Spatial Environment and Conceptual Design

THE CONCEPT OF SOCIAL ECOLOGY AS A MEANS TO INTEGRATE HUMANITIES AND SCIENCE IN LANDSCAPE ARCHAEOLOGICAL RESEARCH

Daniel Knitter
Wolfram Schier
Brigitta Schütt
(eds.)

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THE RELATIONSHIP BETWEEN HUMANS, their landscapes, and the natural environment is complex and underlies mutual non-material and material fluxes. Especially challenging is the attempt to reconstruct this relationship in order to understand the role and relevance of Space and Knowledge of Ancient Civilizations, the core theme of the cluster of excellence Exc 264 Topoi, funded from 2007–2019. In this book we present the results of an attempt to use a system-oriented concept of social ecology as tool for interdisciplinary collaboration and integrative research on aspects of human-environmental relationship. In six different interdisciplinary projects the developed social ecological model is applied and critically discussed.

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Daniel Knitter, Reinhard Bernbeck, Wolfram Schier, Brigitta Schütt

Introduction: Reflections on the Applicability of a Social Ecological Concept to Research in a Framework of Spatial Environment and Conceptual Design

Summary

The Excellence Cluster Topoi (Exc 264) has investigated the Formation and Transformation of Space and Knowledge in Ancient Civilizations since 2007. Different Research Areas, consisting of a broad range of scientific fields have targeted the central terms space and knowledge from different perspectives and applied them to multiple temporal and spatial scales. We present a social-ecological model whose terms and elements are the result of the joint interdisciplinary discussion between the participating researchers of Topoi. The search for an overarching framework results in tensions of content that we consider to be healthy, as they expose both the strengths and weaknesses of a generalized approach to questions of landscape archaeology.

Keywords: social ecology; landscape archaeology; human-environment interaction; interdisciplinarity; geography

Das Exzellenzcluster Topoi (Exc 264) untersuchte seit 2007 die Entstehung und Transformation von Raum und Wissen in alten Zivilisationen. WissenschaftlerInnen aus diversen Disziplinen haben die zentralen Begriffe Raum und Wissen aus sehr unterschiedlichen Perspektiven betrachtet und auf mehrere zeitliche und räumliche Skalen angewendet. Wir präsentieren ein sozial-ökologisches Modell, dessen Begriffe und Elemente das Ergebnis der gemeinsamen interdisziplinären Diskussion zwischen den beteiligten Forscherenden von Topoi sind. Die Suche nach einem übergreifenden Rahmen führte zu inhaltlichen Spannungen, die wir für gesund halten, da sie sowohl die Stärken als auch die Schwächen eines generalisierten Ansatzes zu Fragen der Landschaftsarchäologie aufzeigen.

Keywords: Soziale Ökologie; Landschaftsarchäologie; Mensch-Umwelt Beziehung; Interdisziplinarität; Geographie

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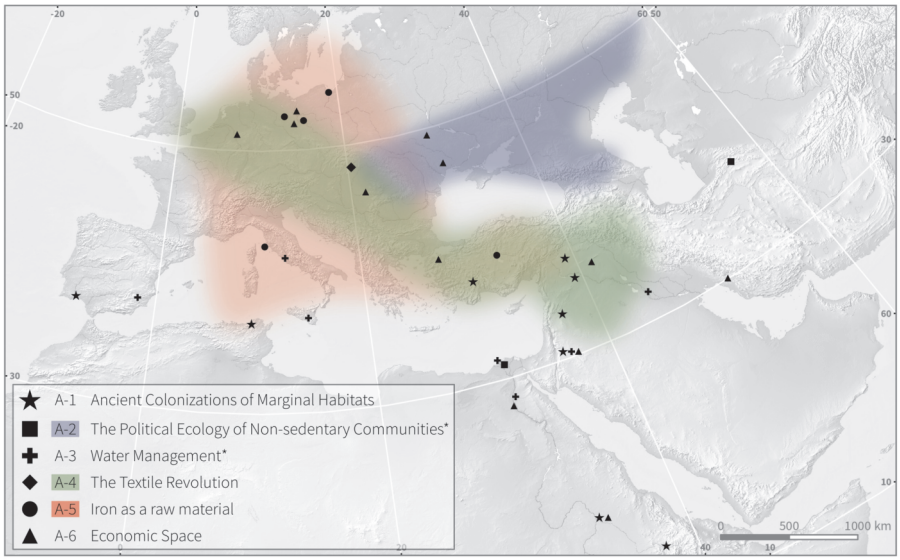

Fig. 1 Spatial distribution of the different projects of Topoi's Research Area A, 'Spatial Environment and Conceptual Design.'

The Excellence Cluster Topoi (Exc 264) has investigated the Formation and Transformation of Space and Knowledge in Ancient Civilizations since 2007. Different Research Areas, consisting of a broad range of scientific fields — from physics and geosciences to archaeology, art, and philosophy — have targeted the central terms space and knowledge from different perspectives and applied them to multiple temporal and spatial scales. The investigation of archaeological remains and, by implication, of societal dynamics and circumstances are the predominant scope of Topoi's Research Area A, entitled 'Spatial Knowledge and Conceptual Design.' Research Area A focuses on the interaction between human beings and their environment. Such a framing results in an analytical preference for the large scale (Fig. 1).

Investigating *spatial knowledge and conceptual design* in the context of settlement history, material flows triggered by natural phenomena, and human activities are of central interest. The relics of these actions and dynamics – in archaeology called *artefacts* and *ecofacts*, in physical geography called *proxy data* – are used to reconstruct the material, energy, and communication flows between human groups and their environment. Our approach conceptualizes reconstructions of the past as approximations based on archive data (geographic, as well as archaeological) that integrate the understanding and functioning of present-day processes, as well as the contingencies of human action. In this way, we follow both the principles of uniformitarianism, as coined by James Hutton

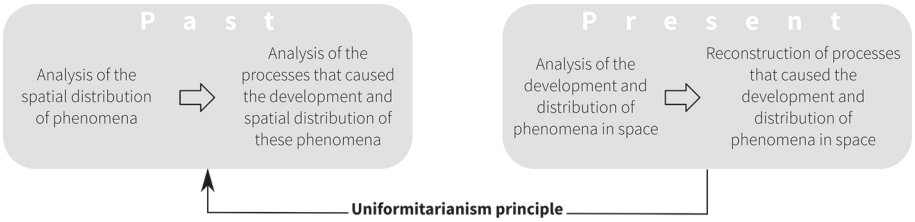

Fig. 2 Research concept for environmental reconstruction in studies undertaken in Topoi's Research Area A, 'Spatial Knowledge and Conceptual Design.'

and Charles Lyell,[1] and the mutually constitutive processes between structure and human action, as outlined by Anthony Giddens, where structures of human societies result from both intended and unintended consequences of action (Figs. 2, 3).[2]

Human environment interactions are understood heuristically as being in a state of a dynamic equilibrium, with *adaptation* and *resilience* being central terms.[3] Using these terms for an analysis of the changes in the state of human groups and their environment enables us to compare the relationships between different cultures, periods, and regions while leaving space for historical contingency. It is assumed that people with a variety of (non)modern technologies were highly limited by natural conditions in their activities. In order to utilize the environment more efficiently, they adapted to it by inventing specific techniques, for example in the agricultural sector. Still, we always need to take into consideration that such adaptations were a matter of choice, that no single cause effect chain or predictability determines the course of human (pre-)history. Adaptations have to be seen as operations that tried to increase a system's resilience in relation to its environment, at the same time providing space for historically contingent trajectories of change. Human activities, for instance due to settling and utilizing hinterlands, caused disturbance of a landscape's dynamic equilibrium, fostering (or obviating) natural processes such as flooding and soil erosion as a consequence of clearing land and agriculture (cf. Fig. 4). The magnitude of resulting material flows depended on the sensitivity of a landscape and the extent of the human impact; these flows of matter were mostly higher in intensity than before the onset of the settlement activities, and also frequently affected the settlement area itself. The extent of these influences becomes evident in studies of human niche construction that illustrate the strong, often deteriorating, effect of human activities on environmental resilience.[4] As a consequence, human groups had to adapt to these self-made conditions. Considering the long duration of the observed systems,

1 Hutton 1795; Lyell 1854.
2 Giddens 1979; Giddens 1984.
3 Schütt and Meyer 2011, 4–5.
4 E.g. Boivin et al. 2016.

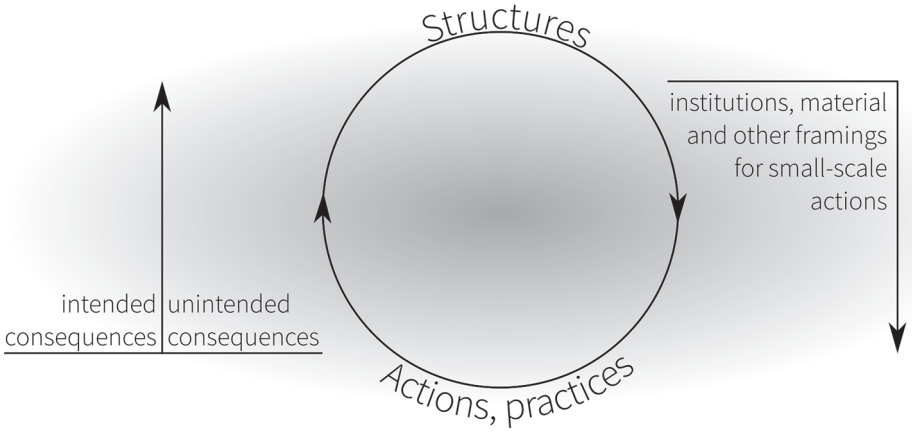

Fig. 3 The co-constitutive relations between structures and actions in human societies, according to Giddens' 'structuration scheme.'

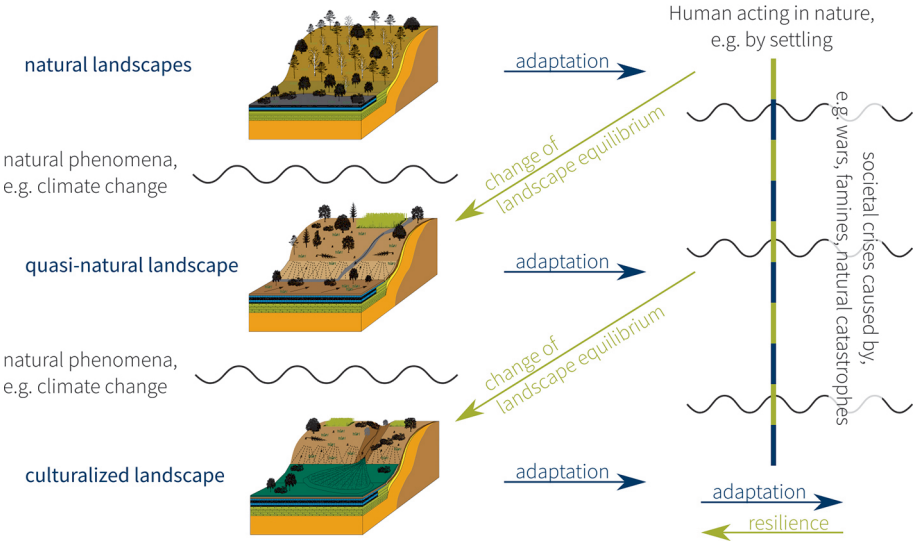

Fig. 4 Processes of adaptation and resilience as a consequence of human action.

changes of the natural environment (e.g. climate change) also have to be taken into account. The human-environment dynamics were furthermore influenced by natural phenomena and extreme events (e.g. droughts, heavy rainfall events, and earthquakes) and cultural phenomena (e.g. wars, technical and other innovations, and loss of knowledge).

However, adaptation and resilience are not just taken as mere descriptions of char-

acteristics for selected case studies. For instance, some of our research in the years 2007 to 2012 focused on the meta-topic of 'Central Places and their Environment' in order to investigate different functional types of central places (e.g. economic, governmental, and sacral), the characteristics of their location, and interactions between central places and their peripheries. In multiple projects with objectives clearly related to the meta-topic but varying in experimental design, the issue has been explored.[5] Through these contributions, we provide important insights into the relations between settlement activities, adaptation strategies, and environmental characteristics.[6] A compilation of several prominent central places in arid environments such as Petra (Jordan), Resafa (Syria), and Musawwarat es-Sufra (Sudan) is presented by Bebermeier et al.,[7] where the emergence of these large central places as seats of residence or sacral places in politically and ecologically marginal regions is analyzed. Another study investigating the diachronic development of Aleppo (Syria) shows that its centrality never vanished despite climatic shifts, as well as socio-economic and cultural dynamics.[8] In contrast, a comparative study investigating the centrality of Ephesos and Pergamon documents the changes in the degree and type of centrality across time, indicating that these are caused by dynamics in the overall political framework, thus highlighting the relative and context-specific role of the environment.[9]

These insights show that the relationship of humans to their natural and culturalized environs is influenced by different factors, with both internal and social conditions playing a variable role.

We are also aware that our work is preoccupied with only one kind of human action that follows instrumental reasoning, rather than communicative or other kinds of reasons discussed in sociology and social philosophy.[10] We recognize that human action may be based on ideas and beliefs that are decidedly non-instrumental, that can even be ontologically radically different from our own world's ideas and beliefs. Still, the unintended consequences of activities carried out utilizing instrumental logic can entail results that appear planned. Sociologist Robert Merton has called this effect the 'latent function' of practical actions.[11]

Stimulated by the empirically-based findings, the ongoing research in the field of human-environment interaction in the framework of Topoi since 2012, is designed around six overarching research topics. Although the researchers focus on different specific questions, they are at the same time integrated into more general topics, like

5 E.g. Beckers, Berking, and Schütt 2013; Beckers and Schütt 2013; Beckers, Schütt, et al. 2013; Berking, Beckers, and Schütt 2010; Berking and Schütt 2011; Del Fabbro 2012; Schmid and Mouton 2013; Schneider et al. 2013; Seeliger et al. 2011.

6 E.g. Knitter, Bergner, et al. 2012; Knitter, Blum, et al. 2013; Knitter, Nakoinz, et al. 2014; Nakoinz 2012.

7 Bebermeier et al. 2016.

8 Knitter, Nakoinz, et al. 2014.

9 Knitter, Blum, et al. 2013.

10 For an overview see Habermas 1987.

11 Merton 1957, 60–65.

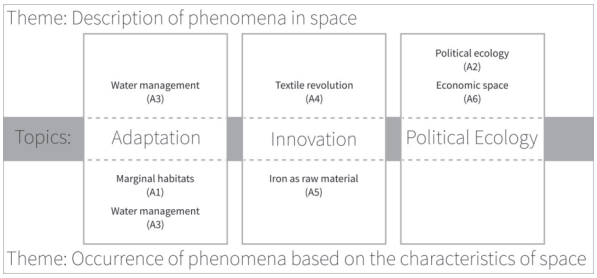

Fig. 5 Research groups of the Research Area A, 'Spatial Knowledge and Conceptual Design' during the second funding phase of the cluster of excellence Topoi 'The Formation and Transformation of Space and Knowledge in Ancient Civilizations.'

adaptation (A-1, A-3); innovation (A-4, A-5); and political ecology (A-2, A-6). Simultaneously, the research strongly focuses on the description of phenomena in space (A-3, A-4, A-6), as well as the occurrence of phenomena based on the characteristics of space (A-1, A-3, A-5) (Fig. 5).

The use of the term *space* in a given context requires some explanation. Since investigations in the Research Area A, 'Spatial Knowledge and Conceptual Design', focus on the intersection of human beings and their environs, *space* has to combine both realms. In order to illustrate this and to integrate our research in a broader scientific context, we refer to this human-environment space as *landscape*. Landscapes are constructed by humans but are at the same time constituted of elements from the natural world. They mirror the specific patterns of adaptation and resilience resulting from human action, innovation, and utilization, but are also based on historically specific patterns of perception of these relations. To cope with these requirements, space is considered to integrate local, regional, and supra-regional dimensions.

1 Definitions

1.1 Landscape

Each human is unique, hence there are innumerable views of the world surrounding the respective individual that can be referred to as *landscape*. Although these views differ in detail, they share a common base in the cultural context of single individuals. In its long history of utilization, the term *landscape* has been variously described as (a) political territories,[12] (b) aesthetic aspects of nature,[13] and (c) technical aspects of an artistic representation of nature.[14] In science it has been used as a holistic construct to integrate human lifeways and nature that had been separated after the advent of a Cartesian worldview and the downswing of teleological worldviews (see e.g. Humboldt's description

12 Troll 1950, 163–164.
13 Hokema 2012, 36–37.
14 Küster 2012, 28–29.

of landscape as "Totaleindruck einer Gegend" or Sauer's view of landscape as a unifying geographical concept).[15]

In its original – geographic – significance, landscape is a section of the earth's surface that is characterized by a combination of: (a) culture-specific perspectives, (b) historical development, and (c) bio-physical characteristics of the environment. Since its introduction to a wider scientific audience, there are continuous debates about the definition of the term landscape, research agendas for its exploration, and concepts of what research might be adequate.[16] In any case, ideas about the role of landscape and its importance differ according to discipline, as well as researchers' epistemological and ontological standpoints (Tab. 1). We see this multiplicity as an advantage, rather than a disadvantage for our own research group, since employing the ambiguity of a term opens the opportunity to create a spatial synthesis of the different research approaches involved;[17] in continuous discussions between scholars involved in Topoi's 'Spatial Knowledge and Conceptual Designgroups', we considered these different viewpoints and encouraged discussion. The least-common denominator is provided by the interdisciplinary character of the research. It is the real, material world as it is apprehended, interpreted, and as it was shaped by human action.

Discussions of the term landscape during the past decades, and its continually changing use and understanding, allow one to identify two general perspectives: (1) a rather old-fashioned and functionalist viewpoint that is currently experiencing a small renaissance and (2) a constructivist viewpoint that includes theories of action.

The *functionalist* viewpoint understands landscape from the perspective of space as a *container*. Its renaissance is due to the upswing of Geographic Information Systems whose overlay techniques are nothing other than a digital version of Hettner's scheme, which was popular in the early 20th century and has been criticized continuously for its simplicity ever since.[18] Nevertheless, although the functionalist viewpoint will always lack some important aspects, it is valuable as a heuristic tool in order to arrive at an overview of different components of any specific landscape that might influence each other. In its traditional application, the multi-dimensional, non-linear relations between the different spheres (Fig. 6a) were understood through qualitative, descriptive approaches;[19] the understanding of this complex interaction pattern was supposed to be based on expert knowledge. Its reinvented digital application in Geographical Information Systems allows the mathematical combination of two or more layers (Fig. 6b). However, it is frequently forgotten that mapped functional relations are not causal ones.[20]

15 Humboldt 1806, 11; Sauer 2008, 98.

16 See summarizing literature in Mitchell and Breitbach 2011; Rose and Wylie 2011; Gailing and Leibenath 2011.

17 See also Jessel 2005, 582.

18 Wardenga 2006.

19 Generally: *Länder-/Landschaftskunden,* e.g. Passarge 1908; Philippson 1914; Lautensach 1932; Wirth 1971; or specific topics, e.g. Büdel 1969.

20 Hacking 1996, 66–70.

Author	Definition	Discipline
Humboldt 1806, 11	"(…) Totaleindruck einer Gegend." (total impression of an area) [translation D. Knitter]	Geography
Schmithüsen 1964, 13–14	"Eine Landschaft ist der Inbegriff der Beschaffenheit eines auf Grund der Totalbetrachtung als Einheit begreifbarem Geosphärenteils von geographisch relevanter Größenordnung. (…) Jede Landschaft ist ein dynamisches Gebilde, ein Sach-Raum-Zeit-System bestimmter Qualität innerhalb der Gesamtgeosphäre. Sie ist (…) ein offenes System. (…) Wir unterscheiden (…): anorganische Naturlandschaften, belebte Naturlandschaften und Kulturlandschaften." ("A landscape is the epitome of the quality of a geosphere part of a geographically relevant order of magnitude that can be understood as a unit on the basis of total observation. (…) Every landscape is a dynamic entity, a material-space-time system of certain quality within the entire geosphere. It is (…) an open system. (…) We distinguish (…): inorganic natural landscapes, animated natural landscapes and cultural landscapes.") [translation D. Knitter]	Geography
Burckhardt 2012, 133	(…) [T]he landscape is to be found, not in environmental phenomena but in the mind's eye of those doing the looking. To espy a landscape in our environment is a creative act brought forth by excluding and filtering certain elements and, equally, by rhyming together or integrating all we see in a single image, and in a manner influenced largely by our educational background."	Architecture
Gramsch 2003, 48	"Landschaft ist (…) das Ganze, das Plenum, der Kontext, sie lässt sich beschreiben als strukturelles Phänomen geprägt durch die Raum-Struktur, d.h. die Dialektik zwischen Ort und Raum als Trägern von Werten (…). Darüber hinaus ist Landschaft ein physisches Phänomen, ein von Menschen stetig veränderter Natur-Kultur-Raum. Landschaft ist somit etwas soziokulturell Geschaffenes, ein mit Werten belegtes und durch die Ideologie dieser Werte gesehenes Ganzes." („Landscape is (…) the whole, the plenum, the context; it can be described as a structural phenomenon shaped by a space structure, i.e. the dialectic between place and space as carriers of values (…). In addition, landscape is a physical phenomenon, a nature-culture space constantly changed by humans. Landscape is thus something created socio-culturally, an entity full of values and perceived through the ideology of these values".) [translation D. Knitter]	Archaeology

Tab. 1 (Part I) Overview of different definitions of the term 'landscape' and its disciplinary allocation.

Author	Definition	Discipline
Ipsen 2006, 76	"Das Konzept des Begriffs Landschaft baut auf [der] (…) Interdependenz von Landschaftsentwicklung, die durch Natur und Nutzung bestimmt ist und der Entstehung von Landschaftsbildern auf. Die Eckpunkte des Landschaftsbegriffs sind natürliche Prozesse auf der einen Seite und die Bearbeitung einschließlich der dazu benutzten Technologien auf der anderen Seite. Bearbeitung heißt dabei nicht nur die landwirtschaftliche oder forstwirtschaftliche Arbeit, sondern auch der Bau von Städten und Siedlungen, der Bau von Verkehrssystemen oder die Produktion von Energie. Zudem ist die Entwicklung der Landschaft gesellschaftlich strukturiert. Eigentumsverhältnisse bestimmen Nutzungsformen und führen so zu bestimmten Landschaften." ("The concept of landscape builds on [the] (…) interdependence of landscape development determined by nature and useage and the emergence of ideas of landscape. The cornerstones of the concept of landscape are natural processes on the one hand and cultivation, including the technologies mobilized for this purpose, on the other. Cultivation does not only mean agriculture or forestry, but also the construction of cities and settlements, the construction of transport systems or the production of energy. In addition, the development of the landscape is socially structured. Property relations determine forms of use and thus lead to certain landscapes".) [translation D. Knitter]	Sociology, planning
Lowenthal 2007, 635	"Landscape is everyone's fundamental heritage. It is all embracing and unavoidable. It inspires and shapes much of what we learn and do. Landscape is where we all make our homes, do our work, live our lives, dream our dreams. Yet for each of us it means something different, formed by unique collective and individual experiences"	Geography/Heritage Studies
Meier 2012, 507	"On the one hand space is structuring action, on the other hand space is simultaneously constituted by action and perception. Thus (…) space is no longer a matter of ontology (a prediscursive container) but a matter of epistemology (a social construct). (…) I would suggest calling such kinds of socially constituted spaces 'landscapes'."	Archaeology
Kühne and Bruns 2015, 18	"Die sozialkonstruktivistische Perspektive versteht Landschaft nicht als objektiv gegebenen und eindeutig definierbaren Teil der physisch-materiellen Welt. Vielmehr wird sie als sozial und kulturell erzeugtes wie auch vermitteltes Konstrukt begriffen." ("The social constructivist perspective does not conceive of landscape as an objectively given and clearly definable part of the physical-material world. Rather, it is understood as a socially and culturally generated as well as a mediated construct.") [translation D. Knitter]	Sociology

Tab. 1 (Part II) Overview of different definitions of the term 'landscape' and its disciplinary allocation.

