to prevent the expansion of the

Spaniards to the north for a long period. Their diet consisted to a significant degree of the bean pods from the Mesquite tree, their main source of flour. The destruction of the forest removed their hunting grounds and, with them, their means of survival. The clearance of the forests left the Guachichites facing starvation and broke their resistance. This allowed the Spanish colonial leaders to open negotiations with them and to offer peace in return for food. '*Paz por compra*', peace through payment, was the term given by the Spanish to this tactic for the pacification, settlement and Christianization of the indigenous population. This new way of life entailed the cultivation of cropland and pasture—a further factor preventing reforestation.

Deforestation as a result of silver mining was followed by overgrazing, first by beef cattle and then by sheep. The once-forested land became ever more desiccated, and the colonial exploitation led to a transformation of the landscape that continues today (Studnicki-Gizbert and Schecter 2010).

At the beginning of this chapter, we noted that the long-term consequences of interventions in nature are rarely a center of focus. The above case illustrates how greed for gold and silver denuded the Mexican landscape, profoundly changed its ecology and caused deaths and disease. Colonial exploitation had long-term effects. Spanish history would have been different without colonial exploitation. The devastated landscapes and diseases continue to affect the present political and economic situation of former colonies. Identifying the distant reasons for the dire postcolonial developments in many former colonies certainly puts them in perspective.

6.4 Long-Term Legacies of Human Interventions in Natural Systems

Environmental History aims to establish the power nature wields over the course of history (within the context of the Historical Sciences), to include LTSER's Social Science perspectives within Ecology and to ensure that a sufficiently complex concept of society is employed in this context. These dialogues within science are necessary to address environmental policy issues by offering the required basic scientific knowledge. The high levels of mercury pollution resulting from the mining activities begun 400 years ago in Huancavelica still have an impact today. The mountains of northern Mexico are barren because the forest ecosystem that once existed there was cleared. The soils quickly eroded, and because soil formation is a very slow process (depending on the parent material, topography, climate and biota), the soils might not be restored before the end of the next ice age.

To interpret the present situation, it is useful to look back at history. Relevant examples can easily be found, ranging from the drainage of bogs in the Netherlands around the year 1000 (see also Chap. 19), which continues to have an impact today, to the effect of Agent Orange on the forests of Vietnam, which have been replaced by the rampant growth of bamboo thickets.

Looking back in time also helps us gain a clearer picture of the future. How will people who discover nuclear waste dumps in 5000 CE (i.e., 3000 years from now) react? It is possible that they will—as absurd as it may sound—interpret them to be the sacred sites of a lost civilization and build shrines in their honor, where they will be subject to radioactive contamination. In principle, we cannot make assumptions about societies 3000 years into the future with any certainty because we simply cannot know what explanations they will find plausible. The isotopes of plutonium (Pu), currently used to produce weapons and to fuel power stations, have a far longer life than 3000 years. Their half-life is approximately 24,100 years, and even after approximately 250,000 years, toxic amounts will remain. Because it seems hardly possible to secure a final disposal site for nuclear waste and mark its location with warning signs that will be correctly understood 250,000 years or more from now, the opposite strategy has been discussed: it might be safer to make the disposal sites so completely invisible that no one will ever discover them. At the Finnish Onkalo Nuclear Storage Site, this is indeed the concept (Upson 2009). Of course, this remains nothing but a vague hope.

The legacies resulting from the utilization of radioactive materials are a particularly extreme example. However, the principle applies that we are burdening the future with the waste we are producing today, and not only radioactive waste. According to a 2006 expert report commissioned by the German Federal Ministry of Economics from the accounting firm KPMG, which is seen as taking a conservative approach by mining experts, the eternity costs of German hard coal mining amount to at least 12.5–13.1 billion € (Preuße and Sroka 2007).

Coal mining is another example of practices with a long-term impact. However, not all are as dramatic and cost intensive. Where future environmental policy-making is concerned, it seems indispensable to focus attention upon long-term impacts and to identify those that entail a particularly high social commitment as a consequence. Technologies that result in such long-term impacts require increased attention or, as a precaution, stricter licensing control procedures as an obligation to future generations given that intergenerational equity features prominently in sustainability discourse. If one examines the past with such a research interest, it becomes apparent that particularly SNSs that were or are used for the production of energy for societies are worth examining in more detail.

Watermills are among the oldest forms of energetic utilization of watercourses. Apart from the millwheel, the arrangement consists of a channel to direct water flow toward the watermill and, in some cases, the raising of the water table in the immediate vicinity. Although usually only a small part of the water volume of a watercourse is diverted into a millstream, it constitutes a long-term intervention. Most of the energy invested goes into constructing the arrangement, although the wooden millwheel must be regularly repaired. If one compares the remains of a mill with those of a modern hydropower plant, then those of the mill appear to be 'benign'. In the worst case, what remains is a walled millstream through which some of the water flow continues to be diverted. Sometimes, interventions at the site to create water storage remain visible after millennia, but they have no transformative impact on the ecology of the watercourse. By contrast, the long-term effects of a large hydropower plant are far more problematic. Indeed, differences begin at the point of construction: power plants are often constructed on dry land, after which a new river bed will be excavated so that the river is 'built into' the power plant.

White (1995) called such hybrids 'organic machines'. If one wishes to maintain a hydropower plant of this kind, a significant investment of energy is required, not only for the power plant itself but also to stabilize the river that is dammed as part of the process. The bedload held back by the power plant needs to be removed upstream of its dam and returned to the river downstream where it is needed to stabilize the streambed. Hydropower plants therefore have a local, regional and sectoral impact upon human practices that extends beyond energy use itself. The power plant's reservoirs are often several kilometers long, and water levels of more than 10 m at the head of the reservoir are by no means rare. Water temperature and river morphology change over time, and with this comes changes to fish fauna. Migratory fish disappear and with them the fishermen who have used the aquatic ecosystem for their particular form of resource extraction. River vessels, by contrast, encounter improved conditions for transportation, mainly because the construction of hydropower plants requires the riverbanks to be reinforced and the depth of navigable waterways regulated.

If a run-of-river hydropower plant is dismantled, it cannot be assumed that the new ecosystem will resemble the ecosystem that existed before the power plant was constructed because profound changes have taken place (Doyle et al. 2005). If it is not dismantled, the costs of creating and maintaining the site, which persist over a long period, must be taken into account.

Coal power plants create a dangerous legacy upstream of the value-added chain in terms of the eternity costs of the coal mining industry. Nuclear power stations, with their energetically intensive form of power generation, have an even greater long-term legacy. If one takes into account the costs of the final deposition of radioactive wastes, including their long-term safeguarding, it becomes clear that the majority of the costs pertaining to this technology relate to their maintenance and stabilization. By comparison, the construction of such facilities is cheap. The requirements in terms of monitoring long-term impacts are high in technical, economic and social terms, and these impacts last several hundred thousand years. Interim and final repositories would probably be identifiable long after the next ice age as a human legacy, unless the greenhouse gas (GHG) emissions produced by humans delay the coming of the next ice age even beyond this time (Berger and Loutre 2002).

We therefore suggest that interventions in nature can be categorized according to whether legacies are associated with them, and if so, which types of legacies. We distinguish among benign, problematic and wicked legacies, which we categorize according to their longevity, the costs they entail and their potential to transform society. Wicked legacies are primarily those associated with arrangements where the expected energy yield is high. In most cases, the societal costs of such energy sources arise mainly after their active utilization has ended. This categorization entails setting the (comparably short-lived) energy yield against the

Table 6.1 Typology of legacies resulting from societal interventions in nature. The characteristics of socio-natural sites (SNSs) can be categorized according to their longevity, the costs they entail and their potential for transforming human practices in the future

Characteristics	Arrangements with short-lived legacies	Arrangements with stable, long-lived legacies	Arrangements with transformative legacies
Type of legacy	Benign	Problematic	Wicked
Longevity of legacy	Short	Middle	Long
Maintenance requirements	Low	Middle	High
Energy expenditure centered on	Production	Production and maintenance	Maintenance
Energy harvest density	Low	Middle	High
Transformative potential (impact on practices)	Local, sectoral	Local, regional, sectoral (one or several)	Societal, global

(generally long-lived) costs and expenditures. Table 6.1 provides an overview of the characteristics of different legacies.