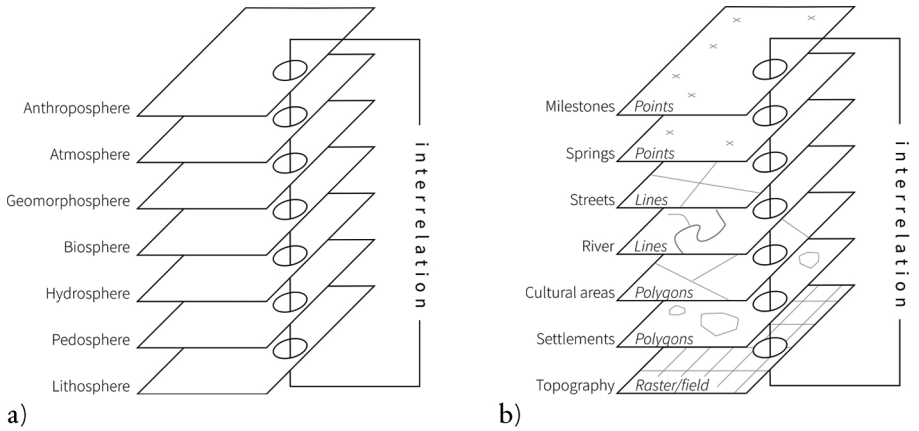

Fig. 6 a – Hettner's scheme; b – Hettner's scheme utilized in the GIS framework.

Moreover, most applications of Geographical Information Systems do not provide the algorithms required to factor in the non-linearity and unsteadiness of relations between different spheres.

The *container space* approach proposes an integration of everything that is perceptible in a Euclidean (geographic) space as real. In the *constructivist approaches,* a function of landscapes starts with the presupposition of basically nothing (besides the assumption of interaction of the elements 'to be defined'). Space is constituted through the agency of individuals who are guided by their imagination and interests. Such approaches explicitly create the connections and entities that are regarded as relevant.[21] To stay with the computer metaphors, though, such approaches are rather uncommon in this context: agent- and individual-based modeling approaches belong to this category.[22] Their deficiency rests in a tendency to assume an omniscient, rational actor where most historical human activities are dominated by fractured, divisive, and contradictory knowledge, as well as 'suboptimal' actions and decisions (at least from a perspective of purposive rationality).

21 E.g. Klüter 1994; Werlen 2010, 44–45: "So wie wir über Handlungen ‚Gesellschaft' täglich produzieren und reproduzieren, so produzieren und reproduzieren wir auch Geographien oder besser: die sozial-geographischen Verhältnisse, unter denen wir leben. Für die Analyse fragt man zuerst, was jemand tut, bevor man nach den räumlichen Bedingungen *dafür* und den räumlichen Konsequenzen *davon* Ausschau hält" (Just as we produce and reproduce 'society' on a daily basis through actions, we also produce and reproduce geography, or better: the social-geographical conditions in which we live. For the analysis, one first asks what someone is doing before investigating the spatial conditions for it and the spatial consequences thereof. [translation D. Knitter]) (emphasis in the original).

22 E.g. Gilbert 2008; Railsback and Grimm 2012; Kohler 2012; Wurzer, Kowarik, and Reschreiter 2015.

In the landscape archaeology context followed by Topoi's Research Area A, 'Spatial Knowledge and Conceptual Design', we intended to incorporate approaches of both strands in order to integrate natural landscape dynamics with those dealing with social and historical aspects. While investigating *landscapes,* this remains a firm commitment, since the internal conception of the Research Area is that landscapes can only be fully understood by referring to both schools of thought. However, we recognize that each project carried out under the umbrella of the Research Area has its own paradigmatic leanings and predilections.

1.2 Resilience, vulnerability

The numerous landscapes studied are unique due to specific cultural, social, and environmental characteristics. In this volume, we focus on the ecological side of the human-environment relations, rather than on the perception of landscapes and those actions that can be directly tied to such phenomenological concerns; in other words, we stick to those aspects of a historical ecology that are located in the realm of instrumental reason. Despite our paradigmatic openness, comparing these multifaceted landscapes in an interdisciplinary approach requires a joint concept and some standardized vocabulary. One such concept is *landscape sensitivity,* which is concerned with the capacity of landscapes to resist forces of change, independent of whether these arise from variability in climate, endogenic triggers, or human impact.[23] As a consequence, the driving forces that change the relationship between humans and their environment are emphasized. From a historical-cultural point of view, we refer to these driving forces as innovations and adaptation strategies, as dissemination of knowledge, and its utilization. At the same time, it is necessary to give thought to the potential of maladaptation and the ambivalence of innovations that ameliorate the lives of some but degrade those of others, other species such as 'weeds' and specific wild animals included. Innovations can aim to improve the general livelihood due to the implementation of new techniques into society, but just as frequently, they provide an impetus for social disintegration.[24] Adaptation seeks to preserve a state of living conditions under changing environmental or societal circumstances;[25] again, intentions of stabilization may actually lead to its opposite in the long run. *Utilization* refers to the appropriation of the environment in order to increase the efficiency of economic exchange or the exploitation of valuable resources.

To understand, describe, and evaluate the process of the introduction and spread of an innovation in the realm of relations between human groups and their environment,

23 E.g. M. F. Thomas 2001.

24 Sanginga et al. 2009; United Nations 2008; Pollock 2017.

25 Osbahr, Twyman, Neil Adger, et al. 2008; Osbahr, Twyman, Adger, et al. 2010.

different kinds of landscape utilization are of central interest. For societies that produce such inventions, triggers for them need to be identified and the paths of innovation dissemination reconstructed – pursuing this is crucial for an understanding of how innovations have changed societies. In our group, a main interest lies in how different innovations have affected the environment. For instance, it has been shown that the introduction of wool-bearing sheep during the Late Chalcolithic to Bronze Age, and its influence on the landscape, were not strong enough to be traceable in sediment archives.[26] In contrast, the Neolithic invention of the plow significantly affected landscape stability, resulting in extended processes of erosion, however, with major local time lags until its onset.[27] Based on these observations, emphasis is put on the question of which forms of appropriation of environmental resources and innovations integrate themselves sustainably in dynamic equilibria of human-landscape systems, which do not, and with what consequences. Furthermore, sustainable forms of landscape utilization (i.e. resource exploitation) include not only technological aspects but often also governance structures and the socio-political dimension in general.[28] Wittfogel's link between despotism and irrigation systems comes to mind, even if it is nowadays debunked as improbable[29] and Descola's *Ecology* of *Others* can be read as a manifesto for the sustainability of low-level resource utilization under circumstances where governance is kept rigorously at bay.[30]

In addition, it has to be considered that the visibility and interpretability of past landscapes, when associated with disturbed dynamic equilibria in present-day sediment archives, depends on the continuity of the archive, structural discordances, and the resolution of the archive. Settlement activities might not directly trigger flows of matter, but change some other variables of a complex environmental system; the onset of reacting processes might happen only after a time-lag. In such a multifactorial context, settlement activities might not affect flows of matter (e.g. soil erosion, surface runoff) until an event exceeds a particular threshold (Fig. 7).

In order to understand the use of landscapes, accompanying technological inventions, their dissemination as innovations, and their effect on landscapes, it is necessary to develop an idea of the societies that were behind such changes, as well as their susceptibility to crises, famines, etc. This includes the integration of modern anthropological and sociological research about societal resilience and vulnerability,[31] and affords the opportunity to explore whether innovations in past societies affected their adaptation or mitigation capacities. In the natural sciences, we can identify two understandings of resilience. On the one hand, resilience is seen as the buffering capacity of a system before

26 Schumacher, Schier, and Schütt 2016.
27 E.g. Kalis, Merkt, and Wunderlich 2003; Bork 2006; Dotterweich 2013.
28 E.g. Gildemacher et al. 2009; Roth et al. 2015.
29 Wittfogel 1957; Adams 1973; Earle 1978.
30 Descola 2013.
31 E.g. Christmann and Ibert 2012; Cutter and Finch 2008; Redman 2005; Curtis 2014.

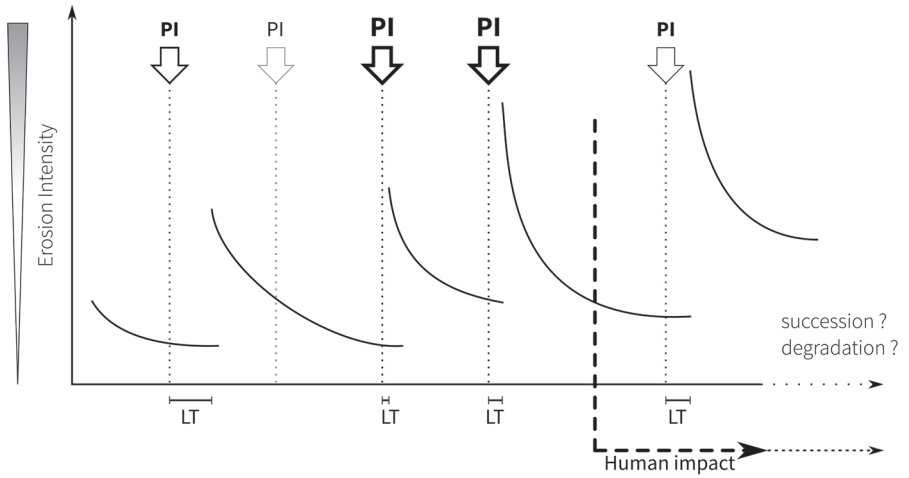

Fig. 7 Sketch of the complex dynamic interaction pattern in a process-response model via the example of surface runoff and erosion between (a) ordinate: process intensity and (b) magnitude of a triggering event, here, in the sense of precipitation intensity PI (the sizes of the letters increase with the assumed magnitude). The abscissa corresponds to the time axis; LT = lag time indicates the delay of the system reaction (surface runoff, erosion) on the impulse (precipitation). (c) The onset of settlement activities is marked by the dashed arrow; the initial lack of erosive rainfall connotes a lack of erosive processes. Due to settlement, activities increased exposure of the landscape and coinciding degraded resilience implies that by now the threshold for erosive rainfall decreased. The perpetuating landscape development depends on whether further use might cause an ongoing degradation or – in the other extreme – an abandonment of the area might cause a succession.

it changes its state;[32] this can be caused by external stress (e.g. climate change) or internal evolution (e.g. increasing population density). The other definition of resilience understands it as the speed of recovery of a system from perturbations or disturbances whose extent is defined by the resistance of a system.[33]

These views can be compared to concepts in the social sciences. The concept of vulnerability is grounded in action under conditions of uncertainty and denotes practices that are due to collective assessments and negotiations in situations of endangerment.[34]Accordingly, resilience highlights societal possibilities to act and react within a relational network that is based on specific perceptions of vulnerability.[35] Resilience can also mean the ability of a social network to respond to major external disasters, whether through organizational flexibility or technological means. Vulnerability can be an analytical term used when societies are analyzed from an external point of view. In such cases, vulnerability assessments denote the threshold beyond which a society risks breakdown because of a lack of means to respond adequately to threats, whether

32 Holling 1973.
33 Adger 2000, 349.
34 Christmann and Ibert 2012, 267.
35 Christmann and Ibert 2012, 267.

of environmental, economic, political, or other kinds. In another way, the internal view means a society or group's perception of being vulnerable. This may cause actions that aim to increase its resilience against perceived risks. Hence, both resilience and vulnerability as terms can be, and often are, regarded as loose antonyms in the social sciences.[36] The higher the perceived vulnerability, the lower a society rates its own resilience. It follows further that vulnerability and resilience vary throughout cultures, societies, space, and time.

In Research Area A, we understand *resilience* mostly in an objective, external way, as the capacity of a society to absorb perturbations (Fig. 8).[37] If we assume a co-evolution between societies and the ecosystems exploited by them, resilience and vulnerability are central characteristics for both social and environmental systems. While ecological resilience can be measured as the physical components of a system, social resilience is more difficult to measure. If the stability of institutions that constitute a society is used, the duration of continuity is not easy to define. Taking a case such as Mesopotamia. Do we measure social resilience within the temporal framework of political dynasties? Or within the *longue durée* of archaeological ages, such as the Early Bronze Age? Resilience of institutions can be based on their historical development as well as their inclusivity and exclusivity.[38] Social resilience can be examined in changes of economic or institutional structure or demographic change, especially migration.[39] Still, the verdict on the usefulness of a concept such as social resilience is open. Do we interpret periods of 'anarchism', such as the time of the Guti in third millennium Mesopotamia, as an expression of resilience against political insecurity, or is this condition itself a sign of the lacking resilience of the preceding time of the dynasty of Akkad? We are on more secure ground when we restrict ourselves to the relationship of *social* and *ecological resilience*, even though factors such as resource dependency are difficult to investigate. Deterministic readings of such relations, whether from a cultural or a natural perspective, aggravate this issue. However, in the realm of relations between a society and its environment, resilience depends both on the diversity of an ecosystem and the rigidity or flexibility of institutional rules that underlie a social system.[40]

Even if continuous change is assumed, the mentioned ideas rely on the general assumption that natural environments, as well as societies, can be characterized by deviations from some general state, often referred to as an equilibrium. Such a view of dynamics as process is prevalent in physical geography but not necessarily in archaeology, with its deep roots in historical and social sciences. Due to the long-term diachronic view taken by archaeology, such research insists on the close interweaving of repetitive

36 E.g. Curtis 2014.

37 Referring to Holling 1973; Walker et al. 2004.

38 For a diachronic investigation of the importance of inclusive and exclusive institutions see Acemoglu and Robinson 2013.

39 Adger 2000, 354.

40 Adger 2000, 345.

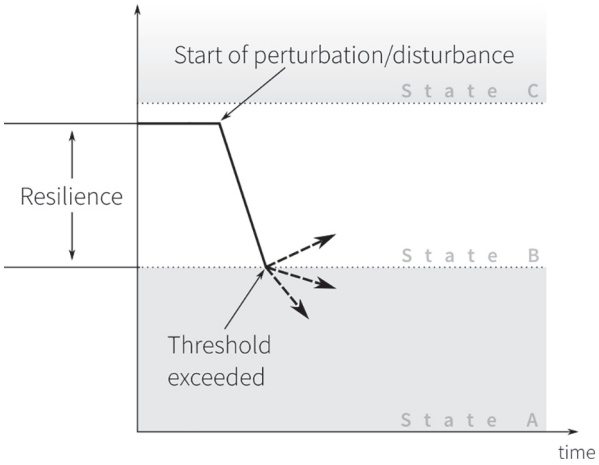

Fig. 8 Resilience corresponds to the ability to absorb disturbances/perturbations before the state of a system changes.

processes and the singularity of historical events. On the social side, therefore, equilibria cannot express the full picture of temporal change, but only the sector that is dominated by a dynamic of recurrence we call 'processual.'

Among the different types of equilibria, steady state equilibria and dynamic equilibria are the most common. According to Ahnert, state equilibria are understood as a stable systemic state characterized by oscillating changes.[41] In dynamic equilibria, however, the oscillating changes neutralize each other, leading to continuous changes of the state of equilibrium (Fig. 9).[42] It is assumed that a system continuously changes corresponding to a decay equilibrium. Simultaneously, it is assumed that internal and external triggers cause reactions and – due to this – changes in the process-response system. As a basic principle, it is supposed that societies or natural environments cannot remain in a steady-state equilibrium.

Although rather functionalist, these principles that originate in the laws of mechanics and thermodynamics, can be transferred to specific sectors of societies; for example, to the exchange and dissemination of technological knowledge, as well as to specific types of flows of matter. These sectors may be documented as types of metabolism. However, it needs to be emphasized that the idea of equilibria does not refer to any real *a priori* condition of equilibrium. It is rather a metaphor to communicate the complexity and complications of landscape systems that include – by definition – human groups.[43] Furthermore, equilibrium concepts refer to process-response-based approaches, since only these are able to investigate the co-evolution of process and form.[44]

41 Ahnert 1994.
42 Schumm 1991.
43 Mulligan 2013, 335.
44 Bracken and Wainwright 2006, 176.

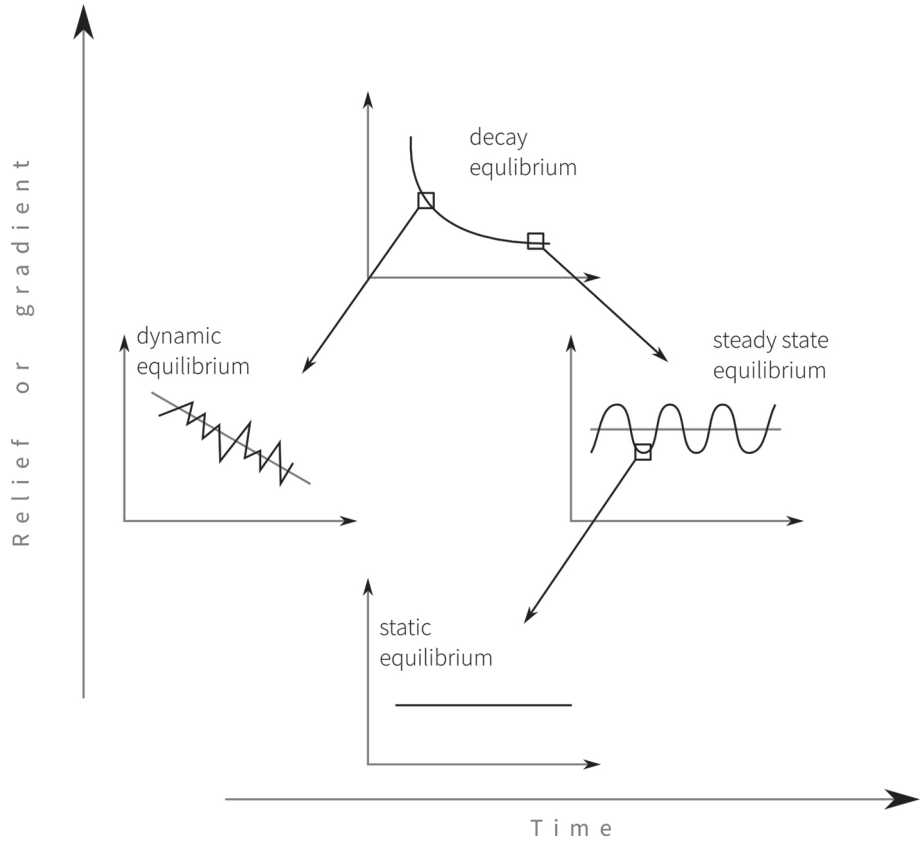

Fig. 9 Different types of equilibria: (a) decay equilibrium, (b) dynamic equilibrium, (c) steady-state equilibrium, and (d) static equilibrium (modified after Schumm 1991).

1.3 Resilience and temporality

As has been discussed above, resilience and vulnerability can be conceptualized as antagonistic terms. If, however, resilience is understood as a general property of a dynamic system whose intensity and sustainability describes the behavior of the system as a whole, we employ the approach of *resilience theory* that integrates a multitude of both spatial and temporal scales into the concept of resilience.

Resilience theory, as originally developed by L. H. Gunderson and C. S. Holling, comprises four stages in the dynamics of a system, arranged in a loop. The four phases 'exploitation' (r), 'conservation' (K), 'release' (Ω), and 'reorganization' (α) together form what has been called an adaptive cycle.[45] The fact that resilience theory comprises both

45 Gunderson and Holling 2002.

physical effects and human agency has made it also attractive to archaeologists. One of the early and committed advocates for the application of resilience theory in archaeology is Charles Redman who argued that its application adds features to the understanding of systems dynamics: change has to be considered as repeated and ultimately inevitable, despite the fact that repetition does not necessarily follow the same pathways.[46] Change, according to Redman, should be considered neither continuous and gradual, nor generally chaotic, but rather 'episodic,' caused by an interaction of fast and slow variables.[47]

The concept of 'adaptive cycles,' composed of these four phases and integrated by a system's resilience, has the great heuristic value of being applicable across different scales of space and time.[48] Attributes and properties of systems are often found to be neither uniform nor scale-invariant, but to occur in a patchy and discontinuous manner.[49]

The overlay of multiple spatial and temporal scales further implies that ecosystems (as well as interacting social systems) lack a single equilibrium. Rather, multiple equilibria or disequilibria (cf. above) characterize functionally different states of subsystems, or even the system in general, at different time scales.[50] This feature of resilience theory provides a theoretical reasoning for the observation that policies intended to stabilize an economic or political system in the short-term (by increased control or improved productivity) quite often destabilize it in the long-term, i.e. it reduces its resilience on a larger temporal scale. An example is in present discussions about whether 'global warming' exists and how to respond to it.

Redman and other archaeologists consider resilience theory an especially promising approach, since archaeology offers a multitude of time scales, from generational to centuries and even millennia. Thus, the resilience and vulnerability of processes can be compared across temporal scales, allowing for differing or even counteracting scenarios. Obviously, causal relations have to be analyzed and discussed for each temporal scale separately in order to avoid logical ambiguities or contradictions.

Consequently, resilience theory has been applied to archaeological phenomena of quite different durations, starting from the persistence of foraging communities in the Levant over millennia,[51] or an adaptive cycle during the Central European Early Neolithic (lasting about 500 years),[52] to a resilience theory approach of collapse in the Late Aegean Bronze Age.[53]

In the approaches within Topoi's Research Area A, most projects have not explicitly applied resilience theory. However, some have integrated concepts of multi-temporality and the distinction of systemic interaction of factors on different time scales.

46 Redman and Kinzig 2003.
47 Redman 2005, 72.
48 Redman and Kinzig 2003.
49 Redman 2005, 72.
50 Redman 2005, 72.
51 Rosen and Rivera-Collazo 2012.
52 Gronenborn et al. 2014.
53 Weiberg 2012.

1.4 Archives/Proxy vs. Artifact

Artifacts are a product of human intelligence, intentionality, or practical experience and most are deliberately made and utilized.[54]Artifacts and installations or monuments from archaeological contexts can sometimes give us clear indications about their function, but mostly they do not. They also rarely enlighten us about their original context and/or later uses. However, we still use these shaky sources to ask questions about past human beings and their actions. They serve, therefore, just like geographical indicators, as *proxies.* Proxies are indirect indicators, substitutes, or stand-ins for a studied subject.[55]

Ecofacts are materials that are not predominantly shaped by human action but that can carry archaeological significance since they indicate human activities.[56] While artifacts reflect human engagement with culture, ecofacts reflect human engagement with nature. For instance, use wear on a *humerus* of a gazelle can indicate that the bone was used as a hammer. Nevertheless, the boundary between the two categories is fuzzy, since all archaeological materials bear witness to their natural origin and cultural modification.[57] For example, the structure of tree rings found in a wooden plate (= artifact, ecofact, proxy) is an indicator for a certain size and type of tree, and provides information on local weather for a specific time period. Based on this evidence, conclusions about certain atmospheric conditions can be derived.[58] However, in general, this information originates from a definable point, the 'archive' (in geographical parlance), and additional information refers to this point. Extrapolation of this punctual knowledge into regional space is frequently scientifically unsafe and strongly depends on a researcher's expert knowledge. In order to reconstruct the distribution of animals or vegetation, proxies are most useful when they have a small ecological niche, as well as short turnover periods and response times.[59] In archaeological contexts, such metonymic argumentation via artifacts or ecofacts is mostly seen as extremely problematic, and statistically representative samples are preferred.

2 Social ecology

By now, it is apparent that any attempt to integrate research on humans and the environment, society and nature, is challenging. To frame the dynamics of human groups within and throughout their landscapes necessitates a concept that is both inclusive and

54 Slater 1999, 344.
55 D. S. G. Thomas and Goudie 2000, 390; Shuman 2007, 179–180.
56 Jones 2005, 64.
57 Jones 2005, 64.
58 Tegel and Hakelberg 2014.
59 Jones 2005, 65; though such advantageous conditions can also cause problems, see Dincauze 2000, 367.

comprehensive. It has to be inclusive in order to consider the different ways in which the humanities and hard sciences investigate and approach their research subjects; it has to be comprehensive in order to reflect the complexity of the human-environmental relationships, dynamics, and development.

The questions and approaches put forward in Topoi's Research Area A follow a specific theoretical standpoint that considers human groups and the environment as (a) two entities that act according to their own rules and (b) as one complex whose existence is the result of the interaction and interrelation between people and their environment. This configuration necessitates a realist ontological position, i.e. natural and cultural phenomena are principally considered to be independent from each other and accessible to understanding. Of course, this is only one way of approaching the different questions raised in the research group assembled here.[60] Nevertheless, taking into account our community of researchers that is anchored in the social sciences, humanities, and natural sciences, we try to adopt a maximally inclusive standpoint. When we try to develop a meta-theoretical synthesis, older disputes in the realm of geography provide a useful backdrop, as the difference between human and physical geography mirrors to some extent the paradigmatic differences encountered among the assembled researchers of Topoi.[61]

We borrow our meta-theory from a social ecology that integrates material and immaterial aspects of human-environmental relationships: to think ecologically about human societies is to consider them in all their potential relations to their environment,[62] but not in the full multiplicity of perspectives, contradictory interests, differentially oriented knowledge, and more or less coordinated practices that are characteristic of the internal dynamics of human groups. This basic constellation is the simplified common ground for a great variety of social ecological theories, discourses, and research fields. A comprehensive overview is given by Becker & Jahn.[63] The approaches collected under the notion of a 'social ecology' are not homogeneous and differ in their definition of central terms like society, culture, nature, etc. Becker et al.[64] propose a framing concept around the theory of 'societal relationships with nature.'[65] It is an elaborate 'framing concept' that intends to be a non-dichotomous theory of human-environmental relationships. However, as a theory it is not explicit enough to serve as a guide for the investigation of links and interrelations of human-environmental systems. As researchers from different disciplines, we were looking for a concept that would support and guide our interdisciplinary endeavor and our discipline-specific methodologies. This led us to

60 See e.g. Bernbeck et al. (A-2) in this volume.
61 Wardenga 2006.
62 Becker and Jahn 2006, 30.
63 Becker and Jahn 2006.
64 Becker, Hummel, and Jahn 2011.
65 Görg 1999.

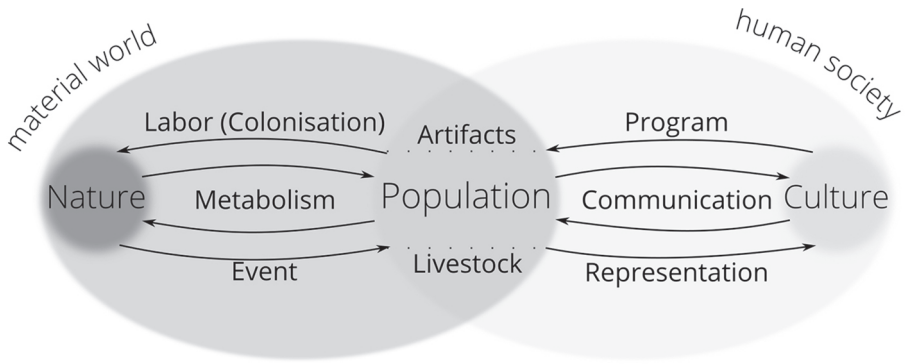

Fig. 10 Epistemological model of interactions between human groups and the environment; for a detailed description see Fischer-Kowalski, Mayer, and Schaffartzik 2011.

choose the rather functionalist concept of societal metabolism developed by the Vienna School of social ecology.[66]

In this social-ecological concept, society is defined as a closed system with links to externalities that are provided by communication and an open system concerning energy and matter. Society is understood as a structural coupling of a cultural system with biophysical elements (Fig. 10).[67]

In the model, the relation between human populations and *nature* or *culture* is based on the conditions for their reproduction. There is a continuous material exchange of people with nature in order to reproduce and sustain the material requirements of a population; this is called *metabolism*. The same continuous exchange prevails between human populations and culture, though in the Fischer-Kowalski model, culture is conceptualized as immaterial and grounded in *communication*.[68] It follows from this scheme that social systems can be understood as a structural coupling between biophysical elements and culture.[69]

Colonization or *labor* is an intentional process that leads to physical changes in the natural realm that are proportional to the amount of energy mobilized for the change, albeit 'proportional' in an unspecific way.[70] Labor is here defined as a process that aims to advance the level of metabolism. This idea of labor harks back to Leslie White's evolutionary theory that is based on human cultures' increasing capacities to harness energy from nature and use it for the transformation of natural resources to their own advantage,[71] an understanding that radically differs from the familiar one that is anchored in

66 Fischer-Kowalski, Haberl, et al. 1997.
67 Fischer-Kowalski, Mayer, and Schaffartzik 2011, 98.
68 Based on Luhmann and his definition of society as a system of recursive communication; see Luhmann 2012, e.g. 259.
69 Fischer-Kowalski and Erb 2006, 38.
70 Fischer-Kowalski and Erb 2006, 42.
71 E.g. White 1949; White 1959.

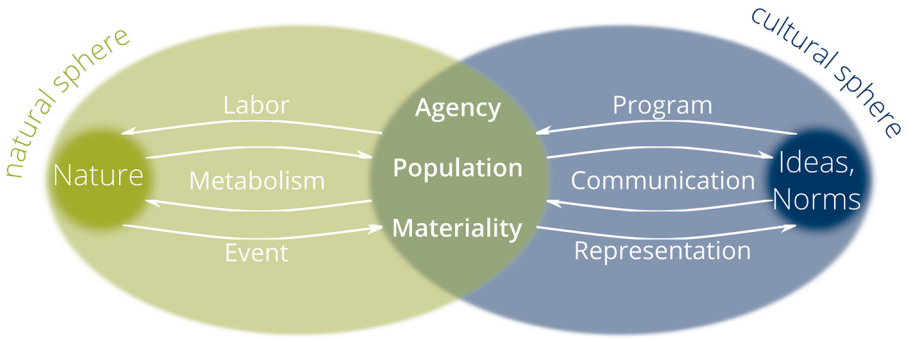

Fig. 11 The model of social ecology in the Area A.

political economy. Examples are agriculture, livestock breeding, and other specific subsistence technologies, including technologies that affect subsistence indirectly.[72] *Events* refer to changes in nature that are perceived by human populations and that need to be culturally *represented* in order to be understandable on the 'immaterial side' of the model.[73] They belong in the realm of a 'Mitwelt' as defined in other papers in our research group.[74] *Culture* constitutes normative and analytical schemes that function as action guiding *programs* leading to changes in the material world.[75]

The higher the level of a society's complexity, the more rigidly its flows of energy and material tend to be organized. Fischer-Kowalski et al. claim that this is necessary not just for sustaining its population, but also to sustain its intermediate biophysical structures that influence social reproduction, e.g. livestock, houses, and infrastructure.

> A notion of society as an open system that sustains itself on a continuous energetic and material exchange with its natural environment (and with other human societies) makes up the core of the socio-metabolic paradigm.[76]

This statement emphasizes the underlying assumption of a unity of human groups and environment in terms of societal development and spatial interactions, and suggests a close link to the aforementioned challenges of resilience and vulnerability.

The mentioned authors who frame and explore ideas about a social ecology are focused almost exclusively on modern societies. Questions about past human-environmental interactions are posed only in very general terms and on a global scale.[77] Hence,

72 Fischer-Kowalski, Mayer, and Schaffartzik 2011, 99.
73 Fischer-Kowalski, Mayer, and Schaffartzik 2011, 101.
74 Bernbeck et al. (A-2) in this volume.
75 Fischer-Kowalski and Erb 2006, 42; Fischer-Kowalski, Mayer, and Schaffartzik 2011, 101.
76 Fischer-Kowalski, Krausmann, and Smetschka 2004, 309.
77 E.g. Fischer-Kowalski and Haberl 1998.

during a long, controversial, and open-ended discussion process in our research group, B. Schütt and D. Knitter adapted the social-ecological model to fit the requirements of an investigation of past human-environmental relationships and their landscapes (Fig. 11).

The model has a basic geographical starting point and will therefore only capture cultural phenomena on a rather large scale (see Chapter Beilke-Voigt at al., A-6). Furthermore, although the model is applicable to quantitative analyses, it is especially useful as a heuristic tool to exemplify approaches and hypotheses of participating researchers from cooperating disciplines in this research collective. The model helps to illustrate the paths towards the formulation of hypotheses, their prerequisites and interrelations between elements of theses, and interpretations. Consequently, it can serve as a background for the development of further research questions and, most importantly, new fields of collaboration can be identified.

We modified some terms of the original model in order to better represent the research problems regarding the natural and cultural spheres appearing under the heading of 'Spatial Knowledge and Conceptual Design' (Fig. 11). 'Spheres' refer to the different forms of connections, i.e. the natural sphere follows the laws of physics, while the cultural sphere is characterized by multiple rationalities of action that co-exist all at the same time. As elaborated above, we consider here only those sectors of the social that are: (a) governed by instrumental reasoning and (b) pertain to the relationship between human groups and their natural environment. The center of our model is made up of the aspects 'population', 'materiality' (i.e. 'material culture'), and 'agency'. Population refers not just to the demographics of past societies but also to its culturally produced needs, such as the kind and amount of specific dietary elements. Material culture denotes the remains of these societies that are the result of processes occurring in both the natural and the cultural spheres. 'Ideas and norms' represent 'culture', which is understood here as the realm of rules, norms, ideas, and ideologies, a concept that is not used wholesale by all of the cooperating researchers. 'Agency', as the power to act, but not necessarily its realization, is driven by interests of individuals and groups, and is linked to specific cultural 'programs' and the social institutions in which they are enshrined.

Instead of elaborating on the model in more detail, we invite the reader to inspect the subsequent chapters in which different groups from Topoi's Research Area A, 'Spatial Knowledge and Conceptual Design', present specific case studies while referring to this model of social ecology and its underlying concepts. It will become clear that they adapt and modify the concept according to the particular historical, cultural, and environmental contexts they study. Several contributions also criticize the basic outlook and/or single elements of a social ecology approach. The search for an overarching framework results in tensions of content that we consider to be healthy, as they expose both the strengths and weaknesses of a generalized approach to questions of landscape archaeology.

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Investigating Marginality within the Framework of Socio-Ecological Interaction Models

Summary

This contribution explores the application of the socio-ecological interaction model proposed by Marina Fischer-Kowalski for an investigation of the colonization of marginal habitats. Central to our approach is the hypothesis that the occupation of areas beyond the 'regular' settlement patterns of (pre)historic, and indeed modern, societies corresponds to colonization processes that reflect specific social strategies and may have stimulated the development of new technological skills. Four case studies from the sites of Resafa (Syria), Petra (Jordan), and Ayamonte (Spain) highlight the potentials, as well as the limits, of applying the socio-ecological model to archaeological material/studies.

Keywords: socio-ecological interaction models; colonization; technical knowledge; marginality; landscape archaeology

Dieser Beitrag untersucht die Anwendbarkeit des Sozialökologischen Interaktionsmodels von Marina Fischer-Kowalski auf/für die Untersuchung der Kolonialisierung von marginalen Räumen. Für unseren Ansatz ist folgende Hypothese zentral: Die Besetzung von Arealen über ‚reguläre' Siedlungsstrukturen (prä-)historischer sowie auch moderner Gesellschaften hinaus stimmt mit Kolonialisierungsprozessen überein, welche spezifische soziale Strategien spiegeln und die Entwicklung von neuen technologischen Fähigkeiten stimuliert haben könnten. Fallstudienzu Resafa (Syrien), Petra (Jordanien) und Ayamonte (Spanien) betonen die Potentiale wie auch die Grenzen der Übertragung des Sozialökologischen Modells auf archäologische Quellen/Studien.

Keywords: Sozialökologisches Interaktionsmodell; Kolonisation; technisches Wissen; marginal Räume; Landschaftsarchäologie

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1 Introduction

1.1 Objectives

The research group 'The Ancient Colonization of Marginal Habitats' (A-1) of the Topoi Excellence Cluster investigates the nexus between environmental requirements for settlement spaces, the cultural acquisition of these spaces, and the development of technical knowledge. The central working hypothesis is that the development and shaping of settlement spaces in past societies was an important engine for the development of technological skills and technical knowledge. This is most plainly evident in places where settlement plans were confronted with disadvantageous environmental conditions. Settling in these places required particular effort with regard to the development and use of technical knowledge and customized settlement strategies.

A major challenge of this research is to reveal the dynamics of the complex processes of settlement from a perspective that is exclusively based on archaeological data. The aim of this contribution is to explore whether, and in which way, the socio-ecological model, which was originally proposed for an integrative research on human-environmental interactions, can be productively adapted in this research context. Based on the socio-ecological model corresponding to Fischer-Kowalski,[1] the authors attempt to draw connections between specific cultural interactions, intentions, and innovations; how this is embedded into the natural environment; how settlement activities adapt to the natural environment; and whether the natural environment triggers technical or social innovations.

The research is being conducted by the interdisciplinary research group 'The Ancient Colonization of Marginal Habitats,' uniting scholars of prehistory, archaeology, building research, and physical geography. The individual research projects build, in part, on preceding studies conducted within the research group 'Central Places and Their Environment' of the EXC 264 Topoi during its first funding phase (2007–2012). Geographically, the eight research projects within the group range from modern Spain to the Jordanian desert and from Turkey to the Ethiopian highlands, thus, covering a different variety of colonized areas and colonizing intentions/settlement strategies (Fig. 1). For each of the case study settlement sites, we attempt to assess the environmental conditions, the motivation, and the process of colonization, as well as its consequences for the natural and built environment. It is evident that only an interdisciplinary approach that comprehensively investigates the history and trajectory of the settlement activities, past environmental conditions, social structures, and technical skills, can yield conclusive

1 Fischer-Kowalski 1998.

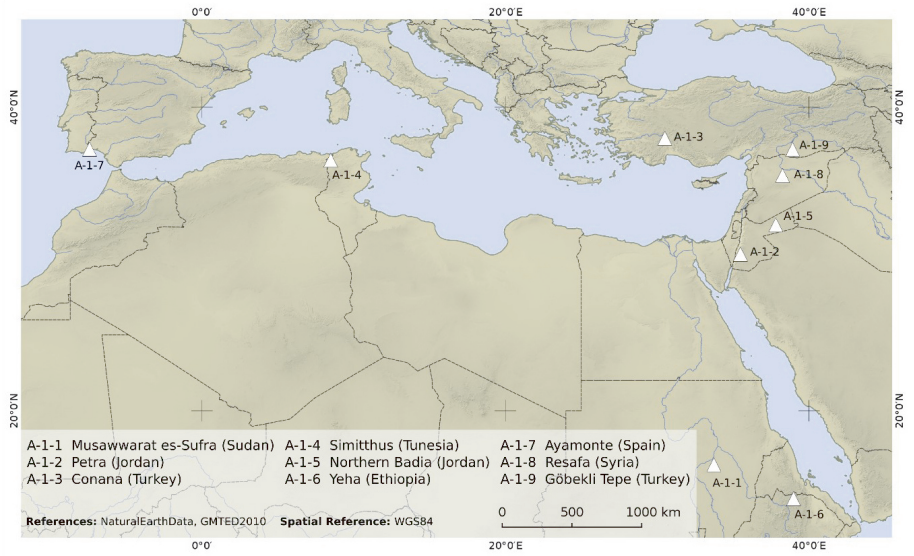

Fig. 1 Location of the study sites of the research group Topoi A-1 *The Ancient Colonization of Marginal Habitats*. Triangles mark the center of the respective region of interest.

results. Further, the work of the research group is not restricted to aspects of socio-ecological marginality, but also deals with aspects of economic and spatial marginality and more.[2]

1.2 The socio-ecological model of Fischer-Kowalski et al. from an archaeological perspective

The socio-ecological model[3] of Fischer-Kowalski et al. (2011) works with a range of aspects/factors that lend themselves as analytical instruments for an archaeological enquiry to a differing degree.[4] The following paragraph will introduce our understanding and partial adaptation of these aspects, and the specific terminology used by Fischer-Kowalski (Fig. 2).[5] We understand *nature* as the environment that is open to human exploration, intervention, and exploitation, while also setting the physical parameters or conditions for human existence. In our perspective, nature is the physical frame of the societal project of colonization. *Labor* is the activity or process of changing nature in order adapt it to human needs or to advance the metabolism between humans and

2 As elaborated in Bebermeier et al. 2016.

3 For a general introduction to this model see the contribution Knitter, Schütt, Schier, Bernbeck (Introduction) in this volume.

4 Fischer-Kowalski, Mayer, and Schaffartzik 2011.

5 Fischer-Kowalski, Mayer, and Schaffartzik 2011.

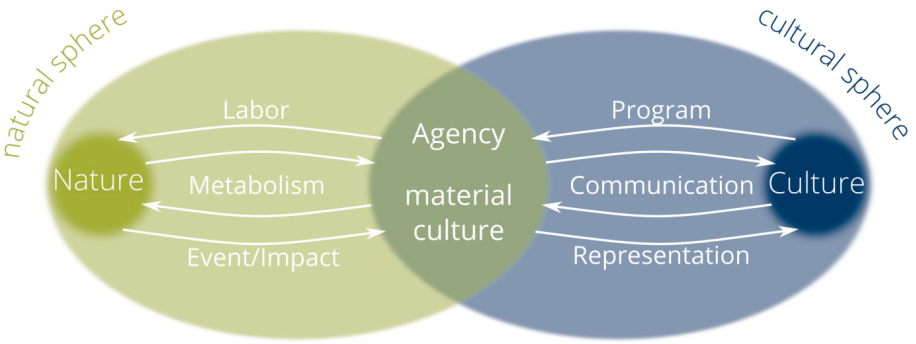

Fig. 2 Adapted version of the socio-ecological model after Fischer-Kowalski, displaying the terms used in the current research.

nature. We define labor as an investment in the environment, thus, appropriating, adjusting, and maintaining it in order to meet the conditions of the colonization project. From the perspective of labor, nature is both a resource, as well as a limiting factor. According to Fischer-Kowalski, *metabolism* is "the most direct connection between society and the material world",[6] and "the acquisition of material and energy as well as their transformation as means for preserving life, enabling labor and finally creating metabolic products".[7] It is the connex/relation "with the shortest cycles […] and when these are interrupted, societal systems are quickly no longer reproductive".[8] However, this conceptualization seems problematic with regard to the differentiation of labor and metabolism. Both involve human actions and social practices – and even the most basic actions are socially conditioned and not a purely metabolic process, in biological terms, as Fischer-Kowalski and Erb concede as well.[9] Thus, labor and actions defined as metabolism differ only by degree, or by the application of arbitrary definitions, e.g. regarding intentionality and range. From an analytical perspective, it seems better to define metabolism as the (continuous) dialectic processes of environmental change, i.e. the actual conversions caused by labor, with labor being defined as any kind of human action or intervention. In contrast to labor, *experience/event/impact* designates all events or impacts of a non-anthropogenic origin that lead to changes in the environment. Obviously, such impacts from natural causes also result in changes in the resource base of the natural environment, which in turn influences social practice.

In the socio-ecological model as it is applied here, *material culture* constitutes the nexus between the spheres of nature and culture. Material culture is one of the most widely discussed terms in social anthropology, archaeology, and the eponymous field

6 Fischer-Kowalski, Mayer, and Schaffartzik 2011.
7 Fischer-Kowalski and Erb 2006.
8 Fischer-Kowalski, Mayer, and Schaffartzik 2011.
9 Fischer-Kowalski and Erb 2006, 42.

of material culture studies,[10] and can be defined as the entirety of all physical objects produced by any given society or social group. Within the perspective of our topic, i.e. colonization, material culture are the material products of the colonization project. Turned into archaeological remains through time, their analysis offers us insights in the particularities of the colonization process, its conditions, trajectories, and consequences. If material culture is both an all-encompassing category, as well as an interpretive battle ground, the same goes for the concept of *culture*. Fischer-Kowalski follow a system theory understanding, as proposed by Niklas Luhmann.[11] For our purposes, it may suffice to define culture as the products of human action and the sustained social communication about them. *Program* is the cultural process that arises from a societal or individual endeavor to master a specific facet of human existence or experience. In this understanding, the colonization of new settlement spaces is a cultural program *par excellence*. As to *communication*, Fischer-Kowalski adhere to a Luhmannian reading of the term, which defines society as a system of recursive communication.[12] Finally, *representation* describes the specific organization of communication, *how* specific experiences, impacts, or programs are communicated. Representation concerns the means as well as the semantics of (symbolic) interaction.

After clarifying the framework of the socio-ecological model, it is necessary to evaluate the database for its archaeological application. Records relating to the *natural sphere* are preserved as, e.g., sediments resulting from soil erosion processes, botanical remains in the form of pollen, or phytoliths act as proxy data for local environmental conditions or topographic features indicating turning active human interventions into natural dynamics. *Material culture*, or more precisely, the physical remains of material culture that have been transformed into archaeological data, form the center of the model, i.e. the 'coupling point' of the two spheres.[13] Thus, archaeology might be in a privileged analytical position, as it operates with data that are central to the dynamics of the model. However, the other aspects of the *cultural sphere*, namely program, communication, and representation, are only indirectly preserved and need to be 'reconstructed', i.e. argued based on their material remains. In many cases, this seems to be straightforward enough; for example, the program of colonizing a new settlement area can be 'read' from the physical result, i.e. settlements in an area previously unoccupied by the given society. However, without additional written records, working from archaeological sources alone, it will be difficult to understand the social motivation and representation of this program. The four case studies in this contribution illustrate this point.

10 See e.g. Hahn 2014; Samida, Eggert, and Hahn 2014; Hicks and Beaudry 2010; Tilley et al. 2006 – to name but four of hundreds of contributions.

11 Fischer-Kowalski, Mayer, and Schaffartzik 2011.

12 Fischer-Kowalski, Mayer, and Schaffartzik 2011, 99.

13 For the concept of 'coupling' see Fischer-Kowalski and Erb 2006, 33, 36, 43.

Another issue is *chronology*. The dialectic, or in the original reading 'causal', relationships of the socio-ecological model imply a processual nature of condition, impact, and consequences or, in short, a diachronic dimension. Such relationships of impact and consequences, and even more so, their social motivation, can be hard to ascertain given the multi-causal conditioning of almost all processes in both the cultural and natural sphere, as well as the patchy archaeological dataset. This observation is also true for the natural sphere: in order to comprehensively reconstruct past environmental conditions and their trajectories, which may allow the identification of the postulated relationships between, e.g. labor and its impact upon the environment, is a real challenge. The following case studies will describe how these challenges are met.

2 Case studies

Colonization and habitation require conditions that are greatly determined by environmental factors. Colonization of unfavorable areas has frequently been accompanied by the development of techniques to overcome natural limitations, such as techniques for storing food and water, or, particularly in drylands, water harvesting, water storing, and water direction.[14] Natural environments changed in conjunction with colonization; natural landscapes were transformed into *cultural landscapes,* with the sediment balance, and water budget, as well as the nutrient fluxes altered. Non-sustainable settlement and land use strategies resulted in land degradation, frequently leading to the deterioration of other site-related factors.

The case studies are geographically widely dispersed across the Mediterranean, and all together they encompass a broad time span, ranging from the 5th millennium BCE to the 1st millennium CE. All of the case studies adhere to a settlement-archaeological approach and apply similar methodologies. At present, the natural environments of the case study sites have a dryland character, ranging from semi-arid to dry-sub humid. As a consequence, the availability of water plays a major role in all cases for all kinds of settlement activities. Moreover, especially in marginal habitats, the exploitation and utilization of building material and the transfer, adaption, and advancement of each kind of engineering process are of heightened interest.

14 Beckers, Berking, and Schütt 2012; Beckers and Schütt 2013; Näser and Scheibner 2013.

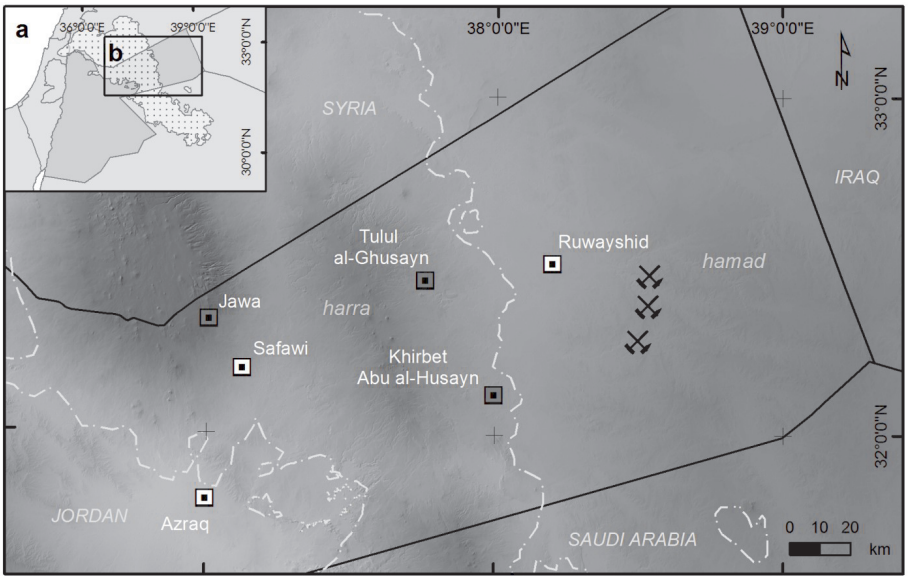

Fig. 3 a) Location of the 'Harrat Ash Shaam' basaltic region within Jordan and neighboring countries. b) Location of modern settlements (white rectangle), C/EBA fortified sites (grey rectangle) and flint mining regions (mine symbol) (after Müller-Neuhof 2014a) within northeastern Jordan.