The last row of this table focuses on the long-term impacts on human society, or the impact such arrangements have on future possible or necessary societal practices. We differentiate benign long-term impacts from problematic and wicked ones by their scale. Benign impacts remain limited to the local level and to individual economic sectors. Arrangements with problematic long-term impacts will have an effect on practices at both local and regional levels and in one or more economic sectors.

In contrast, the transformative potential of arrangements with wicked long-term impacts is global and affects society as a whole. The far-reaching impacts of nuclear accidents such as those at Chernobyl and Fukushima provide a foretaste of the long-term impacts of nuclear technology: large tracts of land could become uninhabitable because of radioactive pollution, and armies of engineers and safety personnel would be required to render the radioactive materials secure in both a technical and social sense. Their stabilization efforts are a battle against natural and social dynamics. ‘Hazardous waste management’ will likely become an increasingly large economic sector that will have to address industrial-age legacies for future societies.

6.5 Conclusions

Every intervention in nature and every creation of an SNS has both desired (or at least, foreseen) consequences and unforeseen ‘side effects’. Indeed, unforeseen side effects have characterized human history. Since at least the Neolithic revolution, keeping stocks of food to provide stable amounts of seed and supplies despite variable yields has been a key factor of success. In addition to the desired impact—avoiding famine during times when harvests fail—such food stores have attracted all types of undesired ‘dinner guests’; the existence of food stores has led to storage pests or vermin around the world. Following the argument proposed by Wilkinson (1973), humans have proven to be particularly innovative when they encounter problems. However, their solutions often lead to the creation of new problems. Tainter (1988) employed a number of historical examples to show that societies become more complex (e.g., develop new bureaucracies and structures) when they attempt to solve problems. However, this increased complexity also increases resource and energy requirements as marginal returns on investment decline, thus creating new problems, which may ultimately lead to a ‘collapse’. In Environmental History, this combination is referred to as the ‘risk spiral’. This term is intended to draw attention to the fact that instead of reducing risk, human responses tend either to displace risk elsewhere or to foster entirely new risks (Müller-Herold and Sieferle 1997). Long-term observation of the relationship between society and nature is a prerequisite to understand this development over time.

The conditions that enable societies to develop, as we initially proposed, are profoundly influenced by the long-term impacts of earlier interventions in nature, which, in many instances, happened in the distant past. This is a significant insight for the sustainability debate. It is not entirely new; the philosophy underpinning environmental sustainability certification and technology impact assessment is built upon such insights. What is new is the extent to which we need to take account of nature and its dynamics and how long ago significant changes happened. There are interventions with long-term impacts that predate the technology of modernity.

However, technologies, and to some extent environmental policies, are not commonly developed with long-term impacts in mind. Rather, they constitute short-term solutions to immediately pressing problems. If one takes seriously Heinz von Förster’s variation of Kant’s imperative, ‘I always try to act so as to increase the number of choices’, then one must give priority to long-term impacts when making decisions, such as those regarding new technologies (von Foerster 1973). This priority would be associated with a significantly different approach to evaluating technologies. The long-term perspective of Social Ecology, whether in its environmental history or its long-term socioecological manifestation, can contribute to the development of a ‘sustainability assessment’ that places particular emphasis on the problematic and dangerous long-term legacies of SNSs.

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Sources and References

Archival Material

Poma de Ayala, & Felipe Guaman (1615/1616). El primer nueva corónica y buen gobierno (1615/1616) (København, Det Kongelige Bibliotek, GKS 2232 4°). Autograph manuscript facsimile, annotated transcription, documents, and other digital resources. Retrieved from http://www.kb.dk/permalink/2006/poma/info/en/frontpage.htm. Last accessed March 20, 2013.

References

Berger, A., & Loutre, M. F. (2002). An exceptionally long interglacial ahead? *Science, 297*, 1287–1288.

Braudel, F. (1977). Geschichte und Sozialwissenschaften. Die longue durée. In M. Bloch, F. Braudel, L. Febvre & C. Honegger (Eds.), *Schrift und Materie der Geschichte. Vorschläge zu einer systematischen Aneignung historischer Prozesse* (edition suhrkamp 814, pp. 47–85). Frankfurt am Main: Suhrkamp.

Braudel, F. (2001). *Das Mittelmeer und die mediterrane Welt in der Epoche Philipps II. 3 Bände*. Frankfurt am Main: Suhrkamp.

Brown, K. W. (2001). Workers' health and colonial mercury mining at huancavelica, Peru. *The Americas, 57*(4), 467–496.

Collins, S. L., Carpenter, S. R., Swinton, S. M., Orenstein, D. E., Childers, D. L., Gragson, T., et al. (2011). An integrated conceptual framework for long-term social–ecological research. *Frontiers in Ecology and the Environment, 9*, 351–357.

Crutzen, P. J., & Stoermer, E. F. (2000). The 'Anthropocene'. *Global Change Newsletter, 41*, 17–18.

Doyle, M. W., Stanley, E. H., Orr, C. H., Selle, A. R., Sethi, S. A., & Harbor, J. M. (2005). Stream ecosystem response to small dam removal: Lessons from the Heartland. *Geomorphology, 71*, 227–244.

Erb, K.-H., Gingrich, S., Krausmann, F., & Haberl, H. (2008). Industrialization, fossil fuels and the transformation of land use: An integrated analysis of carbon flows in Austria 1830–2000. *Journal of Industrial Ecology, 12*(5–6), 686–703.

Erb, K.-H., Kastner, T., Luyssaert, S., Houghton, R. A., Kuemmerle, T., Olofsson, P., & Haberl, H. (2013). Bias in the attribution of forest carbon sinks. *Nature Climate Change, 3*, 854–856.

Fischer-Kowalski, M., & Weisz, H. (1999). Society as a hybrid between material and symbolic realms. Toward a theoretical framework of society-nature interaction. *Advances in Human Ecology, 8*, 215–251.

Gingrich, S., Erb, K.-H., Krausmann, F., Gaube, V., & Haberl, H. (2007). Long-term dynamics of terrestrial carbon stocks in Austria. A comprehensive assessment of the time period from 1830 to 2000. *Regional Environmental Change, 7(*1), 37–47.

Haberl, H., Erb, K.-H., Gaube, V., Gingrich, S., & Singh, S. J. (2013a). Tracing changes in socio-ecological stocks and flows of materials and energy across space and time—An overview of socio-metabolic LTSER approaches. In S. J. Singh, H. Haberl, M. Chertow, M. Mirtl, & M. Schmid (Eds.), *Long-term socio-ecological research. Studies in society-nature interactions across spatial and temporal scales* (pp. 29–52). Dordrecht, Heidelberg, New York, London: Springer.

Haberl, H., Erb, K.-H., Gingrich, S., Kastner, T., & Krausmann, F. (2013b). Human appropriation of net primary production, stocks and flows of carbon, and biodiversity. In R. Lal, K. Lorenz, R. F. Hüttl, B. U. Schneider, & J. von Braun (Eds.), *Ecosystem Services and carbon sequestration in the biosphere* (pp. 313–331). Berlin: Springer.

Haberl, H., Winiwarter, V., Andersson, K., Ayres, R., Boone, C., Castillo, A., et al. (2006). From LTER to LTSER: Conceptualizing the socio-economic dimension of long-term socio-ecological research. *Ecology and Society, 11*(2), 13. http://www.ecologyandsociety.org/vol11/iss2/art13/

Krausmann, F., & Haberl, H. (2007). Land-use change and socioeconomic metabolism: A macro view of Austria 1830–2000. In M. Fischer-Kowalski & H. Haberl (Eds.), *Socioecological transitions and global change* (pp. 31–59). Cheltenham: Edward Elgar.

Le Quéré, C., Andres, R. J., Boden, T., Conway, T., Houghton, R. A., House, J. I., et al. (2012). The global carbon budget 1959–2011. *Earth System Science Data Discussions, 5*, 1107–1157.

McNeill, J. R. (2000). *Something new under the sun. An environmental history of the twentieth century*. London: Allen Lane.

Müller-Herold, U., & Sieferle, R. P. (1997). Surplus and survival: Risk, ruin, and luxury in the evolution of early forms of subsistence. *Advances in Human Ecology, 6*, 201–220.

Nriagu, J. O. (1994). Mercury pollution from the past mining of gold and silver in the Americas. *The Science of the Total Environment, 149*, 167–181.