2.1 The Early Bronze Age settlement of Jawa and its hinterland, the Northern Badia

The Jordanian Northern Badia is a vast steppe desert that is located between Southern Mesopotamia and the Southern Levant (Fig. 3). The region is characterized by a limestone steppe desert in the east (*hamad*) and a basalt steppe desert in the west (*harra*). Recent research has shown intensive anthropogenic activities, especially during late prehistoric times, lasting from the 7th to the 4th millennium BCE.[15] The geoarchaeological project chronologically focusses on the Chalcolithic and the Early Bronze Ages (the 5th to the 3rd millennium BCE). It is motivated by the fact that early complex societies evolved at the same time in the neighboring regions of Southern Mesopotamia and the Southern Levant, a process with possible effects on the socio economy of the centrally located but arid Northern Badia. The project's major aims are the identification of evidence of Chalcolithic/Early Bronze Age socioeconomic activities in the Northern Badia, the evaluation of the character and scope of these activities, and their possible external relations.

The central research outcomes of the project are:

15 C.f. Akkermans, Huigens, and Brüning 2014; Betts et al. 2013; Müller-Neuhof 2014a; Rollefson, Rowan, and Wasse 2014.

1. In the limestone steppe desert (*hamad*), large opencast flint mines and cortical tool blank production sites adjacent to the mines have been identified. Several millions of these typical Chalcolithic/Early Bronze Age tool blanks were produced in this mining region.[16]

2. In the basalt steppe (*harra*), a large number of clustered enclosure sites along wadis have been recorded, attesting to an intensive utilization of this area by nomadic pastoralists.[17] Parts of theses clustered enclosures are dated to the Chalcolithic/Early Bronze Age.[18]

3. In the vicinity of the Early Bronze Age settlement of Jawa, one of the major towns in the Middle East during the 4th millennium BCE, irrigated agricultural terrace systems were discovered, which are so far the oldest known artificially irrigated terrace systems.[19] The site is located in the western part of the basalt desert steppe.

2.1.1 Nature

Northeastern Jordan can be divided geologically into two main areas: the *hamad*, is composed of limestone of a cretaceous and tertiary age, covered by chert gravels,[20] and the basaltic *harra* is part of the North Arabian Volcanic Province 'Harrat ash shaam' that extends from Southern Syria to Saudi Arabia, consisting of several Quaternary and Neogene volcanic basalt lava flows.[21] The surface of the *harra* is covered with extensive basalt stone pavements resulting from the weathering of the volcanic rocks.[22]

The local topography is dominated by a gently undulating plain declining from north to south, with elevations ranging between ca. 1200 and 400 meters asl.[23] Within the basalt plateau, depressions filled with fine-grained sediment deposits are common, locally called *Qa'a*.[24] The natural vegetation cover around Jawa is patchy – occurring as grasses, herbs, and shrubs – and classified as part of the Saharo-Arabian plant region.[25]

Climatically, today the Northern Badia is located in the transition zone between the Mediterranean environment and the fully arid zone of the Syrian Desert.[26] Following the Köppen-Geiger classification, the area is classified as a hot desert climate,[27] characterized by marked seasonal variations, with hot, dry summers and cool, moist winters.[28]

16 Müller-Neuhof 2006; Müller-Neuhof 2013; Müller-Neuhof 2014a.
17 Meister, Knitter, et al. 2019.
18 Müller-Neuhof, L. Abu-Azizeh, et al. 2013; Müller-Neuhof 2014a.
19 Meister, Krause, et al. 2017; Müller-Neuhof 2012; Müller-Neuhof 2014b.
20 Bender 1968.
21 Allison et al. 2000; Bender 1968; Taqieddin et al. 1995.
22 Allison et al. 2000.
23 Allison et al. 2000.
24 Al-Homoud et al. 1996.
25 Al-Eisawì 1996.
26 Al-Homoud et al. 1996.
27 BWh; Kottek et al. 2006.
28 Allison et al. 2000.

In the northwest of the study area, average rainfall rates exceed 150 mm due to its westerly location and the orographic effects of the Jebel Druze. Towards the south and east, rainfall rates decline, reaching less than 50 mm in the southern regions.[29]

Rainfall occurs mainly between November and March; at Jawa it averages about 115 mm.[30] Based on the isotope records from the Soreq Caves, it is assumed that, in general, climatic conditions in the Eastern Mediterranean region have been similar to those of the present for about seven thousand years. The Early Bronze Age I is characterized by small fluctuations, where moist conditions alternated with drier periods.[31] Since there is a lack of high-resolution proxy records in the Northern Badia,[32] detailed paleoenvironmental reconstructions for the Holocene are missing.

2.1.2 *Labor*

For the ancient settlement of Jawa and its hinterland, the Northern Badia, there are four main fields of labor 'activities':

1. Exploitation of mineral resources: In the *hamad*, evidence of C/EBA mining of flint is documented.[33] The exploitation activities were undertaken in order to detect high-quality raw material, sinking pits and trenches in the surface, quarrying the flint nodules, splitting the flint nodules, preparing knapping platforms, and detaching palm sized flat cortical flakes from these flint nodules. Production output (unretouched cortical flakes) were, thereupon, exported to consumer regions.

2. Usage of natural basalt stones: In the *harra*, weathered basalt stones are ubiquitous and in a good shape to be used as a building material. One dominant architectural structure, are the widely spread clustered enclosures[34] that were supposedly used as campsites and/or as animal corrals of herders.[35]

3. Settlements: The ancient settlement of Jawa was built as a fortified settlement. Next to the fortification itself, its natural position on a plateau improves its defensive character. Next to Jawa, other (smaller) fortified settlements are documented in the *harra*.[36]

29 Tansey 1999.
30 Meister, Rettig, and Schütt 2018.
31 Bar-Matthews et al. 1999.
32 C.f. Finné et al. 2011; Rambeau 2010.
33 Müller-Neuhof 2006; Müller-Neuhof 2013; Müller-Neuhof 2014a.
34 Meister, Knitter, et al. 2019.
35 Betts 1982.
36 C.f. Müller-Neuhof 2014a; Müller-Neuhof, L. Abu-Azizeh, et al. 2013; Müller-Neuhof and W. Abu-Azizeh 2016.

4. Water harvesting systems: At the EBA site of Jawa, the water management systems contain multiple elements, such as canals, deflection canals, dams, water reservoirs, spillways, overflows, and agricultural terraces that were used in other to manage and control the water. For water collection, surface runoff and wadi runoff were used. The collected water was directed to water reservoirs and agricultural fields.[37] On the agricultural terraces, next to water storage enhanced sediment, accumulation improves the agricultural use of cultivation areas.[38] Further terraced gardens have been identified at two other LC/EBA settlements in the Badia.[39]

2.1.3 Metabolism

The complex water harvesting and agricultural terrace systems point to the metabolism of this area. Nevertheless, the exact energetic demand of people during Early Bronze Age is not known. Crop yield simulations of the floodwater/runoff irrigated agricultural terrace systems around Jawa provide the first insights into potential crop yields and, thus, their energy production.[40] The complex water harvesting systems also document the need for drinking water for people and livestock. The clustered enclosures in the *harra* point to the metabolic usage of breeding animals for diet.

2.1.4 Impact/Event

Today, the region is characterized as arid, with very high rainfall variability, erratic rainfalls, and, subsequently, short and intensive runoff events.[41] Interannual precipitation variability might be recognized as having an impact on water availability and security and, therewith, also food security. Extreme runoff or longer droughts might have occurred as catastrophic events.

2.1.5 Material Culture

Within the project, artefacts are grouped into three different classes: architectural remains, archaeological surface finds, and geographical archives. The most prominent architectural remains are the remnants of permanent fortified settlements, such as ancient Jawa.[42] The remnants of water harvesting systems such as dams, reservoirs, pools, canals, spillways, overflows, deflection walls, and agricultural terraces, however, are also documented artefacts.[43] Clustered enclosures, potentially used for pastoral activities, are

37 Helms 1981; Meister, Krause, et al. 2017; Müller-Neuhof 2014b.
38 Meister, Rettig, and Schütt 2018.
39 Müller-Neuhof, L. Abu-Azizeh, et al. 2013; Müller-Neuhof and W. Abu-Azizeh 2016.
40 Meister, Rettig, and Schütt 2018.
41 Meister, Rettig, and Schütt 2018.
42 Helms 1981; Müller-Neuhof 2014a.
43 Helms 1981; Meister, Krause, et al. 2017; Müller-Neuhof 2014b.

architectural remains spread all over the basalt desert of the *harra*.[44] Archaeological finds are mostly lithic artefacts and some pottery remains, but also petroglyphs and archaeobotanical material.[45] The examined geographic archives act as artefacts, if the sediment deposition is driven by human activity. Based on short sediment profiles within the agricultural terraces, various proxies, such as geochemistry and phytolith analysis, have been investigated.[46] All 'objects' (artefacts) of the material culture of the above named classes have been taken for interpretation, which is documented in the marked papers.

2.1.6 Culture

For the Chalcolithic/Early Bronze Age, written sources are lacking. Thus, no detailed information on the culture of the inhabitants of ancient Jawa and the people migrating to the study area can be given.

2.1.7 Program

The cultural processes that arise from the societal or individual endeavor of the inhabitants of ancient Jawa and its hinterland form cultural programs that can be grouped into three major classes: resources (excluding water), settling, and water harvesting.

- Resources program: In the *hamad*, the natural mineral resources of flint were detected for systematic mining purposes. A differentiation of the flint layers by means of the quality of the resulting products was established. This means that knowledge of flint formation, with a focus on the resulting tools, was established in the entire mining area. Different types of mining are documented as well.[47] Animals as resources can be differentiated by use in terms of game hunting and animal husbandry. Clustered enclosures (campsites, animal corrals) spread throughout the entire *harra*, document early transhumance pastoral activity. The trading activities of these resources cannot be clearly proved, but has to be assumed.

- Settling program: In the vast arid region, the detection of favorable sites for establishing settlements can be named as part of the program. The settling strategy might have been directly linked to the water harvesting strategy, but this cannot be clearly proven. Further, expansion and fortification of settlements belong to the program of the societal group. If the settling program were directly linked to the resources, and thus to exchange and trade, remains unclear, but can be assumed.

44 Meister, Knitter, et al. 2019.

45 Müller-Neuhof, L. Abu-Azizeh, et al. 2013; Müller-Neuhof and W. Abu-Azizeh 2016.

46 Meister, Krause, et al. 2017.

47 Müller-Neuhof 2013.

– Water harvesting program: The implementation of water diversion and storage systems, described above (labor), secured water availability for people and livestock.[48] The construction of irrigated agricultural terrace systems enhanced and secured the crop yields for the inhabitants of ancient Jawa.[49]

2.1.8 Communication

Disentangling the modes of recursive communication of the societal groups, or individuals of the study area, is at the present hampered due to the complete lack of written sources. However, communication within the region and probably also with external communities is assumed to have been carried out via communication routes. In the almost inaccessible environment of the basalt steppe desert, such communication routes run along wadis and mudpans. Imported artefacts and exported goods (e.g. cortical scrapers) are archaeological evidence of such communication.

2.1.9 Representation

The given artefacts within this project do not allow us to understand the specific organization of communication. A reconstruction of the structural functioning of certain architectural remains might be a first step towards gaining insights into interactions.

2.1.10 Conclusions

For the given project setting and its emerging results, it can be stated that most of the terms of the adapted version of the socio-ecological model based on Fischer-Kowalski's work can be filled with content.[50] The main field of research in the model is the central part named 'material culture', or in this case more precisely, 'artefact'. With the research on architectural remains, archaeological surface finds and geographical archives generated by the project provide an idea of the chain of action of the inhabitants of the Early Bronze Age region of Jawa and its hinterland, Northern Badia. The different programs, derived from the artefact information, lead to a differentiation of the fields of labor, in this case, the exploitation of mineral resources, the usage of natural basalt stones, and the implementation of water harvesting systems. In particular, the crop yield simulations of the irrigated agricultural terrace systems around Jawa provide a first idea about the energy potential of these systems, thus, a first step towards quantifying the energetic metabolism for Early Bronze Age Jawa. Only little information can be given regarding communication and representation in this area at this time.

48 Helms 1981.
49 Meister, Rettig, and Schütt 2018.
50 Fischer-Kowalski, Mayer, and Schaffartzik 2011.

The adapted version of Fischer-Kowalski's socio-ecological model helps to incorporate the research from the different disciplines into one culture-nature framework.[51] It shows the systematic connections and, thus, the logical connections between the research carried out. The model can be used as a common container or communication basis. As described, not all terms can be elaborated within one project setting, but knowledge of the relation to the missing links is crucial for gaining results without disciplinary blinkers.

2.2 Petra/ Jordan

The Nabataean capital, Petra (Jordan; ca. 100 BCE–106 CE; Fig. 4), has been researched in terms of the organizational and technological efforts and innovations needed in order to facilitate a permanent and representative settlement within an unfavorable natural environment.[52] In addition to its arid climate, with an average precipitation of 180 mm (1951–2000),[53] Petra is most striking due to its strategically disadvantageous location in a steep valley that is vulnerable to uncontrolled flashfloods. Belonging to the Jordanian Highlands east of the Wadi 'Arabah floor and lying on a heavily mountainous ridge, Petra is situated within the most rugged landscape in modern-day Jordan, with a difference in elevation of up to 1500 m over only a few kilometers.[54] This terrain was caused by extreme uplifting and tilting.[55] Furthermore, the Petra Valley is flanked north-south by the down-sloping al-Quwayra Fault in the west and the up-sloping al-Mataha Fault in the east.[56] While the al-Mataha Fault consists of various limestone formations (Jabal as-Sharra),[57] the al-Quwayra Fault contains parts of the extensive Ahaymir Volcanic Suite, which extends even farther westwards.[58] Not only is this volcanic igneous rock extremely difficult or even impossible to pass by foot, donkey, or camel, it is also along this volcanic suite that the topography drops suddenly and dramatically several hundred meters towards the Wadi 'Arabah in the west.[59] Only the Petra Valley itself consists of the soft Cambrian-Ordivician sandstone that is good as a building material.[60]

Nevertheless, in the course of the Hellenistic Period (323–330 BCE), the Nabataeans gained control of the Arabian incense trade, turning from their originally nomadic traditions and gradually shifting into a state-like entity, with Petra as the heart of the

51 Fischer-Kowalski, Mayer, and Schaffartzik 2011.

52 The timeframe explored here is based on the archaeologically evidenced monumentalization of urban Petra in the first century BCE until the Roman annexation of the Nabataean realm on 106 CE (compare, e.g. Schmid 2012, 138–141).

53 Beckers, Schütt, et al. 2013; Kouki and Tenhunen 2013, 56–57.

54 Barjous 2013, 51–52; Besançon 2010.

55 Barjous 2013, 51.

56 Barjous 2013, 51.

57 Barjous 2013, 43.

58 Barjous 2013, 44, 51.

59 Kennedy 2016a.

60 Barjous 2013; Besançon 2010.

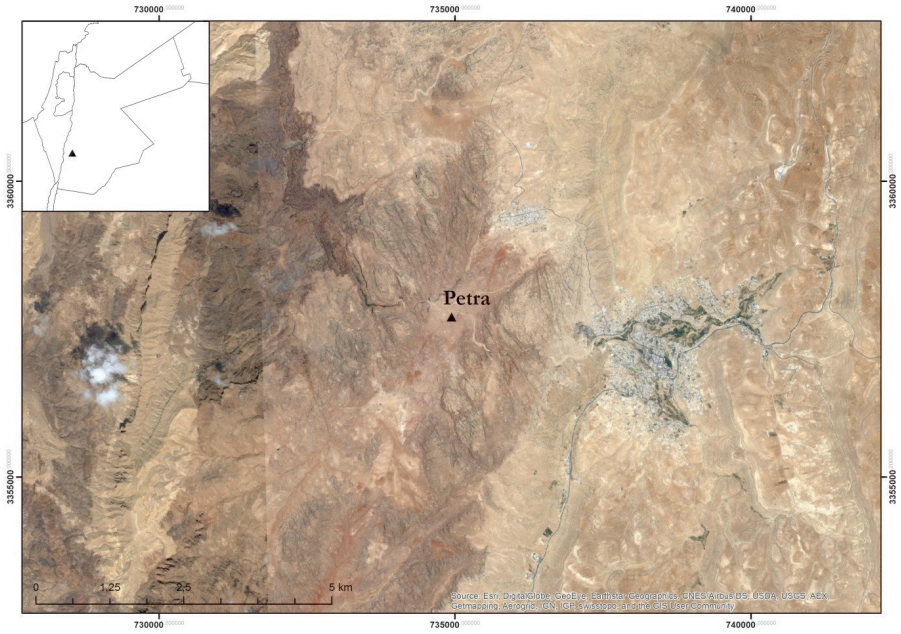

Fig. 4 Petra and its hinterland.

Nabataean Kingdom.[61] Petra developed into an important central place, particularly famous for its monumental funerary architecture, amalgamating oriental and Graeco-Roman traditions.[62]

However, Petra's hinterland remains less monumental and more affected by natural landscape factors, reflecting still persisting semi-nomadic traditions within Nabataean culture.[63] In Petra's immediate environment, there is archaeological evidence of both temporary tent-like structures, thus, being more 'mobile architecture' pertaining to a more nomadic way of life, as well as well-built and more substantial structures that represent a more sedentary aspect of Nabataean society.[64] It may be argued that Petra´s extreme natural settings played a central role in shaping and determining Nabataean culture.[65]

Assessing the interdependencies between the natural environment and Nabataean culture is, therefore, not only vital for comprehensively understanding the landscape organization and spatial strategies of rural Petra, but also for grasping Nabataean society in its entirety. The social ecology model proposed by Fischer-Kowalski recognizes these

61 Wenning 2013; Schmid 2008; Schmid 2001.
62 Schmid 2012; Schmid 2009; Schmid 2007.
63 Kennedy 2016a; Kouki 2012; Lindner 2003.
64 Kennedy 2016a.
65 Kennedy 2016a.

intricate mutual relations between natural and cultural processes.[66] Derived from sociological and ecological theory, the model does not aim to achieve a universally applicable position on nature–culture relations, but rather to present a concept for comprehensively understanding societies. Within the Petra case study, the model is adapted to the archaeological research questions and is used as a tool in order to simply organize the vast data available for both the natural and cultural sphere, as well as the indicative area termed here as material culture at first. By doing so, it is then possible to highlight specific causal connections from the otherwise indistinct blur of complex nature–culture relations.

2.2.1 Natural Sphere

For Petra and its hinterland, the natural settings (*nature*) are, at first glance, extremely disadvantageous, affecting ways of human adaptation (labor) to nature significantly. This includes the lack of water[67] and other natural resources such as wood[68] and metal deposits,[69] little agricultural possibilities,[70] and the arid climate,[71] as well as the generally unfavorable topographical and geological settings (see above).[72]

Labor entails (a) the exploitation of and reaction to the natural, i.e. untouched nature, determining very specific spatial strategies (e.g. the selective placement of strategically important watch posts),[73] but also (b) the exploitation of nature primarily for economic purposes (mining, foresting, modification of water sources, etc.).[74] The numerous agricultural terraces on the western slopes of the Jabal as-Sharra in the hinterland of Petra are good examples of Nabataean changes to the natural landscape (see above).[75]

Metabolism includes (in hierarchical order): (a) the water supply (constant maintenance of water sources),[76] (b) pastoralism (constant care of livestock etc.),[77] (c) agriculture,[78] (d) the supply of raw materials for singular human needs (e.g. wood for simple structures (tents), or as burning material), and, finally, (e) the industrial processing of

66 Fischer-Kowalski, Mayer, and Schaffartzik 2011; Fischer-Kowalski and Erb 2006; Fischer-Kowalski and Haberl 1998.

67 Bellwald 2012; Ortloff 2005.

68 Kouki and Tenhunen 2013, 60–62; Lindner 1997; Kühne and Wanke 1989.

69 Lindner 2003, 96–98; Lindner 1997, 34–35.

70 Lavento, Silvonen, and Kouki 2013, 213–229; Al-Salameen 2005; Lindner 1997, 31–32.

71 Beckers, Schütt, et al. 2013; Kouki and Tenhunen 2013.

72 Kennedy 2016a; Barjous 2013; Besançon 2010. It should be noted, however, that while the eastern ascent to the eastern highlands through the Jabal as-Sharra poses topographical difficulties, this region is also characterized by its comparatively high rainfall rates, and was extensively exploited for agricultural purposes in antiquity.

73 Kennedy 2016b; Kennedy 2013.

74 Lavento, Silvonen, and Kouki 2013; Ortloff 2005; Lindner 1997.

75 Beckers, Schütt, et al. 2013.

76 See e.g. the measures taken not only to divert fresh water into the city, but also to control potential flash floods: Bellwald 2012; Ortloff 2005; Ruben and Bellwald 2003.

77 Rosen 2007.

78 Lavento, Silvonen, and Kouki 2013.

raw materials for production and trade (copper, bitumen, incense, and spices).[79] While the latter does not necessarily fall within the exact study area, it is nevertheless important for understanding the overall metabolic strategies of the Nabataeans on a larger scale.

Impact entails the very particular and, at first glance, disadvantageous natural landscape settings of the Petra region, which affected spatial strategies greatly.[80] For example, the lack of water in the region called for technological and infrastructural advances that, in effect, ensured a permanent living environment.[81] Also, certain geological and topographical features (e.g. disadvantageous volcanic formations, in combination with steep slopes, see above) impacted settlement choices or means of communication significantly.[82] Finally, natural landscape factors greatly affected the economic system as well, and determined the adaptation of an agricultural and/or pastoral system.[83]

2.2.2 *Material Culture*

All types of archaeological evidence within the study area, i.e. military, religious, funerary and commemorative structures, exploitation/industrial sites, settlements, and communication infrastructures, as well as archaeologically unspecified structures and features with their particular subcategories make up the *material culture*. All types of archaeological evidence are closely intertwined with the natural and cultural spheres, and express human adaptations to both spheres within the archaeological record.

2.2.3 *Cultural Sphere*

Culture encompasses the aspect of (semi-)nomadism and a sedentary lifestyle, as well as the mixture of oriental and more Graeco-Roman cultural traditions, which is vital for understanding Nabataean society.[84] Nabataean culture was significantly defined by these two contrasting societal structures and can be observed in the political, economic, military, and administrative organization and the kingdom's religious beliefs, as well as Nabataean funerary customs.[85]

Program describes the endeavors of a Nabataean elite to shift from a fully nomadic lifestyle organized by tribal laws and regulations, into a state-like, sedentary entity with a ruling monarch. While this shift might be explained with the growing political and economic power of the Nabataeans, core tribal elements of societal organization were nevertheless maintained.[86]

79 Schmid 2001.
80 Kennedy 2016a.
81 Ortloff 2014.
82 Kennedy 2016a.
83 Lavento, Silvonen, and Kouki 2013; Rosen 2007.
84 Schmid 2001.
85 Schmid 2001.
86 Kennedy 2016a; Nehmé 2013; Schmid 2001.

Communication may entail (legal) regulations of water distribution, division of land-ownership, or the interaction between the semi-nomadic and sedentary populations of Petra and its hinterland in general.

Representation can most prominently be exemplified by Nabataean funerary customs. The famous façade decorations of Nabataean tomb complexes in Petra took over architectural and spatial designs from both oriental as well as typical Graeco-Roman luxury architecture.[87] These tomb complexes however, were exclusive spaces and were reserved only for a specific family or clan. The persisting tribal structure of Nabataean society is, thus, monumentalized in prominent (sedentary) funerary architecture. In contrast however, the adaptation to disadvantageous natural settings in the form of more mobile architecture (e.g. tent-like installations) in Petra's immediate environment, can be argued to be an expression of the more semi-nomadic aspect of Nabataean society.[88]

2.2.4 Conclusions

As mentioned above, the social-ecology model helps to organize the archaeological and environmental data available for both the natural and cultural sphere. Furthermore, however, the Petra project is a good example of the adaptation of the model. It was shown that the very specific natural environment of the Petra region was a major factor in both determining Nabataean spatial organization, as well as shaping the semi-nomadic and sedentary side of Nabataean culture. For example, although the impact of the extreme topographical conditions of the Petra area first seem disadvantageous for extensive regional control, the Nabataeans managed to use this as an advantage by placing watch posts at selected highpoints and even exploiting untouched nature, thus, falling back on more nomadic traditions. On the other hand, however, the successful and technologically innovative water management system enabled the permanent and sedentary colonization of the city of Petra itself. This constant metabolic interaction between the cultural and natural sphere, as proposed by Fischer-Kowalski, may in fact be a valid explanatory model for the advancement of Nabataean society as a whole. However, considering the overall immense effort put into building the most important central place of the Nabataeans, we still do not fully understand why, precisely, the 'marginal' location of Petra was chosen. In order to provide a fitting explanation, we probably have to take other elements into consideration as well.