Preuße, A., & Sroka, A. (2007). Technische Abschätzung von Folgelasten des Steinkohlenbergbaus. *bergbau 12*, 540–546.

Redman, C. L., Grove, J. M., & Kuby, L. H. (2004). Integrating social science into the long-term ecological research (LTER) network: social dimensions of ecological change and ecological dimensions of social change. *Ecosystems, 7*, 161–171.

Robins, N. A. (2011). *Mercury, mining, and empire: The human and ecological cost of colonial silver mining in the Andes*. Bloomington: Indiana University Press.

Robins, N. A., & Hagan, N. A. (2012). Mercury production and use in colonial andean silver production: Emissions and health implications. *Environmental Health Perspectives, 120*, 627–631.

Robins, N. A., Hagan, N. A., Halabi, S., Hsu-Kim, H., Gonzales, R. D., Morris, M., et al. (2012). Estimations of historical atmospheric mercury concentrations from mercury refining and present-day soil concentrations of total mercury in Huancavelica, Peru. *The Science of the Total Environment, 426*, 146–154.

Sieferle, R. P. (1997). *Rückblick auf die Natur*. München: Luchterhand.

Singh, S. J., Haberl, H., Chertow, M., Mirtl, M., & Schmid, M. (2013a). Introduction. In S. J. Singh, H. Haberl, M. Chertow, M. Mirtl, & M. Schmid (Eds.), *Long-term socio-ecological research. Studies in society-nature interactions across spatial and temporal scales* (pp. 1–26). Dordrecht, Heidelberg, New York, London: Springer.

Singh, S. J., Haberl, H., Chertow, M., Mirtl, M., & Schmid, M. (Eds.). (2013b). *Long-term socio-ecological research. Studies in society-nature interactions across spatial and temporal scales*. Dordrecht, Heidelberg, New York, London: Springer.

Singh, S. J., Haberl, H., Gaube, V., Grünbühel, C. M., Lisievici, P., Lutz, J., et al. (2010). Conceptualising long-term socio-ecological research (LTSER): Integrating the social dimension. In F. Müller, C. Baessler, H. Schubert, & S. Klotz (Eds.), *Long-Term ecological research, between theory and application* (pp. 377–398). Dordrecht, Heidelberg, London, New York: Springer.

Studnicki-Gizbert, D., & Schecter, D. (2010). The environmental dynamics of a colonial fuel-rush: silver mining and deforestation in New Spain, 1522 to 1810. *Environmental History, 15*(1), 94–119.

Tainter, J. A. (1988). *The collapse of complex societies (new studies in archaeology)*. Cambridge: Cambridge University Press.

Upson, S. (2009). Finland's nuclear waste solution. Scandinavians are leading the world in the disposal of spent nuclear fuel. Retrieved from http://spectrum.ieee.org/energy/nuclear/finlands-nuclear-waste-solution/0. Last accessed November 10, 2014.

von Foerster, H. (1973). On constructing a reality. In F. E. Preiser (Ed.), *Environmental design research* (vol. 2, pp. 35–46). Stroudberg: Dowden, Hutchinson & Ross.

Waszkis, H. (1993). *Mining in the Americas: Stories and history*. Cambridge: Woodhead Publishing Limited.

White, R. (1995). *The organic machine: The remaking of the Columbia river*. New York: Hill and Wang.

Wilkinson, R. G. (1973). Poverty and progress: An ecological model of economic development. London: Methuen.

Winiwarter, V., & Schmid, M. (2008). Umweltgeschichte als Untersuchung sozionaturaler Schauplätze? Ein Versuch, Johannes Colers „Oeconomia" umwelthistorisch zu interpretieren. In T. Knopf (Ed.), *Umweltverhalten in Geschichte und Gegenwart: Vergleichende Ansätze* (pp. 158–173). Tübingen.

Winiwarter, V., Schmid, M., Hohensinner, S., & Haidvogl, G. (2013). The environmental history of the Danube River basin as an issue of long-term socio-ecological research. In S. J. Singh, H. Haberl, M. Chertow, M. Mirtl, & M. Schmid (Eds.), *Long-term socio-ecological research. Studies in society-nature interactions across spatial and temporal scales* (pp. 103–122). Dordrecht, Heidelberg, New York, London: Springer.