87 Schmid 2009; Schmid 2007.

88 Kennedy 2016a.

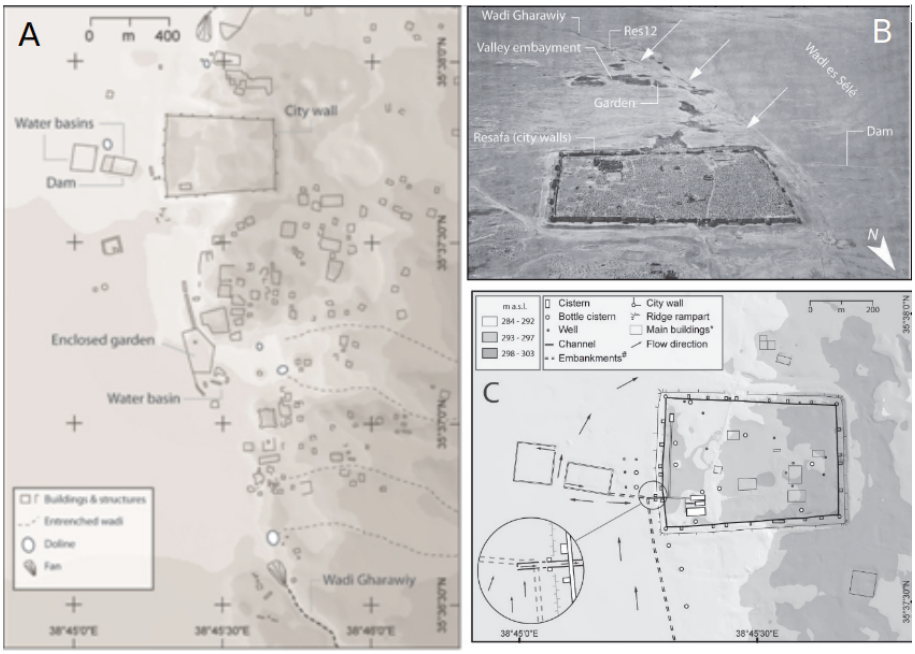

Fig. 5 A: Map of the archaeological finds, basic hydrography and topography of Resafa. B: Edited aerial picture of Resafa and surrounding; the arrows indicate the location of the assumed embankment (copy from Poidebard SJ) C: Detail sketch of the floodwater harvesting system of Resafa. The dashed line indicates the assumed embankments in the northern part. Note that the number of cisterns and wells intra muros is not correct. However we lacked information on the location of some of the structures.

2.3 Resafa-Sergiupolis – Rusafat Hisham /Syria

Resafa, in Northern Syria, lies in the semiarid steppe zone approximately 25 km south of the Euphrates (Fig. 5). Despite difficult environmental conditions, a settlement was founded here and later enlarged several times: built at the site of a former Roman castrum of the Eastern Limes, a pilgrimage city developed in Late Antiquity and a caliphal residence in the early Islamic period. This is testified by archaeological remains, proving a continuous settlement from the middle of the 1st century CE, until its abandonment in the last third of the 13th century CE.[89] To allow the survival of the settlement, the site had to be 'customized' with substantial effort to cover the needs of its inhabitants in the respective stages. Thus, several adaptation processes to cope with the natural conditions are clearly visible in the archaeological record.

89 C.f. Sack, Gussone, and Mollenhauer 2013.

One of the main research topics of the so-called 'Resafa Project' is the analysis of urban development.[90] This colonization of a marginal habitat and its determining factors are the focus of the research.[91] The socio-ecological interaction model of Fischer-Kowalski is discussed here in order to evaluate whether its application can be made productive for the understanding of the site.[92]

2.3.1 *Nature*

The environmental conditions of Resafa were unfavorable for the foundation of a large city. Integral parts of the natural resources of Resafa include the parent bedrock composed of gypsum and clay, which was exploited for the built environment.[93] The settlement is located on a plateau-like land surface at the edge of the Wadi es Sélé (Fig. 6). Perennial water sources providing year-round freshwater are lacking, with only brackish groundwater, unsuitable for drinking, accessible through wells.[94] Furthermore, the site is situated in a semiarid climate zone where rainfall occurs mainly in the cold winter months (October – March), while the summers are hot and dry, with no rainfall at all. The average annual precipitation is about 150 mm, with a minimum of 100 mm, which on the gypsum plateaus, allows rain-fed agriculture only in years with an above-average amount of rainfall.[95] In contrast, the alluvial plain of the Wadi es Sédé is periodically flown through by runoff water originating from the headwater areas in the southward located Jabal Abu Rujmayn and Jabal Bishri.[96] As a consequence, water harvesting measures in the alluvial plain allowed a reliable yearly harvest from irrigation agriculture.[97]

2.3.2 *Labor*

Regarding the settlement of Resafa, the category *labor* was realized in the efforts made to build the urban fabric and the infrastructure system that served the city and its inhabitants. To provide drinking water for the inhabitants and visitors of the city, the seasonal runoff was collected and stored.[98] This process of exploitation of the natural resources for building material, the collection of the seasonal runoff with several water harvesting methods, and the related sophisticated water supply system, represent the relation between the *natural condition* and the *material culture* of Resafa.

90 Sack, Gussone, and Kurapkat 2014; c.f. Sack and Gussone 2015.
91 Bebermeier et al. 2016.
92 Fischer-Kowalski 1998.
93 Bessac, Abdul Massih, and Valat 1997.
94 Wolfart 1966, 35; Wirth 1971, 442.
95 Wolfart 1966, 28; Wirth 1971, 88–93; current statistic: Berking, Beckers, and Schütt 2010, 819–820.
96 Beckers and Schütt 2013.
97 Berking, Beckers, and Schütt 2010.
98 Brinker 1991, 135–136; Garbrecht 1991, 239–241; Beckers, Berking, and Schütt 2012.

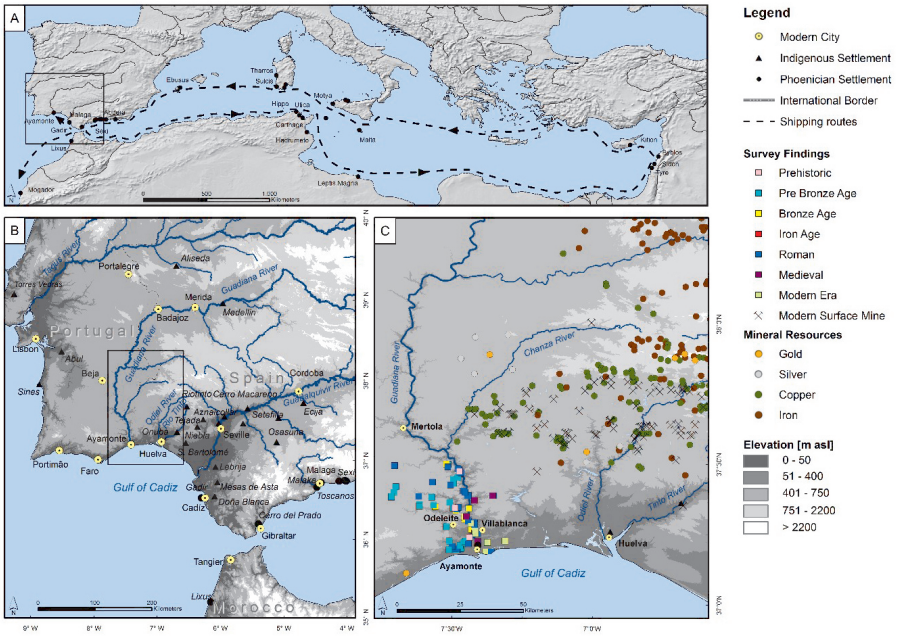

Fig. 6 Supraregional distribution of Phoenician settlements in the Mediterranean. A: Phoenician settlements and trading routes of the Mediterranean; B: Phoenician and indigenous settlements of Southwest Iberia; and C: locations of archaeological survey findings and mineral resources in the wider area of the two prehistoric settlements Ayamonte and Onuba.

2.3.3 *Metabolism*

If we understand *metabolism* as the basic relationship between the unconscious use of a certain site and its resources, we can describe this process for Resafa; for example, the everyday consumption of water and food, or the transport of goods from other places to Resafa using tracks, which caused beaten tracks or hollow ways that are visible in the surroundings. This process could also be seen as the direct or causal interrelationship of natural resources of a specific site, e.g. the gypsum bedrock or the clay and the material culture that is produced, such as the buildings that were erected from the material quarried here. However, if supply from outwards was brought to Resafa, we have to take into account the material flows and their balance on a larger scale – in respect to the socio-ecological, as well as the cultural and economic.[99]

99 Gussone and Sack 2013.

2.3.4 Event/impact

The intervention into the environment of Resafa changed the natural condition to a certain degree, thus, creating a significant *impact* on its *material culture.* A geo-archaeological investigation of the water harvesting system at Resafa[100] provides data on the amount and the sources of water, its collection, and its storing measures, as well as an analysis of the natural preconditions for, the functioning of, and the reliability of the water harvesting system. It emphasizes the 'relative reliability' of the system, which even in dry periods allowed the city-cisterns to be filled at least once every 13 to 14 months, providing drinking water for the inhabitants of the town.[101]

It has to be stated that the success of these ventures – *labor* and appropriate reactions to the challenges of a site, namely the unfavorable *natural conditions* and their *impact* – to a great extent depend on a society with highly developed organizational skills and technical specialization. It seems desirable that this inevitable precondition would be reflected more clearly in this model (as actually generalized, presented in Fig. 2). The same is true for the interaction of antagonistic stakeholders, both on an intra- and intersocietal level.

2.3.5 Material culture/agency

The intermediate position of the *material culture* of Resafa between the *impact* of its *natural resources* and the influences of the *cultural sphere* is clearly visible. During a research history of approximately 100 years, a large amount of archaeological data has been collected at Resafa. There is a wide range of artifacts, ranging from monumental architectural remains like the impressive city wall, five large churches, and the caliphal residence in the surroundings, up to pottery sherds and small finds.[102] The relationship between the preserved monuments and the available natural resources is obvious as, "the city is rising above its own building material",[103] which is recognizable from several quarries and the use of the specific gypsum stone for the churches[104] and the city wall,[105] along with the use of mudbricks for the palaces of the caliphal residence.[106] The *natural resources* of the site were used in both cases, but the changing preferences for the one (gypsum bedrock) or the other (mudbricks) through time are probably explained by varying strategies of usage and changing orientations to different *cultural* backgrounds. The impact of the *cultural sphere* upon the *material culture* of Resafa can be deduced from

100 Beckers and Schütt 2013; Beckers, Berking, and Schütt 2012; Berking, Beckers, and Schütt 2010.
101 Beckers and Schütt 2013; Beckers, Berking, and Schütt 2012.
102 Sack, Gussone, and Mollenhauer 2013 with further literature.
103 Schiller 1977.
104 Brands 2002.
105 Karnapp 1976.
106 Konrad 2016.

the rich archaeological record, which shows a great variety of influences and modes of receptions throughout its history.[107]

Also visible in the *material culture* are several phases of enlargement of the settlement, as well as modifications of the water harvesting methods towards an elaborate supply system,[108] which corresponds first to the political will to install a large city in this place and second to the ability to react to the challenges of a disadvantageous environment. Thus, the growing size of the cisterns and the development of a more sophisticated water supply system seem to be an indication of a successful adaptation to the requirements of the *natural condition*.

Using the socio-ecological model as a working tool, the question arises of how to evaluate a balance between the different parameters of the model, e.g. which amount of building material and what workforce (and how much supply for the workforce) were necessary to produce the constructions, whose remains allow the calculation of their former extent.

2.3.6 Cultural sphere

The area in which Resafa was founded, as a military station, was perceived at that time as a 'Barbarian plain', a remote place at the eastern border of the Roman empire, situated in a conflict area between Rome and the Eastern empires, where political and military considerations were relevant issues.[109] In the Byzantine/Sasanian era, the political and military sphere continued to be dominant, which is reflected by imperial patronage of construction activities and several military campaigns in Resafa's surroundings. In addition to this, however, the religious sphere gained greater significance when Resafa also became an important Christian pilgrimage city, due to the veneration of S. Sergios.[110] Artistic and architectonic discourses are recognizable in the *material culture*. In the early Islamic period, the place still functioned as a place of veneration, whereas the military aspect was less important. In contrast, aspects of political representation became more pronounced due to the city's function as the caliphal residence.[111] Later on, in the 12th and 13th centuries, Resafa flourished as a commercial center with production facilities on a smaller scale,[112] before it was abandoned in the aftermath of the Mongolic invasion, when the Euphrates became the border between the Mamluk and the Ilkhanid empires.[113]

The existence of Resafa spans a period of approximately 1200 years, with a complex historical, intellectual, and *cultural background* that is partly comprehensible through

107 Gussone and Sack 2013.
108 Brinker 1991; Westphalen and Peter 2004.
109 Fowden 1999.
110 Sack 2014.
111 Sack, Becker, et al. 2004; Gussone 2016.
112 Gussone and Müller-Wiener 2012.
113 Sack 1996.

a broad base of data from written sources.[114] In contrast to the comparatively stable environmental conditions, these processes are very dynamic.

2.3.7 Program

The *program* that was to be mastered at Resafa was actually four cultural societal endeavors that were developed successively: first, the function of the settlement as a fortified station on the Eastern Limes; second, the pilgrimage city; third, the caliphal residence; and, finally, a minor commercial and production center. These four different functions entail strategic, urbanistic, and architectural considerations and concepts. The transmission of technological knowledge, e.g. the implementation of fortification guidelines or the installation of the water supply infrastructure, is an important dimension of these strategies.

2.3.8 Communication

Equivalent to *metabolism* in the *natural sphere*, *communication* is understood as the direct, uncontrolled relation between the cultural sphere and material culture, reflected in the techniques and typo-morphological repertoire of traditional craftsmanship. Thus, the city wall of Resafa shows a significant variation in the execution of the masonry and construction details, indicating the activity of different workgroups.[115]

2.3.9 Representation

There is a certain vagueness in this category, as this aspect of *representation* seems to be similar to the process of 'unintentional interaction' of the category of *communication*. Whereas communication hints, e.g., at 'unconscious' cultural techniques such as traditional craftsmanship, the category *representation* corresponds to *material culture* as a source for general *cultural* concepts of a society.

The *material culture* of an archaeological site is always informed by its *cultural background*, which is also reflected in the respective *material culture*. Regarding the case of Resafa, for example, the churches represent the religious as well as the architectural discourses of their period. The design and furnishings refer to liturgical procedures,[116] their decoration signify the activity of different workgroups of varying (*cultural*) provenance.[117] Another example is pottery evidence that comprises types that are clearly related to Iraqi traditions of pottery production, thus, indicating processes of trans-

114 Late antiquity: Fowden 1999; Brands 2002. Early Islamic: Kellner-Heinkele 1996; Müller-Wiener 2016b.
115 Hof 2010.
116 Schuhmann 2016.
117 Brands 2002.

regional and, at the same time, intercultural exchange during the late Umayyad period.[118]

2.3.10 Conclusions

The impulse to settle in Resafa came from the *cultural sphere*: strategic considerations led to the colonization of a site that would not have been chosen otherwise, due to its unfavorable *natural condition*. It is obvious that the foundation of Resafa, its phases of growth, as well as its end have been steered by outside political powers (*cultural sphere*), and was independent from advantages or disadvantages of the *natural condition* of the site.

The *natural conditions* of Resafa and its surroundings were gradually altered into a cultural landscape – for example, the skillful exploitation of water harvesting (*labor*), or by sedimentary processes (*impact*) – but the basic conditions remained relatively stable in the long term. This refers to the topographic position, the availability of building material, and – most important of all – the semi-arid climate (rainfall variability) that was nearly the same for the last 1500 years.[119] To grasp these dynamics in the model of Fischer-Kowalski is problematic, as it does not differentiate between *nature* or *natural conditions* and *cultural landscape*, provided that *cultural landscape* is not considered as being a part of the *material culture.*[120]

To allow survival at this place, *labor* was invested to exploit the *natural resources* of the site. Based on the preconditions of the *natural resources* and the *cultural background* of the respective period, a rich *material culture* was created by actors with highly developed technological skills and a complex social organization. The application of the socio-ecological model of Fischer-Kowalski to the pilgrimage city of Resafa and the caliphal residence in its surroundings, leads to the conclusion that this societal organization and the dynamics of the colonization processes is only partly represented by this model.[121] A further modification of this model should be considered in order to represent the complex societal adaptation strategies used for the colonization of marginal habitats more adequately.

2.4 Ayamonte/Spain

The aim of this contribution is to explore whether the socio-ecological model of Fischer-Kowalski can be adapted to landscape archaeological research on a Phoenician settlement in the politically and economically margins of the Phoenician sphere of influence

118 Müller-Wiener 2016a.

119 Beckers and Schütt 2013; Beckers, Berking, and Schütt 2012.

120 Fischer-Kowalski 1998.

121 Fischer-Kowalski, Mayer, and Schaffartzik 2011.

(Fig. 6). The socio-ecological model of Fischer-Kowalski was originally proposed as a concept for integrative sociological research; it was adapted to present based geographical human-environment research by Weichhart & Wardenga.[122] However, the basic approach of the socio-ecological model in general relies on in-depth socio-scientific observations and data. The landscape archaeological research on the Phoenician settlement Ayamonte, in its current status, includes: (a) an initial archaeological survey of the Phoenician and Roman settlement of Ayamonte and some burial grounds in its vicinity[123] and (b) detailed geomorphological, sedimentological, and geophysical studies in the environs of Ayamonte.[124] As a consequence of the fragmentary archaeological knowledge on Phoenician settlement activities, this reflection on the applicability of the socio-economic model focuses on the natural sphere, the use of landscape, and its direct and indirect shaping by human impact, as defined by Schütt.[125]

Previous studies show that the Phoenicians colonists preferred specific locations for establishing their harbors. In Levantine Sidon and Tyre, the Phoenician homeland, islands or coastal promontories guaranteed protection from weather-driven events.[126] Phoenician settlements along the coast of the Gulf of Cadiz show properties very similar to those of their homeland. Generally, the most important Phoenician settlements are located close to estuaries and alluvial plains of major rivers.[127]

Prior to the discovery of the Phoenician settlement and necropolis in the modern town of Ayamonte in 2007, the Guadiana estuary was a *terra incognita* in terms of Phoenician settlement activity. Results of the archaeological excavation of the necropolis and the remains of the Phoenician settlement are manifold, but remain preliminary, due to missing current research activities.

2.4.1 Nature

The natural characteristic of the settlement site at the Guadiana estuary were of crucial importance for the Phoenicians. The topography of Ayamonte and its surroundings met the needs of the Phoenician traders: the isolated settlement-hill allowed a settlement secure from floods and invaders, with water-bearing coves that offered sheltered anchorage grounds that were renowned throughout the Mediterranean. Already known quarries in the hinterland, where ore-deposits were mined, were unequivocally of major relevance, expanding the Phoenician settlement network of intra-Mediterranean trade to the East (Fig. 6).

122 Fischer-Kowalski 1998; Wardenga and Weichhart 2006; Wardenga and Weichhart 2007.
123 E.g. Marzoli et al. 2014.
124 Klein et al. 2016.
125 Schütt 2006.
126 Marriner and Morhange 2006; Marriner, Morhange, Boudagher-Fadel, et al. 2005; Marriner, Morhange, and Doumet-Serhal 2006.
127 Aubet 2001.

2.4.2 *Labor*

During the Phoenician settlement phase, the major structures of the natural environment of Ayamonte were already set, as the post-glacial sea level rise had ended. Natural matter flows included (a) the discharge of the Guadiana River and its sediment load, with maximum amounts during the winter and spring,[128] and (b) a daily alteration of the high tide, pushing salty sea water into the Guadiana Estuary up to 50 km inland[129] and a mean tidal range of 2.0 m, causing the deposition of bars.[130] With the Phoenician settlement, increased human impact on the environment resulted in significant changes of the estuary and coastal landscape close to the Guadiana River mouth. Post-Phoenician examples include the erection of tidal mills, the construction of salines, and the development of numerous reservoir dams. Increased soil erosion in the hinterland of the Estuario de la Nao caused its siltation; as a consequence, the former anchorage site today is under agricultural use.[131]

The sediments in the vicinity of Ayamonte provide only few direct proofs of the 'material culture', as artefact findings are rarely in the sediments and generally are relocated. Rather, characters of the extracted artefacts in the sediments provide clear evidence of human impact. This includes increased concentrations of lead and other heavy metals identified in slope deposits, giving the indication of ore processing in the catchment and the accompanied waste production,[132] documenting a direct intervention in the balance and flow of matter. In contrast, increased deposition rates of detritals provide evidence of human impact on the factors controlling surface runoff and erosion (corresponding to the balance and flow of matter) and, thus, are understood as indirect influence.

2.4.3 *Metabolism*

Since ancient times, humans have made efforts necessary to maintain living conditions in the environs of the estuary. Access to waters rich in fish and the combination of a flat surface topography with strong summer insolation and evaporation, facilitates the production of salines and the subsequent export of transportable and durable fish products. The seafaring identity and the maritime know-how, complemented by the special topography, resulted in the establishment and usage of marine infrastructure. The situation is similar with the occurrence and management of mineral resources. The availability of

128 González et al. 2004; Camacho et al. 2014.
129 Fletcher 2005.
130 Borrego, Morales, and Pendon 1995; Morales 1997.
131 Klein et al. 2016.
132 Thorsten Klein (and others). "Human-Environment Interactions at the Phoenician Site of Ayamonte (Huelva/Spain): Insights from Terrestrial Borehole Data". *Zeitschrift für Geomorphologie* (submitted) and Torsten Klein. "Geoarchaeological Case Studies at the Lower Guadiana Estuary:Paleogeographic Development and Human-Environment Interactions at the Phoenician Site of Ayamonte (SW-Andalusia/Spain)". Dissertation FU Berlin 2018 (https://refubium.fu-berlin.de/bitstream/handle/fub188/23488/Dissertation_Klein.pdf?sequence=4&isAllowed=y; last visited 09/06/2020).

metallic ores and water supported the establishment of metallurgy workshops and the processing and export of high-quality goods.

2.4.4 Impact

Human actions were strongly affected by natural processes and unintentional human impacts. A relatively stable sea-level from around 6000 years BP and increasing erosion rates in the Guadiana drainage basin, resulted in increased sediment load and increased siltation of alluvial loam, reducing the navigable open lagoonal waterbodies and number of favorable anchorages.[133] Natural processes, in particular, were of relevance for the population when they faced extreme events; a particularly dramatic moment resulted from a tsunami, which generated the Great Lisbon earthquake on November 1, 1755.[134] For the environs of Ayamonte, about 1000 deaths related to this tsunami are presumed.[135]

2.4.5 Material Culture

The archaeological knowledge about the Phoenician settlement(s) in Ayamonte and its environs are exclusively based on archaeological surveys, while extensive excavations had not been conducted until recently. Archaeological evidence for the Phoenician period in the environs of Ayamonte comprises fragments of Phoenician pottery, remains of metallurgic furnaces, remains of Phoenician houses, and remains of a metallurgic workshop. Recently discovered materials include fragments of a Phoenician vessel and amphorae. Excavations in nearby Phoenician tombs have revealed numerous mortal remains, with precious grave goods and traces of an *ustrinum*.[136]

2.4.6 Culture

The local cultural interpretation regarding the Phoenician population in the environs of Ayamonte, is primarily obtained by the composition and presentation of burial equipment.[137] The Phoenician community at the Guadiana Estuary buried the deceased essentially with the same ritual that they practiced in the Levantine motherland.[138] However, some peculiarities within several tombs occurred, indicating different traditions, chronologies, and/or societal affiliations. An intermixture between the Phoenician and local population in Ayamonte and other necropolises of the Iberian Peninsula have not been observed until now.[139]

133 Klein et al. 2016.
134 Andrade 1992; Gupta and Gahalaut 2013; Klein et al. 2016; Lario et al. 2011.
135 Álvarez 2007.
136 Teyssandier and Marzoli 2014.
137 Teyssandier and Marzoli 2014.
138 Teyssandier and Marzoli 2014.
139 Teyssandier and Marzoli 2014.

2.4.7 Program

The cultural program regarding the Phoenician population in the environs of Ayamonte producing artifacts or spatial structures can be – due to the current fragmentary character of the archaeological knowledge – described best by the burial rites. Habits and practices were launched with the immigration of the Phoenicians, which remodeled or replaced habits and practices of the local, original inhabitants.[140] Achieving cultural continuity by traditional burial rite were, especially for early cultures, of central importance for cultural development.[141] Traditional elements maintained the awareness of a 'Phoenician identity', united in the form of a community within a Mediterranean diaspora.[142] Further archaeological studies have to prove if preliminary observations of a cultural connection to Carthage and Sardinia can be confirmed.[143]

2.4.8 Communication

Disentangling modes of communication of the Phoenicians settling in the environs of Ayamonte is at the present hampered, due to the complete lack of written sources.

2.4.9 Representation

The 'Phoenician architecture' within Ayamonte and its surroundings is badly preserved, and at the present provides only a rudimentary understanding and reconstruction of the structural functioning.

2.4.10 Conclusions

The archaeological research on the Phoenician settlement of Ayamonte is still in its initial stage, with only few archaeological surveys conducted.[144] The reconstruction of past environmental conditions and their trajectories clearly indicate human impact in the drainage basin. During the settlement phase, increased deposition rates of sediments and the increased heavy metal concentrations (metabolism) in the sediments point to settlement activities in the hinterland. They are indirect indicators, and document a changing environment (labor) coinciding to human settlement activities – and, thus, have been attributed to it. Direct indicators of human impact on the landscape, such as a constructed environment, have not yet been investigated. Sedimentological investigations also provide clear evidence on the 1755 tsunami triggered by the Lisbon

140 Teyssandier and Marzoli 2014.
141 Teyssandier and Marzoli 2014.
142 Marzoli et al. 2014.
143 Teyssandier and Marzoli 2014.
144 Teyssandier and Marzoli 2014; Cabaco Encinas 2011; Pérez Macías, Cabaco Encinas, and García Teyssandier 2012; García Teyssandier and Cabaco Encinas 2009; Elisabet García Teyssandier. Memoria Preliminar de la Actividad Arqueológica de Urgencia en el Plan Parcial, Sector 12, ›Nuevo Parque‹ del Término Municipal de Ayamonte (unpublished).

earthquake (event/impact) at least. However, the short-term impact on livelihoods and the long-term impact on, e.g., settlement strategies can only be assumed. Some general investigations on adaption and mitigation strategies referring to the 1755 Lisbon earthquake were conducted, but predominantly focused on governmental aspects.[145] A compilation on the structural changes that occurred in Lisbon itself is presented by Pais.[146]

3 Insights

In the introduction to this paper, we raised the issue of differentiating between labor and metabolism, as defined by Fischer-Kowalski.[147] The point is made particularly clear by scenarios involving societies or groups who leave relatively few physical imprints in/on the environment, e.g. foragers or nomadic groups, as their socioeconomic and sociocultural strategies, i.e. programs, are often not designed to change nature, but rather to interact with it in a way which leaves few physical traces. The Petra case study highlights these aspects nicely. It was made clear that the particular environmental factors of the Petra region impacted the structural appropriation of Petra's environs significantly, therefore, influencing societal developments greatly as well. On the one hand, the unfavorable geological and topographical settings of the region allowed only limited movement through the landscape and the erection of structures of temporary use only. This may, therefore, reflect the persisting semi-nomadic aspect of Nabataean society. On the other hand, very specific natural landscape factors also offered good conditions for permanent structures and settlements that represent a more sedentary lifestyle in Petra's hinterland. Finally, the climax of the colonization of a marginal habitat with permanent structures lasted for a comparably short time, and within a wider cultural-political environment favorable to such massive efforts in order to dominate the unfavorable natural setting.

The dynamics that led to these efforts can clearly be localized within the cultural sphere, driven mostly, though not exclusively, by aspects of representation. The contribution of the Badia case study has also show how to gain an idea of the chain of action of the inhabitants of the Early Bronze Age region of Jawa and its hinterland, Northern Badia, based on the research carried out on architectural remains, archaeological surface finds, and geographical archives. Derived from the information gained from the artefacts, three different fields of labor 'activities' – the 'exploitation of mineral resources', 'usage of natural basalt stones', and 'implementation of water harvesting systems' – were

145 Mendes-Victor et al. 2008; Mullin 1992.
146 Pais 2009.
147 Fischer-Kowalski, Mayer, and Schaffartzik 2011.

distinguished. With the crop yield simulations of the irrigated agricultural terrace systems around Jawa, a first understanding about the energy potential of these systems and, thus, a first step towards quantifying the energetic metabolism for Early Bronze Age Jawa can be derived. The cultural processes that arise from the societal or individual endeavors of the inhabitants of ancient Jawa and its hinterland, form cultural programs that can be grouped into three major classes: resources program (excluding water), settling program, and water harvesting program.

In contrast, the case of Resafa shows that significant efforts were undertaken to customize the natural setting of the semi-arid Syrian desert-steppe to collect seasonal run off that allowed the existence of a large settlement in an unfavorable natural area. Nevertheless, a close interrelation between the natural resources and the material cultural of the site shows a clear dependency on both parameters.

A further result is that the reasons for interventions in an unfavorable setting, as well as the complex requirements to maintain the installations, can only be explained through inter-societal processes. It has been realized that the model does not consider these inter-societal processes adequately. However, these processes are vital for research on colonization that brings two or more societies into contact and results in regular interaction.

Here, the socio-ecological model provides a tool to calculate the requirements of interaction between the natural and cultural spheres, which both influence the material culture of archaeological sites. An opportunity of the model is its systemic approach, to see singular phenomena not as static, isolated relics, but as a part of an evolving, processual entity, whose components have to be balanced.

Despite the fact that the exploration of Ayamonte is still at its beginning, some interesting aspects, nevertheless, stand out. Here, the Phoenician settlers found a favorable environment that was, in some points, similar to their homeland. The major challenge, in terms of marginality, must have been the distance to their cultural base, no matter whether we consider this to have been rooted in Phoenicia or Carthage. The interaction between the natural and the cultural sphere seems to have been driven by the aim to exploit natural resources. This, in the long run, apparently led to a certain deterioration of the initially favorable setting, provoking the need for new settlement strategies. Hence, the socio-ecological interaction clearly plays an important role, but in order to be able to more explicitly comment on the applicability of the model discussed here, more data has to be collected.

All in all, the model offers a comprehensive framework for analyzing human interactions with nature, illustrating the dialectic processes arising from this interaction in a systematic way. From an archaeological perspective, however, its application is hampered by the fact that much data of explicit past interactions, which constitutes the main parameters of the model, are not available in the archaeological record. There-

fore, reconstructing causal relationships between the various elements of the model may appear very speculative and argumentative. One crucial point, in this regard, is the diachronic resolution and ordering of data obtained for both environmental conditions and changes, as well as events or processes of human impact. Another point concerns facets of societal communication and (symbolic) representation, which cannot be 'read' directly from material culture remains.

Thus, while a comprehensive reconstruction of past socio-ecological dynamics based on Fischer-Kowalski's[148] model has proven to be problematic, at best, it is still deemed fruitful to alter the analytical orientation of the model and its resolution. As a more abstract tool, the model can help to plot possible interactions and interrelations between different phenomena of the natural and cultural spheres and to identify specific data one may want to look for and identify in one's material: as illustrated in the case studies, the model can, in this sense, act as a heuristic devise.

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Temporalities in the Study of Mobility

Summary

The research group *Political Ecology of Non-Sedentary Communities* examines differently mobile societies from the Epipaleolithic in the Nile Delta to Neolithic and Aeneolithic settlements in the foothill plain of the Kopet Dag in Turkmenistan and Aeneolithic and Early Bronze Age groups in the Eastern European steppe. We recognize mobility as a feature of every society. To describe different forms, conditions, and strategies of mobility and avoid a dichotomy of non-sedentariness vs. sedentariness, we emphasize temporalities. In this context, crucial questions are how extensive, how routine or unusual, over what periods of time mobility occurs and which segment(s) of a group are engaged in different aspects of mobility. We exemplify our approach through a comparison of two case studies.

Keywords: temporality; political ecology; scalarity; mobility; Eurasian prehistory

Die Forschungsgruppe *Political Ecology of Non-Sedentary Communities* untersucht unterschiedlich mobile Gesellschaften vom Epipaläolithikum im Nildelta bis zu den neolithischen und äneolithischen Siedlungen, nördlich des Kopet Dag in Turkmenistan und äneolithischen bis frühbronzezeitlichen Gruppen in der osteuropäischen Steppe. Um verschiedene Formen, Bedingungen und Strategien der Mobilität zu beschreiben und eine Dichotomie der Nichtsesshaftigkeit vs. Sesshaftigkeit zu vermeiden, analysieren wir Temporalitäten und die Frage, wie umfangreich, routinemäßig oder ungewöhnlich sowie über welche Zeiträume hinweg die Mobilität auftrat und welche Segmente einer Gesellschaft an welchen Mobilitätsaspekten teilhatten. Als Illustration dient der Vergleich zweier Fälle aus Süd-Turkmenistan und der osteuropäischen Steppe.

Keywords: Temporalität; Zeitlichkeiten; politische Ökologie; Skalarität; Mobilität; Eurasische Vorgeschichte

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1 Resilience, political ecology, and time scales

Large, multidisciplinary research groups are faced with the challenge of developing or identifying concepts that allow meaningful collaboration across a multitude of individual projects. The socio-ecological model discussed in many of the contributions in this volume, which was developed and refined over several decades, principally by a group led by Marina Fischer-Kowalski,[1] has strong parallels in the Anglophone literature (see chapter 1, this volume). Such models of resilience and vulnerability present a number of serious problems, however, when one attempts to merge them with ideas derived from political ecology. We mention just a few of the problems that have been highlighted in recent discussions on the subject.[2] First, the overall approach of a socio-ecological framework is a systemic one that is interested in equilibria, disturbances, and the various processes that lead a disturbed system back to a more stable state or transform it into a new system. In contrast, the interests of political ecology center on inequalities and power differences rather than (dis-)equilibria. Second, resilience – a central tenet of socio ecology – is, as Katrina Brown writes, "conservative, focused on the persistence of a 'system'" that is threatened from the outside, but not from within.[3] Political ecology starts from the assumption that all social phenomena are inherently instable because of *internal* power differentials. Third, while both of these approaches are firmly interdisciplinary, political ecology research is fundamentally driven by a critical approach, whereas a systems paradigm is pragmatic in its aim to support policy planning and ecological management.[4] Fourth, approaches focusing on adaptation and resilience include the assumption that 'desirable states' in an adaptive cycle are obvious. However, the boundaries of a system, indicating what is conceptualized as resilient and what is not, are insufficiently questioned, and even when they are, resilience remains in the eye of the beholder, as demonstrated in an example that emphasizes issues of differential political-economic power.[5] Finally, as mentioned in the introduction to this volume, the social side of social-ecological models is envisioned as a mirror of the ecological, leading to an imagination of societies that is functionalist and reductionist in its negligence of people's motivations for action on, and in, the environment.

This paper lays some groundwork for a rapprochement of political ecology and resilience approaches by starting from the side of political ecology. Both approaches evince preoccupations with change and temporality. In resilience theory, change is conceptualized as non-linear but with a strong bent for an assumed recurrence of 'adaptive

1 Fischer-Kowalski, Mayer, and Schaffartzik 2011; Fischer-Kowalski and Weisz 2005.

2 Berkes, Colding, and Folke 2003; Brown 2014; Turner 2014; Ingalls and Stedman 2016; Kull and Rangan 2016.

3 Brown 2014, 109.

4 Turner 2014, 8–9.

5 Beymer-Farris, Bassett, and Bryceson 2012.

cycles'.[6] In contrast, political ecologists envision social change as historically contingent and driven by both the agency of humans and structural conditions for human action. For our research group, the dynamics of multiscalar change are of fundamental importance. Change unfolds at very different but interwoven temporal scales. This paper reflects on multiple temporal dimensions and their potential inclusion in archaeological-ecological research. In terms of the model of Fischer-Kowalski, we remain largely in fields that are described as the relations between material and the immaterial characteristics of culture.

1.1 Scales and temporalities

Archaeological investigations typically begin with conventional periodizations. These broadly and often poorly defined periods, such as the Epipaleolithic, Neolithic, and Aeneolithic, may in turn be divided internally into sub-periods or phases. These kinds of division are premised on the notion of (relative) homogeneity within a particular (sub-)period and significant variation between periods. Transitions tend to be conceptualized as sudden breaks rather than gradual changes, whereas it is assumed that little or nothing changes fundamentally *within* a phase. This, of course, oversimplifies a much more complex reality.

We approach matters of temporality from several premises. First, we acknowledge that change is always present, except – or perhaps even when – people work actively to prevent it. That said, the degree, tempo, and form of change are highly variable. Second, our typically coarse temporal divisions offer a general orientation, but they are by themselves inadequate for many of the questions we ultimately wish to address. Third, as such, periodizations are generally used in archaeology. They tend to imply that there was long-term planning behind the trends we observe, but in fact people's actions in the short-term usually have unintended consequences. As a result, we argue that it is crucial to take a closer look at a range of scales varying from short- to long-term. as well as the ways they are interrelated, in order to investigate the bestowal of meaning on chronological sequences. We work towards an analytical framework that allows the investigation of the interconnectedness of different dimensions of time and the positioning and participation of practices and dispositions of historical actors across these dimensions. Such a framework must ultimately take into consideration multiple temporalities linked to change, recurrence, and duration.

In recent years, there have been a variety of theoretical discussions about concepts of time. These are relevant to a wide variety of issues, including the human perception of time and change. In the treatment of change over time, an area in which archaeologists

6 Folke 2006, 255–258.

have traditionally operated with long-term diachronic comparisons, one can now identify a trend towards differentiation among temporal processes in terms of their speed, range, and duration.

The early impetus for a multiscalar consideration of time came from the neighboring discipline of history, through the reception of the works of Fernand Braudel and other historians of the Annales School.[7] Above all, Braudel's notion of history as a composite of varying temporal rhythms – *longue durée*, *conjoncture* or *moyenne durée*, and *événement* – held out an epistemological potential for archaeological inquiries into change and its temporal dimensions. While Braudel associated the *longue durée* with ecological time, the *conjoncture* with economic cycles, and the *histoire événementielle* with the realm of political decision making, archaeologists have often turned this tripartite division of temporal scales into a short-term associated with events that occur within an individual's lifetime, a medium scale measured in several generations, and a long-term involving multiple centuries or even longer. This Braudelian scheme has also created opportunities for the integration of small-scale research questions.

More recent approaches, such as that of Geoff Bailey's time perspectivism,[8] picked up the idea of multiple time scales and called for a distinction between short-term and long-term archaeological phenomena. Bailey argues that phenomena operate on different time scales and investigating them requires better resolution of archaeological data and different explanatory principles. This dichotomy between short- and long-term is mirrored in treatments of time in processual and post-processual archaeology: the one school addressing principally long-term processes, the other tending rather to filter out any large-scale dimensions because of its research focus on local, if not individual, experiences of the world.[9]

An important element in postprocessual understandings of time originates in Michael Shanks and Christopher Tilley's radical critique of the chronological understanding of time in archaeological research: an 'abstract time' that is construed through a capitalist chronometry and produces narratives that have nothing to do with the way people in the past understood time.[10] They contrast this concept to substantial time, which takes shape and is experienced through social practices.[11]

Recent works that develop these ideas further provide a more comprehensive treatment of chronological and experienced time in archaeological discourse and open up room for the interpretation of archaeological remains as temporalized objects.[12] Yannis Hamilakis, for example, has emphasized the notion of multi-temporalities in his work.[13]

7 For more detail see Knapp 1992; Smith 1992.
8 Bailey 1983; Bailey 1987; Bailey 2007.
9 Robb and Pauketat 2013.
10 Shanks and Tilley 1987.
11 See also Fabian 1983 for an anthropological critique.
12 Thomas 1996; Lucas 2005.
13 Hamilakis and Anagnostopoulos 2009; Hamilakis 2013.

Drawing on Bergson's idea of duration, he notes that material things – the stuff of archaeology – are able "to re-enact multiple, coexisting times".[14] Time as experienced is not something abstract and uniform, as we conceive of it in our chronologies, but is rather "diverse, multiple, and socially and materially produced".[15]

As Hamilakis argues, archaeological materials are already multi-temporal by virtue of having been taken – by us – out of the context of past experience to be re-experienced and re-conveyed from the present into the past. The act of decontextualizing archaeological objects through excavation can be seen as a collision of chronological and experiential time. Can 'objective' or external time be linked to experiential time at all? Alsdair Whittle et al. see an opportunity to depict not only long-term processes but also short-term developments by using models with very high chronological resolution, achieved through Bayesian statistical analysis.[16] Whittle and his colleagues draw on considerations of events as perceived by people and the fact that their perceptions can encompass different temporal durations. Crucial is the concept of memory, the "kinds and scales" of which are "inescapably part of the nexus of structure and agency, in which social existence unfolds".[17] In their exposé, archaeological time scales are differentiated more finely than usual.[18] Events occur within an individual's experience, personal memory involves lifetimes and generations, active memory extends as far as one's 'grandmother's grandmother', social memory into centuries, and finally myth is something outside time. A problem that arises when trying to frame scalar categories from the outset, however, is that there is every reason to think that different criteria play variable roles in different social and cultural contexts.[19]

The diversity of approaches to temporalities and the complexity of investigating them archaeologically take us well beyond the scope of a brief paper. Here, we endeavor to take the first steps toward a multiscalar approach to our own research projects.

We begin with a basic notion of time as treated by archaeologists in the past decades, which acknowledges both external and internal perspectives and long and short scales. An external view refers to time scales conceivable and time resolutions achievable by archaeological chronologies. An internal or experiential view focuses on the perception and representation of time in past societies, inspired by research and theoretical reflections in sociology and anthropology.[20] Linear vs. cyclical concepts of time, chronotypes, and the notion of social and cultural memory are just some of the key issues in this experiential perspective on temporality.[21] Since short-term events and practices are often easily perceptible, an internal perspective is frequently thought to be more applicable

14 Hamilakis and Anagnostopoulos 2009, 78.
15 Hamilakis and Anagnostopoulos 2009, 79.
16 Whittle, Bayliss, and Healy 2011.
17 Whittle, Bayliss, and Healy 2011, 911.
18 Whittle, Bayliss, and Healy 2011, Fig. 15.28.
19 E.g. Haber 2016, 475–476.
20 Lucas 2005, 61–67.
21 Lucas 2005, 71–92; Reinhold and Hofmann 2014.

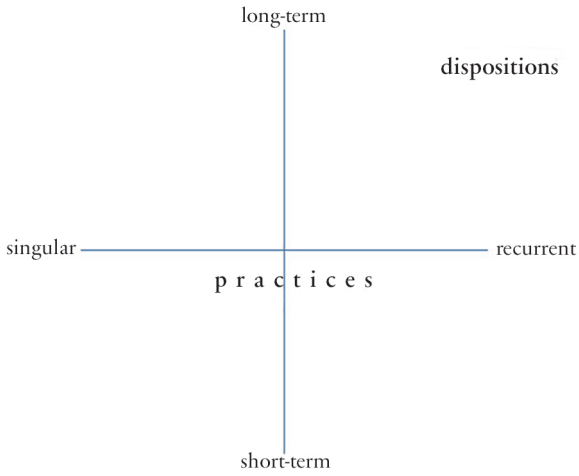

Fig. 1 Two axes of temporality based on scale and degree of recurrence.

at the short end of time scales, while long-term changes tend to be considered as externally triggered and beyond the motivational horizon of actors. Long-term dynamics and change are often assumed to be the result of social institutions within which people act.

Here, we draw attention to another aspect of temporality: recurrence. Events or practices may occur singularly, sporadically, or regularly. If recurrent, practices may happen more or less frequently. Recurrence and its frequency and rhythm are important elements of the degree of unexpectedness versus familiarity in a horizon of expectations of social time. Social practices can thus be mapped along two intersecting axes of temporal occurrence (see Fig. 1).

In the remainder of this paper, we focus on time viewed from an external perspective, with attention to the interwovenness of scales, frequencies, and recurrence. We provide examples for the interdigitation of temporal scales from research projects in Turkmenistan and the eastern European steppes. Toward the end of the paper, we draw on some of the ideas of the historian Reinhart Koselleck as an entry point for thinking about experiential time.[22]

2 Temporalities at Monjukli Depe, southern Turkmenistan

In research on early settlements in the foothills of the Kopet Dag of southern Turkmenistan, standard narratives have focused on evidence of major shifts between the Late

22 Koselleck 1985.

Neolithic and Early Aeneolithic periods (6000–4000 BCE). These are said to include significant changes in pottery production and use, textile production, the appearance of copper, and the layout of settlements. Our work at Monjukli Depe has shown that this picture of clearly divided, internally homogeneous periods is too simple. There are, on the one hand, surprising long-term continuities, for example, in building forms and the organization of space in houses. On the other hand, some elements show more change than the standard narratives would lead us to expect; these include settlement layout, practices of house abandonment, and variations in small-scale practices that took place in houses or in open spaces.[23]

To address these variable elements and their associated temporalities, we start from the understanding that long-term dispositions and processes and short-term practices are mutually constitutive. In contingently developing (pre-)historic settings, culturally specific dispositions are formed by recurrent practices, and those dispositions in turn guide and structure practices. Change in deeply engrained routines may either occur slowly and remain almost unnoticed by actors, or it can happen suddenly through external impetus or critical internal thresholds. Our questions, therefore, center on the ways that practices contribute to longer or shorter-term dispositions that in turn structure those practices, as well as the ways in which different temporal rhythms – of productive activities and engaging with the products of those activities – intersect to produce tensions that may then engender fundamental change.

2.1 Recurrent practices and the dispositions they produce

We begin with architecture. The built environment is widely acknowledged as being a product of the social and natural environment of those who construct it and live in and with it, while at the same time the built environment structures people's practices, dispositions, and social relations.

At Monjukli Depe, portions of 20 Aeneolithic buildings were excavated, many of them quite well preserved. There was a marked continuity in house plan and configuration over four Aeneolithic building levels, which lasted for an estimated total of between 115 and 315 years.[24] These speak to a shared, long-lasting disposition regarding the form of a dwelling as well as elements of its internal arrangement. Houses typically consist of a more or less square room divided in two by means of opposing buttresses and a low threshold that separated the front and back portions of the structure. Installations for food and storage are found in the lower, front part.

23 Bernbeck, Cubasch, et al. 2016.

24 Heit 2019.

In contrast to the well documented Aeneolithic buildings, only fragments of Neolithic architecture have been exposed at Monjukli Depe. Although one should not ignore the importance of potential regional variation, we draw tentatively on observations from Neolithic houses at other sites from the Kopet Dag piedmont zone for purposes of comparison. This reveals a remarkable continuity in the general structure of houses: a single, more or less square room but with a division of the space suggested by an oven located in the center of one wall and, in some cases, a slight protrusion or buttress on the opposite wall.[25]

Overall, house plans remained substantially similar over the approximately 1500 years of the Late Neolithic and earliest Aeneolithic occupation in the Kopet Dag piedmont zone. Since living with, and in, buildings was a part of everyday life for most people from birth to death,[26] they also framed the social relations of those occupying such buildings. The striking similarity in both plan and size of the houses suggests a modular village organization, where similarly structured domestic architecture implies an unspecifiable but similar kin structure. We do not know how often houses were newly constructed, although each of the four Aeneolithic building levels at Monjukli Depe are estimated to have lasted from between 40 and 75 years.[27] Since it is most unlikely that all houses were abandoned or rebuilt at the same moment, it seems reasonable to assume that a new house was built at least every decade or two. Thus, house construction would have been a recurrent, albeit episodic, short-term practice that would have taken place within a shared space – a settlement – consisting of other similar houses, a material frame that organized social experiences and helped maintain social life in specific, likely unquestioned and unquestionable limits.[28] This long-term continuity of social structures from the late 6th to the mid-4th millennium BCE is also evidence for a stable economic relationship between this society and its natural environment. Furthermore, household configurations are strong indicators for economic structures.

Although house form remains largely similar from the Neolithic to the early Aeneolithic, settlement layout shows a different rhythm of change (and/or perhaps greater regional variation). Some early Neolithic settlements such as Jeitun and Pessejik consist of free-standing structures with no apparent plan and no discernible paths/streets, whereas middle or late Neolithic architecture in Chagylly and Chopan Depe tends to be agglutinative and there are some hints of paths through the villages. These trends become clearer in early Aeneolithic sites such as Monjukli and Chakmakly Depe, which have straight streets along which houses are aligned.[29] The layout of a village is some-

25 Müller-Karpe 1982, 16–22.

26 Unless there was substantial medium- or long-term mobility that took at least some members of the community away from the settlement for lengthy periods of time.

27 Heit 2019.

28 Goffman 1974.

29 For an overview see Müller-Karpe 1982, for Monjukli Depe see Pollock and Bernbeck 2019.

thing within which people were enmeshed in their everyday lives, and movement from one part to another was likely so taken for granted that it remained largely unquestioned and uncontested. It is, therefore, all the more surprising that changes in settlement layout occurred more rapidly than those in house form. The change from free-standing buildings to agglutinative ones is unlikely to have been an explicit decision; however, the result was the need to plan and maintain a thoroughfare. Could there have been outside threats? No evidence for inter-community violence could be discerned, and the burials analyzed do not contain any traces of broken bones.[30] Threats from wild animals can likely be ruled out as well, both because of the absence of village walls and the rarity of wild species in the faunal remains. The most likely reason for the concentration of houses on the mound is flooding in springtime when the winter snows melt in the Kopet Dag.

In Aeneolithic Monjukli Depe, there is intriguing evidence for a practice of ritual closing of houses prior to abandonment. In three buildings, small cobblestones were found strewn across the last floor. The three houses are from three different building levels, implying that this was an occasional practice that was transmitted over multiple generations. The performance of this kind of abandonment ritual may thus have taken place every generation or two. The fact that such deposits occur only in certain houses suggests a degree of flexibility in deciding how to leave a dwelling and/or different reasons for ending the residential use of a house. It is possible that such abandonment practices were triggered by highly specific preceding events, such as the death of a family member; we have no empirical data to assess such connections.

Another recurrent practice that, like the strewing of stones on a house floor prior to abandonment, was never uniformly followed, was the burial of some individuals in graves with L-shaped cross-sections. This grave form is known in Central Asia until the end of the Bronze Age.[31] Considering the number of graves recovered at Monjukli Depe, it is clear that not all of the deceased were buried within the settlement, but it is likely that the interment of a person in an L-shaped grave was an event that occurred once every several years at most.[32] Death is, of course, expectable in a general way, but its timing is at best barely foreseeable. As vividly portrayed by Fredrik Barth,[33] ritual occasions in small-scale societies that occur irregularly and at intervals of several years or more strain the knowledge of those who perform them to the point that the participants may invent elements as they go along. We cannot ascertain to what extent this was the case for burials in L-shaped graves at Monjukli Depe. However, detailed documentation of the burial practices shows an astonishing level of variability, pointing perhaps to such

30 Steadman 2019.
31 Teufer 2013, 23–25.
32 Rol 2019.
33 Barth 1987.

conditions.[34] This constellation – an overall long-term continuity marked by shorter-term, smaller-scale variabilities – indicates a sociocultural formation that has strongly resilient elements.

Among the portable objects that people made and used in later Neolithic and especially Aeneolithic societies, pottery is often regarded as an element of daily life. Changes in technology, vessel morphology, and decoration are often employed as chronological markers, and the situation in the Kopet Dag piedmont zone is no different in this respect. Neolithic pottery is thick-walled, vegetal tempered, often has a dark core indicating incomplete oxidation, and is only rarely painted. In contrast, the early Aeneolithic pottery is well-fired, thin-walled, contains either fine sand or no temper, and is frequently painted. Surprisingly, however, Aeneolithic pottery is quite rare, occurring in much lower densities than Neolithic ceramics.[35] Based on occasional finds of unfired clay vessels as well as basketry, it appears that the Aeneolithic inhabitants mostly used non-ceramic containers. This is in stark contrast to the contemporary situation in highland Iran. Whether the changes in pottery frequency, technology, and decoration occurred abruptly or gradually cannot be determined, as the Neolithic and Aeneolithic occupations are separated by as much as 800 years. Whether pottery vessels were a part of daily life in Aeneolithic Monjukli Depe also remains an open question. However, as in the case of burial practices, the production of pottery vessels was a recurrent practice, but must have occurred only sporadically. This leads to the question of how such a technology persisted. Archaeometric analyses show that pots were made of local clay, so a foreign origin can be excluded. Another possibility is the existence of itinerant craftspeople, in which case, it would have been the social contact with non-local people that was of a sporadic character.

The spinning of fibers is an integral part of textile production. The Aeneolithic levels at Monjukli Depe contain a large number of clay spindle whorls, in sharp contrast to their near absence in Neolithic times. The spindle whorls are simple and seem to have been made and probably discarded relatively quickly, suggesting that spinning was a frequent and recurrent practice.[36]

2.2 Singular events

In the back portion of the Aeneolithic House 10 at Monjukli Depe, the footprints of a child, as well as the paw prints of two dogs, were found impressed into the mud plaster of a floor, suggesting that the dogs and the child had run in opposite directions across the newly plastered surface.[37] Replastering of a house floor was an event that probably

34 Rol 2019.
35 Schönicke 2019.
36 Keßeler 2019.
37 Egbers 2019.

occurred only every few years, based on the number of floors per house. The time required to lay the plaster and allow it to dry amounted to perhaps one to two days, depending on the time of the year. This is a very brief period of time, and dogs were not particularly frequent animals in the faunal assemblage at the site. The paw prints in House 10 as well as in a second house are, therefore, unlikely to have been a purely accidental occurrence – the likelihood that by chance dogs gained entry to two houses when the floor plaster was fresh, but otherwise did not do so, are statistically extremely low. The fact that the houses in which the paw prints were found are from two separate levels of the Aeneolithic village indicates that allowing dogs the run of the house was not restricted to one specific house or a particular moment in the village's history. Indeed, the presence of paw prints on one floor in each of the two houses suggests that it was not uncommon for dogs to be in houses, although there were probably attempts, not always successful, to keep them out when floors were newly plastered. In other words, we can distinguish between what may have been a familiar occurrence – dogs gaining access to houses – and a nearly singular event in which dogs entered a house with a freshly plastered floor.

An event that for now appears to have been a unique occurrence at Monjukli Depe, is the painting of designs on a buttress in House 14.[38] While buttresses were invariably plastered, often multiple times and with pigmented plaster, the application of painted designs occurs only once. In most other respects, House 14 is similar to the others, although it is the only one yet excavated that was abandoned following a major conflagration. Whether those two events were connected is unclear.

These two examples make clear that it is possible to identify singular, unusual events archaeologically. In one of these cases (the wall painting), the event seems not to have been repeated, in the other case (paw prints), the occurrence was rare. They stand in contrast to recurrent practices and their associated dispositions that characterize contexts in which people are immersed in a particular (built and social) environment. However, the two cases of particular events diverge in another temporal respect. One, the wall painting, was carried out with the prospect of an enduring and visible result, whereas the other, the paw and footprints, were inadvertent and without any expectations of leaving a trace for future reference by those who created them.

3 Temporalities in the eastern European steppe

The transition from Aeneolithic to Early Bronze Age (3500–2500 BCE) in the eastern European steppe is marked by a clear change in funerary traditions. Until 3100/3000 BCE,

38 Bernbeck and Pollock 2016, 73–75.

only a small number of graves are observed, and they exhibit highly variable constructions and burial rites. They are attributed to different archaeological cultures. After 3100/3000 BCE, pit graves with very homogeneous features were built under or in burial mounds, and the number of burials increases enormously in comparison to the Aeneolithic. But longstanding traditions can also be observed. The first grave mounds were already erected in the 4th millennium BCE, but only in the 3rd millennium BCE did they became ubiquitous in this vegetation zone.

3.1 Short-term processes

As was also pointed out for Monjukli Depe in southern Turkmenistan, the short-term scale has often been ignored in archaeological research on the Aeneolithic and Early Bronze Age in the Eastern European steppe. This is quite astonishing, as burials are the main element of the archaeological record in both periods and they have been investigated intensively. One can look at each burial as the result of a short-term process, at least when post-interment activities lasting over a longer period can be excluded. We discuss in more detail the changes in burial rites and grave constructions observed in a burial mound that was used for several generations as an example of medium-term processes. For now, each grave can be understood as a sequence of events: a ceremony of interment of the deceased and the closing of the grave – sometimes covered with an earthen layer or tumulus – perhaps followed by several post-burial rituals. The excavated graves reflect only a part of these events. They have mostly been investigated from a purely analytical point of view in order to classify and date them without trying to reconstruct a concrete burial ceremony.

In our current project, we examine subsistence strategies and lifestyles of the inhabitants of the steppe. In the 3rd millennium BCE, subsistence was based on specialized cattle breeding in the Eastern European Steppe zone, with seasonal cycles determined by the search for good pastures. The differences between summer and winter residences can be reconstructed with the help of isotope analyses.[39] The residential shifts perceived by an individual at that time may have been more regular than was the case in the second half of the 4th millennium BCE, when different subsistence strategies were used. A more flexible exploitation of environmental resources can probably be assumed for groups living in the 4th millennium BCE in the same vegetation zone; thus, people might have changed their resource strategies several times during their lifetimes or even within one particular time span in their lives.

As subsistence strategies might be reflected by the food people consumed, Simona Mileto conducted residue analyses of pottery with the aim of identifying changes in the

39 Gerling 2015.

use of vessels and to investigate the foods that were cooked in them.[40] In addition to changes in the human diet, which she investigated diachronically using the conventional division into Late Aeneolithic and Early Bronze Age and also spatially (forest steppe and steppe zone), it is possible to study changes in the life of a pot. All analyzed fragments of ceramic vessels were found during excavations in settlements in the basin of the river Dnieper. Some fragments exhibited residues from different sources, indicating that they were used for cooking different kinds of meals. This might lead to a new understanding of the use of pots, since at least some of them were not restricted to specific tasks such as the preparation of milk, meat (of a specific species), or fish, but rather were used for several of them. This can lead to questions of whether they were used by only one person or by several, for how long, and how often.

3.2 Medium-term processes

The Eastern European steppe settlements of the 4th and 3rd millennium BCE are poorly investigated and mostly of ephemeral character. Especially for the 3rd millennium BCE, however, a large number of burials in mounds have been excavated. With the help of well stratified sequences taken from graves within a single burial mound, which have been verified through radiocarbon dating, it is possible to analyze the differences among graves of one specific archaeological culture. At a burial mound known as Sugokleya, excavated near the city of Kirovograd, despite the generally very similar construction of Yamnaya culture graves and comparable burial rites, certain differences do appear.[41] According to the results of radiocarbon dating and a small number of dendrochronological analyses, some of the graves were dug into the existing burial mound one by one over a relatively short span of time (3000–2800 cal BCE, or ca. 6–8 generations). This must have been the result of a medium-term routine. Although the grave structure and burial rites associated with these interments are directly comparable to one another, two of them contained parts of a wagon with disc wheels, and in one of them there was also a dugout. The radiocarbon date of grave 16 shows that it was erected around two centuries later than the other chronometrically dated burials of the Yamnaya culture in the Sugoklaya Mound. How are we to explain these similarities and differences? How were changes in the communities that buried these people reflected in changes in burial rites, the accompanying objects such as wagons and differences in grave construction? Were the burials in this mound deposited continually by one and the same social group, or were there temporal interruptions or use by others, and what might be associated with changes of that kind? We have just begun to explore the answers to these questions.

40 Mileto 2018.

41 Nikolova and Kaiser 2009.

3.3 Long-term processes

It is interesting to note that up to today there is no agreement on the extent to which a real division can be made between the Aeneolithic and the Early Bronze Age in the Eastern European Steppes. Nikolai Ya. Merpert assumed a continuous development, assigning the early Aeneolithic groups to the Yamnaya culture on the basis of certain characteristics of burial rites, such as the flexed position of the bodies, the use of ocher, and the construction of burial mounds.[42] In contrast, Dmytry Ya. Telegin distinguished a Srednyi Stog culture for the Aeneolithic north of the Black Sea and claimed that the Yamnaya culture could only be discerned as fully developed in the Early Bronze Age.[43] This caesura was also accepted by Yuri Ya. Rassamakin.[44] However, he distinguished between different burial traditions within the Aeneolithic (4500–3100 cal BCE) and regarded these burial customs partly as a characteristic of specific archaeological cultures.

In recent investigations, changes in subsistence strategies from the late Aeneolithic to the Early Bronze Age have become more and more evident and can be differentiated with reference to archaeozoological,[45] but also to stable isotope data[46] and organic residue analyses.[47] Unfortunately, preservation and the state of research on the settlements in Eastern Europe are still too limited for changes in the patterns to be detected. Changes in the subsistence economy seem to happen more or less at the same time as fundamental changes in the funerary sphere start to appear. As already mentioned, the number of burials increases after 3100 cal BCE in the steppe zone, the interments were mostly connected with a burial mound, and the grave constructions and burial rites became more and more homogeneous. But can we suppose any interrelation between changes in subsistence economy and the funerary sphere? And if so, how can we understand that relationship?

4 A hermeneutic approach to multiscalar time

As discussed throughout this paper, multiple time scales can be measured in the external, objectivized time of archaeological research: calculated in calendar years via probabilistic radiocarbon dates and their modelling into stratigraphic-sequential time series. However, we argue that an internal view of time needs to complement this external one. In archaeology, subjective and objective temporalities stand in a mutually constitutive relation, since the perception of time and its material manifestations led to historically

42 Merpert 1974.
43 Telegin 1986.
44 Rassamakin 1999; Rassamakin 2004.
45 Kaiser 2010.
46 Gerling 2015.
47 Mileto 2018.

specific human actions in the past. These actions resulted, in turn, in materializations of routine or singular practices, producing a culturalized landscape.

A problem that emerges in investigating subjective ('emic') time for societies without writing is the difficulty of knowing about the modes in which time was conceived: linear, cyclical, concentric, pendulum-like, or variable in different spheres of life.[48] Here we briefly explore Koselleck's notions of a 'horizon of expectation' and a 'space of experience' within which human activities are located, viewed from a present moment. Neither expectations, nor experience imply temporal linearity in terms of an arrow of time from a limitless past to a limitless future, as in materialist Western conceptions, nor do they depend on any other specific temporal mode. However, horizons of the future and spaces of the past potentially include scalar differences.

Koselleck stands in a tradition that approaches the past phenomenologically, analyzing perceptions and their linguistic expression. For prehistory, we are restricted to non-linguistic elements that are apprehended through the senses. Traditionally, phenomenological approaches in archaeology have been cast in static terms. Tilley's analysis of past worlds as sets of bodily perceptions describes states of color, tactility, movement, and so forth.[49] We attempt to insert the potential of temporal change into such perceptual universes. This can be accomplished via Koselleck's abstract temporal vocabulary of horizons of expectation and spaces of experience. While research on the particularities of a single case may produce some insights, the full potential of such a phenomenological and temporally sensitive approach comes to the fore in comparative analysis. For illustrative purposes, we draw again on the two case studies of Monjukli Depe and the Eastern European steppe region.

Both of these landscapes consist of plains, one with mountains to the south, the other with the Black Sea as its limit. Both included stands of low-growing shrubs, in the case of Turkmenistan, mainly tamarisks, in the Eastern European, feather grass steppe. Both plains were also dotted with mounds. In southern Turkmenistan, some but not all of these mounds were topped by villages and, in later times, cities, while in the steppes of Eastern Europe, the mounds rose above a steppic environment of mobile camps and were not covered by large population agglomerations.

On a purely visual level, the difference between the two regions is not radical. The mounds were surely known to be related to human activities and may have had the status of place markers for orientation, whether purely geographic, group-related, or other. However, the initial practices that led to the emergence of these elevations above the plain were markedly different in the two regions. In the Eastern European steppes, the mounds were primarily the result of massive tomb constructions. As burial mounds, they were not necessarily built at one point in time and then left in the landscape as

48 Reinhold and Hofmann 2014.

49 Tilley 1994.

symbols of a deceased individual. Rather, they were frequented continuously, to add another grave or another layer of earth, therefore, increasing their height and size. Still, the initial construction and enhancement of such mounds were rare events in the long-term history of the European Steppe. In contrast, mounds in southern Turkmenistan developed gradually through the act of living there, constructing houses and other buildings out of mud and mud brick, and discarding rubbish. Over time, they became visible features, but they were not planned with that in mind. As topographic elevations in the landscape, they would have grown almost imperceptibly in terms of individuals' perspectives.

We might then ask, what was the 'horizon of expectations' connected to such mounds? To answer this question, we need to consider different moments in their history. At the point of building a *kurgan*, there was an expectation oriented towards the immediate future, namely to bury one or several people with grave goods and to erect a mound of earth on top. The design of such mounds led to expectations that they would have a shape and a height comparable to, greater, or less than other mounds. There was, thus, a relatively narrow horizon of expectations bound up with practical actions of erecting a grave mound. These actions relied on different scales of experience. On the one hand, people contributing to the construction must have had the necessary bodily, conceptual, and organizational skills to produce the mound. This may sound trivial, but when considering the placement of a burial within a mound, the decisions about how to organize the construction, the slope and the height, not to mention ritual actions that may have taken place alongside the physical labor, it is clear that such a task of communal labor was far from an easy endeavor.

In the realm of decisions over design, we encounter a different scale of experiential spaces. People in the Eastern European steppes were accustomed to a landscape of burial mounds, and the additional one they were erecting certainly included conceptual comparisons with others in the region: should a particular one be larger, flatter, or differently shaped? This matter also involved 'personalized time': the mound to be constructed was for one (or a select few) person(s), and the comparative scale included knowledge that other mounds originated in similar considerations and events. Thus, the space of experience included the notion that a mound stood for a person, even when the particulars of that person had been lost in the mists of time. Starting to produce a new mound must have set in motion an intense process of collective memory that led to the remembrance of individuals or ancestors who were entangled in a complex mounded landscape.

Mounds in the Eastern European steppe display a dimorphism of experiential time. A short-term horizon of construction time in which instrumental reason and know-how played the main role is clearly separate from a long-term horizon of expectations, in which a person-mound-complex will be remembered in the future. This adds a new

relation to an already complex network of materially symbolized landscape relations. Remembering, itself, belongs to the realm of experiences, and the erection of a mound may be described as a projected experience.

The mounded landscape in southern Turkmenistan is quite different in these respects. Mounds there did not emerge out of momentary actions, but rather from continuous quotidian practices that derived from the tradition of living in one place over generations. People who moved about in the strip of land between the Kopet Dag mountains in the south and the Karakum Desert to the north were surely aware of the fact that mounds of a certain shape were the result of human activities, mainly the construction and decay of houses, plus the accumulation of debris from daily life. They were the result of decades, if not generations, of life at one spot – whether those occupations were continuous or episodic. It is possible that the reason for their existence was the search for a safe spot against flooding. When houses dotted the top of an early Aeneolithic mound, it is likely that a visitor would have known whose they were, since recent analyses suggest that seasonal movements away from a settlement were of limited frequency and distance. An abandoned mound was a sign of leaving a living space, in contrast to the European Steppe example, in which a mound meant the occupation of a place (in death) by a specific individual or small number of individuals. An outsider's knowledge about a mound in southern Turkmenistan was most likely less explicitly discursive than in the Eastern European steppe: on the one hand, inhabitants were known not as buried individuals, but rather collective occupants and, on the other, it was a matter of course that the customary habit of living in one place would slowly create a mound. However, the sight of an uninhabited mound as opposed to an inhabited one would likely have led to a consideration of the reasons for abandonment.

The relations between moments of action and inaction at mounds in the Kopet Dag piedmont zone is the reverse of that in the Eastern European Steppe. Abandonment of a mound – halting its imperceptible daily growth – marks the beginning of a relatively steady, long-term state. Abandonment was the result of a move to a different place. At the time of a move, the concrete content of past actions and people associated with them at a particular place, likely involved an expectation of forgetting, but without a specific idea about when it would set in. At Monjukli Depe, where there are indications of a hiatus lasting some 800 years after the Neolithic occupation, this abandonment was, in experiential terms, an abandonment *forever.* No specific memories connected to individuals or events at the old place were likely to be associated with a re-occupation after such a long abandonment.

There must have been frequent encounters with a variety of abandoned mounds in the plains north of the Kopet Dag. They could have been accompanied by the knowledge that there was once a group that lived there, carrying out its quotidian practices, but most likely without more specific notions of who they were.

	Eastern European Steppe	Southern Turkmenistan
	A c t i o n	
Horizon of short-term expectations	Construction of mound (addition of layers, burials)	Abandonment of settlement mound
Long-term expectations	Remembrance of individuals or lineages	Quotidian recursive practices

Tab. 1 Different shapes of landscapes.

In comparison, the shape of landscapes, while not fundamentally different in these two regions, was likely dominated by a 'political mapping' of (in)equalities in the case of the Eastern European Steppe, and by a completely different 'ecological mapping' of dwelling safety in the case of southern Turkmenistan.

5 Summary

We started this paper with a discussion of the relationship of political ecology and resilience, in order to highlight the relevance of a differentiated understanding of temporalities for both of these approaches to space/time processes for past human societies. This entry point led us to argue for a comparative approach to temporalities in archaeology that takes the complexities of temporal scales, degrees of recurrence, and multiperspectivity into account. Our approach is not conducive to a systematic manner of dealing with temporalities in archaeology. Despite the fact that time is one of the most obvious and oldest pre-occupations of archaeology as a discipline, the complexities of various temporalities have yet to be dealt with adequately. Our goal here has been to show some of the problems that arise when attempting to give a nuanced account of (pre-)historic change, rather than providing clear solutions.

A question of major theoretical and empirical importance is how dispositions and the routines they engender – that which makes up the everyday lives of most people most of the time – change. Examples from southern Turkmenistan and the Eastern Eurasian steppes offer some first steps toward unraveling some of the ways in which such changes came about.

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Material and Cultural Aspects of Water Management

Summary

Water is a precious natural resource and at the same time very important in many social and technical dimensions. Research questions and problems concerning water mostly deal with water management, and the dimensions of this management include water availability, water technology, and social organization. The respective research problems are, therefore, inter- or multi-disciplinary, requiring holistic approaches.

Keywords: water availability; water technology; social organization; irrigation; water conflicts

Wasser ist eine der wertvollsten natürlichen Ressourcen und zugleich wichtig in vielen sozial- und technischen Bereichen. Fragen und Probleme im Zusammenhang mit Wasser beschäftigen sich meist mit seinem Management. Die Dimensionen des Wassermanagements sind: Wasserverfügbarkeit, Wassertechnik und soziale Organisation. Die jeweiligen Forschungsprobleme sind also inter- oder multidisziplinär und brauchen ganzheitliche Ansätze.

Keywords: Wasserverfügbarkeit; Wassertechnologie; soziale Organisation; Bewässerung; Wasserkonflikte

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1 Objectives

Water management is a broad topic, with a variety of disciplines and agendas dealing with issues concerning water management. The research presented here is dedicated to interdisciplinary research into water supply in the Mediterranean region and the Near East in time periods ranging from the Bronze Age to the Middle Ages. In addition to creating an inventory of, classifying, and mapping water management structures and technologies, we also examine the legal basis for water management and investigate the impact of environmental and social changes on it.

This research focuses on different issues related to water management at various time and spatial scales, following the definition of Scarborough: "(…) *water management is the human interruption of the natural water cycle undertaken by a society*".[1] The socio-ecological model introduced by Fischer-Kowalski et al. in 2011 builds an appropriate theoretical background to describe the complex patterns between the natural environmental conditions and their technical modification to improve settlement conditions interaction between nature and material culture, (see the section on material culture below) and the social, governmental, and legal interactions resulting out of it and required for it (interaction between culture and material culture, see the section on material culture below).[2]

Water management has three dimensions (Fig. 1):

1. water availability,

2. water technology, and

3. social organization.

Water availability refers to natural water sources. The primary water source is precipitation and its subsequent surface or groundwater runoff. It is important to note, that the specific climatic conditions, hydrological regime, and landscape and catchment characteristics make water availability a dynamically changing and manifold process.[3]

Water technology refers to all technical measures of water management, specifically: (1) wells and springs, (2) open and closed canals, (3) open and closed reservoirs, (4) temporal and permanent dams, and (5) water lifting devices.[4]

1 Scarborough 1991, 1.
2 Fischer-Kowalski, Mayer, and Schaffartzik 2011.
3 Horton 1945.
4 Hanaki 2011.

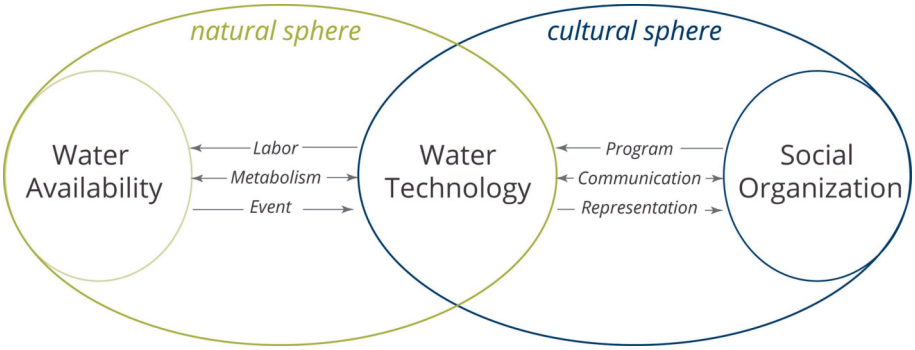

Fig. 1 Integration of the three dimensions of water management adopting the systemic model of Fischer-Kowalski and Haberl 1998.

Social organization, with respect to water management, refers to the way in which water is shared, provided, and used among individuals and groups. Often societies develop, or have developed, special governance structures to regulate water as a resource.[5]

2 Material culture

The availability of water is an indispensable precondition for any settlement activities. Thus, water supply is a crucial part of many cultural activities. Especially in dryland regions, where freshwater is a scarce resource, the population is highly vulnerable to weather conditions and extreme events, especially droughts. In such regions, the implementation of technical measures to control, store, and distribute runoff increases the resilience of the societies.[6] The technical knowledge about water management is represented by water technology. Specific water technologies, no matter whether it is a pump or an aqueduct, represent a specific connection between the humans who invented and used them and their environment. These technical measures can be referred to as artifacts, because they are man-made materials (bricks, mortar, etc.) and they incorporate a specific technical knowledge that references the time they were implemented in and the culture they were shaped by and/or implemented in.

The control, storage, and distribution of water requires different technical devices that will be presented via examples in the following paragraphs. The specific techniques are classified as (a) interaction between nature and material culture or (b) between culture and material culture (Fig. 1).

5 Schlager and C. Bauer 2011.

6 Beckers and Schütt 2013.

Fig. 2 Left – one of the most common water harvesting methods used is agricultural terraces; right – an agricultural terrace with olive trees, North-East Andalusia.

3 Interaction between nature and material culture – examples of technical measures

3.1 Water harvesting techniques

Water harvesting measures are devices or techniques that collect, store, or increase the availability of intermittent surface runoff and groundwater – mostly utilized in drylands and areas with a seasonally negative water balance (Fig. 2). Water harvesting is applied to irrigate crops and to supply water for animal and human consumption, or for other beneficial uses.[7] Commonly, these techniques are distinguished by the source of the water harvested and are called *groundwater* harvesting, *runoff harvesting,* or *floodwater* harvesting. They are often referred to as *traditional*, which means they are based on the knowledge, innovations, and practices of indigenous or local communities.[8] These practices imply effective or, at best, sustainable schemes of human-environment interactions.[9]

3.2 Water lifting devices

The main ancient water lifting devices are the shaduf, the waterwheel, the bucket-chain, the Archimedean screw, and the force-pump; the most commonly used waterwheel can be subdivided further into different types of waterwheels, for example, the saqiya.[10] These technologies were generally used to lift water either from rivers, wells, reservoirs, or groundwater. In addition to their main field of application – the raising of water for agricultural purposes – they also served as dewatering equipment in Roman mines in

7 Beckers and Schütt 2013.
8 Simon 2011; Hussain, Husain, and Arif 2014.
9 Beckers and Schütt 2013; Berking, Beckers, and Schütt 2010, 815–836; UNESCO and Earthscan 2009.
10 Oleson 1984.

Spain[11] or for waterwheels, for gaining water power, as exemplified by some of the most innovative devices in antiquity, the water-mill and the water-powered stone saw.[12]

The systematic investigation of such devices in order to reconstruct the chronology of their appearance in relation to the geographic regions over which they spread, furnishes insights on different levels. This concerns, first of all, the relationship between the ancient processes of appropriation of technological innovations. This is related, on the one hand, to the hydrological conditions of the regions in which specific devices were in use and, on the other hand, to specific cultural factors. An example of the specific cultural factor is the installation of elaborate bucket-chains in Pompeian baths in order to provide enough water despite the low groundwater table.[13]

Another level regards the diffusion of technological knowledge over time and space by using the example of water-lifting devices. In addition, the new and novel study of ancient water technology by means of a geoarchaeology approach has recently become more common.[14] The lime incrustations (calcareous sinter) from Greek and Roman water mills can provide material for investigating palaeo-environmental conditions during classical antiquity. This approach may create a new gate for scientists to study the Roman economy, by tracking water mill activities.[15]

3.3 Wells and reservoirs – the example of Greek Public Baths

Water management is crucial to the operation of bath buildings, but it has barely been studied for Greek baths. This approach examines the availability, distribution, use, and drainage of water in Greek baths, and the impact that water management had on the development of an increasingly sophisticated bathing culture in the Hellenistic period. It is based on a catalog of all known Greek bathing facilities in the entire Mediterranean, on an intensive study of selected sites, and on excavations of a Greek bath building in Sicily (Morgantina, South Baths, 250–211 BCE), and of Roman bath buildings in Pompeii (Republican Baths, Stabian Baths, 2nd century BCE to CE 79, see Fig. 3) that are comparable with many of the Greek baths. Before the late 1st century BCE, Greek and Roman bath buildings commonly were not supplied with running water by pipe systems, but only by wells, cisterns, and reservoirs. An exception includes the few large pools appropriate for swimming. Located next to rivers or close to springs, these pools were most likely continuously fed by running water from the rivers and springs and, thus, were conceived as flow-through pools.

11 Wikander 2000.
12 Mangartz 2010.
13 Eschebach 1979.
14 Sürmelihindi 2013; Sürmelihindi et al. 2013.
15 A specific database and further material concerning the diffusion of ancient water technologies in the Mediterranean basin is available under: https://drupal.mpiwg-berlin.mpg.de/watermachines/ (last visited 13.03.20).

Fig. 3 Photo from Pompeii, the Stabian Baths Water Reservoir.

While the early public baths provided only simple bathing forms that did not require much water (hip-bathtubs for cleansing shower baths), from 250 BCE onwards, some baths were equipped with bathing forms that used lots of water (immersion bathtubs and pools for relaxing baths), constituting a quantum leap in the concept of bathing. This development should be reflected in the water management of baths, notably an increasing sophistication of supply systems.

The few sufficiently known water management systems of Greek baths do not support the notion of a simple linear development, however. According to recent research, the earliest known Greek bath building in Athens (Dipylon Bath, 2nd half of 5th century BCE), with 20 simple hip-bathtubs, was already supplied by a well and a system of three underground cisterns, interconnected by tunnels.[16] In contrast, the South Baths in Morgantina (ca. 250 BCE), with a highly sophisticated bathing program (15–18 hip-bathtubs and a large collective heated immersion pool), were only provided with a large reservoir that was fed by rainwater from surrounding roofs. Written sources (Hellenistic period) testify that public baths sometimes could not be operated because of a lack of water, and the archaeological evidence confirms that not all baths were provided with diversified water supply systems that granted (or at least facilitated) year-round operation. While safe evidence of sophisticated water lifting devices (*shaduf*, waterwheel, and

16 Stroszeck 2014b; Stroszeck 2014a.

Archimedean screw) is still lacking for Greek baths, ongoing research in the better preserved Late Hellenistic baths in Pompeii may provide further insight into contemporary practices for baths, regarding both the lifting and – crucial, but commonly neglected – distribution of water within the building. Finally, a planned interdisciplinary field study of a well-preserved important example (e.g. Olympia, see Fig. 3) may allow us to reconstruct in more detail the catchment, available quantity, distribution, and use of water in public baths.

For now, research of both Greek and Roman baths confirms that after the introduction of relaxing bathing forms in the 3rd century BCE, another quantum leap in the development of the bathing culture did not occur before the systematic introduction of urban public water pipe systems from the Augustan period onwards (earlier urban pipe systems, e.g. in Archaic Athens or Hellenistic Pergamon, did not safely serve to feed baths). Only then were baths provided with large cold water pools (frigidaria, natationes) and with an increasing number of warm water pools.

4 Interaction between culture and material culture – examples of societal and administrative measures

4.1 Roman water law

Our knowledge of Roman law adds to the understanding of the control assumed by authorities, as well as by individuals, over a common natural resource. It is the framework and the basis for a peaceful use and conflict management.

With its high concern for private and public interest, the legal thought of the Roman period offers compelling insights into Roman conceptions of the relationship between man and the natural environment, whether people make use of their natural environment (e.g. irrigation infrastructures) or have to protect themselves from it (e.g. droughts and floods).

4.2 Large-scale irrigation networks – the example of ancient Mesopotamia

Early Mesopotamian societies were essentially agrarian. In the North and in the piedmont regions of the Fertile Crescent, annual precipitation allowed for rain-fed or dry farming. In the southern alluvial plains along and between the Euphrates and Tigris rivers, agriculture, in principle, was based on local forms of irrigation.[17] In the 3rd millennium BCE, larger regional and cross regional irrigation networks were established.[18]

17 Bagg 2012; Wilkinson 2013.

18 Nissen 2016.

These systems were triggered by two coinciding factors: (1) a substantial growth of the population in the southern plains and (2) decreasing water levels due to the late 4th millennium BCEE climate event. Textual sources from the area provide deep insights into the technical and social changes involved in the implementation of these large-scale irrigation networks. This configuration of data is used to test Fischer-Kowalski's model of *social metabolism* under the conditions of fragmented historical evidence.[19] The historical perspective allows for a SWOT (strengths, weaknesses, opportunities, and threats) analysis, i.e. whether the model is accurate regarding systemic interdependency and the consequences for Mesopotamian society.

The set of data used relates to the petty-state of Lagash (ca. 2475–2320 BCE), a cluster of four major cities including their hinterlands situated along the Tigris.[20] Commemorative inscriptions name the construction of canals and weirs as part of royal building activities[21] and the regulation of inter-state conflicts about water.[22] Whereas these sources relate to the implementation and maintenance of large-scale irrigation networks, the smaller waterworks are referred to in administrative texts found in temple-archives. Besides its religious functions, the Sumerian temple was primarily a socio-economic institution that owned huge tracts of agricultural land, provided for the population through subsistence economy, and was subservient to the king.[23]

Both groups of texts show the huge amount of labor, knowledge, and planning invested regularly in the irrigation facilities by the Sumerian society. The professionalization of water-harvesting technologies is mirrored in the technical vocabulary: from the river water flowed to '(main) canals' (Sumerian i_7), regulated by 'weirs' (ĝeš-keše$_2$-ra$_2$), to the '(primary or secondary) off-takes' (pa$_5$); here, the water was directed to ditches raised on 'dikes' or 'levees' (eg$_2$) and distributed by 'regulators' (kab$_2$-ku$_5$/tar) to 'furrows' (absin$_3$) in the fields.[24] Local works, i.e. construction and maintenance of dikes surrounding fields, and regulators, were organized by the heads of the temples who could call upon corvee troops,[25] i.e. the upper class of the temple dependents, including the militia and prebend holders obliged to take part in irrigation works in exchange for subsistence fields (Fig. 4).[26] The construction of large-scale irrigation networks such as main canals and weirs, in contrast, was the king's duty who drew on the corvee troops of the various temples and is exclusively reported in royal inscriptions. The bipartition of responsibilities perfectly reflects the dichotomy between the palace (i.e. the king) and the temple.[27] The installation of large-scale irrigation networks demanded a centralized

19 Fischer-Kowalski, Mayer, and Schaffartzik 2011.
20 For an extensive study of these source see Schrakamp 2018; Schrakamp 2021.
21 Laurito and Pers 2002.
22 Bagg 2002.
23 Schrakamp 2013.
24 J. Bauer 1973, 9–15; Civil 1994; Dight 2002; Hruška 1998; Steinkeller 1998.
25 Maeda 1984; Steinkeller 1998.
26 Schrakamp 2014.
27 Schrakamp 2013.

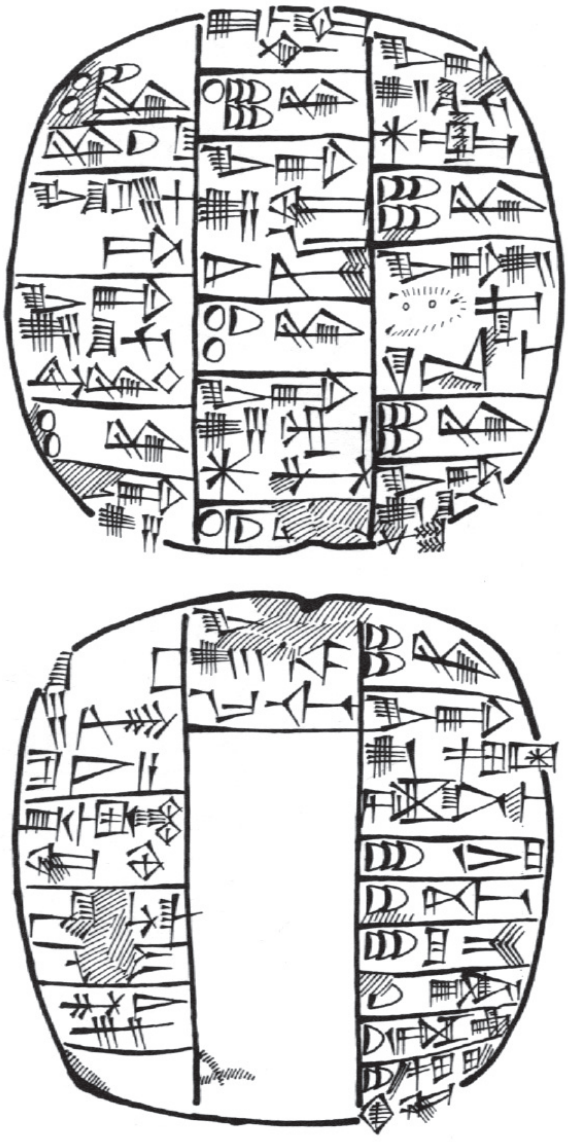

Fig. 4 Old Sumerian administrative texts recording assignments of the work quota for corvee workers of a temple household from ancient Girsu (Tello), South Iraq, ca. 2325 BCE .

authority.[28] Since the construction of main canals is almost exclusively referred to in the inscriptions of the first rulers, we may assume that the implementation of the first large-scale irrigation network throughout the state occurred shortly after its political unification.

28 Nissen 2016; Rost 2011; Wittfogel 1957.

The lack of earlier, i.e. pre-Lagashite, textual evidence for irrigation as a social undertaking has been explained as being due to the earlier writing system that does not differentiate between rivers, main canals, and off-takes.[29] However, administrative texts pertaining to large-scale irrigation networks are likewise lacking in earlier periods. Accepting the hypothesis that "technical terms only become necessary when the object described becomes important enough to be addressed unambiguously",[30] the texts from Lagash most probably document the implementation of (one of) the earliest full-fledged irrigation networks in Sumer.[31]

In terms of Fischer-Kowalski's *social metabolism,* the implementation of large-scale irrigation networks corresponds to the *cultural program* that addressed the *impact* of decreasing water levels and population growth. The assignments of labor documented in administrative texts reflect the *input of energy* required for the sustenance of the metabolism. However, the texts supply additional sets of data that are not operative in the model, i.e. the dynamic factor provided by socio-economic, political, and 'ideological' frames. The *power* exerted by these frames explain that water management becomes a major cultural technique, reflected in laws and judicial regulations concerning the usufruct or misuse of water;[32] technical solutions, including the dislocation of rivers and aqueducts;[33] and in complex belief systems centered around water. Studies of cuneiform sources from various periods allow us to more closely investigate the role of water as part of the *social metabolism* of Mesopotamian societies. A major problem to be tackled when historizing the model, concerns the balance of knowledge linked to time-tested methods of water management and the incentives that lead to the implementation of new solutions.

4.3 Water clocks

At first view, the invention and establishment of the water clock in Egypt and the passing on of this device seems to display one of the best documented developments in the history of ancient technology. We not only possess knowledge about this center, in terms of a description by the inventor himself in his grave inscription, it is also possible to compare and contrast nearly 30 preserved, more or less complete Egyptian, Hellenistic, and Roman water clocks (as well as an Arabic manual), distributed over more than 2500 years and found all over the Mediterranean (as well as examples pictured in the grave chambers of Ramesside Pharaohs). They represent the largest preserved collection of water clocks – in terms of specimens, depictions, and descriptions – from antiquity in general (Fig. 5).

29 Civil 2013; Krebernik 2007; Veldhuis 2006.
30 Nissen 2016, 93.
31 Schrakamp 2018; Schrakamp 2021.
32 Arnaud 1982; Bagg 2002.
33 Bagg 2000; Bagg 2004.

Fig. 5 Sketch of an Egyptian Water clock.

As the first man-made clocks, they can be interpreted as the forerunners of all modern time measurement. While they seem to be quite simple devices, they nevertheless show the application of a profound knowledge of hydrodynamics, respectively, Torricelli's law, more than 3000 years before it was even stated. By using the shape of a truncated cone, its inventor succeeded in stabilizing the outflow rate of the water, since the diminished circumference provides for a constant outflow. As a consequence, time can be easily read by a sinking water level against hour scales within the vessel.

To construct a vessel of such a specific shape and to build accurate scales, both working together in order to measure time precisely, was an outstanding achievement. Unfortunately the history of the water clock can serve as an example of one of the most misunderstood advances in the history of technology itself. Due to the fact that there seemed to be no fundamental progress since the study "Altägyptische Zeitmessung" by Ludwig Borchard,[34] who doubted their proper functioning profoundly, a reconsideration is overdue.

In this regard, a new and more complete collection of the material is fundamental. Considering the distribution of the preserved examples in museums all over the world, and their fragmentariness, modern technology offers a new approach for investigations. 3-D-scans of preserved water clocks are used to measure, analyze, and reconstruct these genuine testimonies of ancient technology in detail, with reference to their development, functionality, and purpose in a previously unique way.

34 Borchardt 2013.

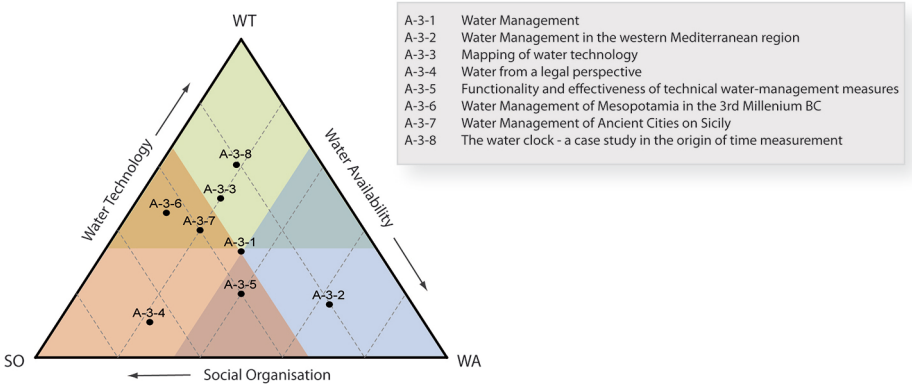

Fig. 6 Classification of different research approaches in a water management triangle. The triangle represents the three dimensions of water management on each edge, with increasing importance to their corresponding corners. Left – the dots correspond to specific projects and their research priorities on: Water Availability (WA), Water Technology (WT) and Social Organization (SO); right – table of the depicted research projects. (Further information on the specific projects can be found here: http://www.topoi.org/group/a-3/).

5 Research approaches

The aforementioned examples of techniques or approaches can be grouped or classified in a way that is analogous to the main entities of water management with (a) water availability corresponding to the 'natural' background, (b) water technology corresponding to the 'material culture', and (c) social organization corresponding to the social, governmental, and legal 'program' of a society to run the technical measures. The authors' research background of the given examples is now combined with the respective proportion of *a, b,* or *c* (Fig. 6).

5.1 Material world/material metabolism

The utilization and regulation of water constitutes a 'nature and society' interdependency. Both, humans and the environment interact with each other, are integrated entities, and should be treated holistically, requiring interdisciplinary approaches in the respective research projects. The systemic approach of this social-ecological metabolism is introduced in chapter 1 of this volume.

The fact that humans depend on water and nutrition results in efforts of individuals or groups to obtain them. However, nutrition requires a certain amount of energy to develop, which is provided by the sun. Water and nutrients are needed for plant growth and, subsequently, animal growth. The water is provided by the hydrologic cycle and nutrients are provided due to weathering and erosion processes – both are driven by solar

energy and require water as an agent.[35] Beyond this, humans employ a certain amount of energy to harvest and process agricultural products. In this sense, human activities are represented by artifacts that, in the case of technological water constructions, serve to control, store, and divert naturally available water for certain purposes.

This is illustrated with the example of the construction of a dam (Fig. 7). Dams are one of the most prominent examples of hydraulic engineering and water technologies. They have been constructed in various dimensions, to serve different purposes, at least since the Bronze Ages.[36] To typecast dams, it is possible to distinguish between dams that (1) either store water permanently or (2) store water temporarily. Dams for temporary storage are those that block runoff only to a certain extent or for a certain time span; examples include weirs, check dams, or terraces. The permanent dams correspond to river dams and their respective reservoirs, which serve to impound the total amount of water of a stream and release it or provide it in relation to demand. The construction of an idealized dam requires a lot of energy and technological knowledge. The energy required for building a dam can be described as labor; contrariwise, the energy produced by runoff is now impounded and can be released when it is required (e. g. for water mills). Consequently, the dam will have an impact on the environment. The temporary water surplus due to storage can be described as a positive metabolic gain. During the time of dam construction, the costs and energy (labor) required typically leads to a negative balance compared to the original status. Once the dam is built, the society has to organize continuous communication in order to spread the knowledge of how to maintain it, and to preserve the new metabolic level. This is part of the new level of metabolism. The example of the construction of a dam, thus, illustrates the concept of a changing metabolism, differentiated into: (1) an initial stage, with a demand for (surplus) water; (2) the construction phase, with a large energetic effort and advanced technological knowledge being required; and (3) the 'in operation' phase, in which the labor is punctually high and the knowledge must be preserved and communicated, e.g. from one generation to the other.

The example of the Argolid, Greece, documented by van Andel et al., nicely shows that the continuity of knowledge about the implementation and maintenance of technical measures, in this case agricultural terraces, builds the precondition for sustainable land use.[37] If this knowledge gets lost, e.g. through the displacement of an ethnic group or culture as a consequence of a war, the measures stop functioning until the knowledge is established again. In a similar way, Roth et al. document that the transfer of technical knowledge and governance structures – including adaptations to changing cultural demands – might provide a functioning water management system for centuries.[38]

35 Brantley et al. 2011; Schmidt 2014.
36 Viollet 2005.
37 van Andel, Zangger, and Demitrack 1990.
38 Roth et al. 2015.

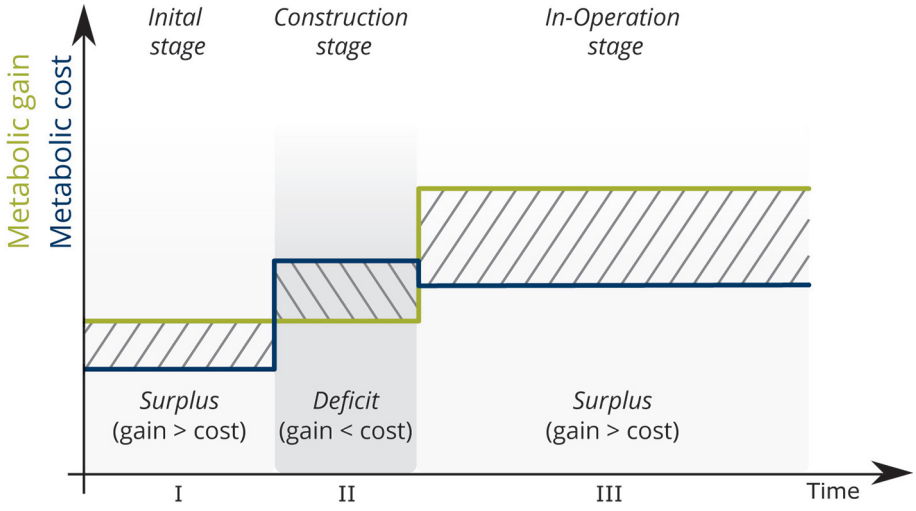

Fig. 7 Metabolic costs for the construction and operation of a dam.

5.2 Immaterial world/metabolism

The management of water is a dynamic process, as it always has to adapt to changing situations, such as temporally and spatially changing water availability and water demand, technical innovations, and changing societies. The dynamics of natural water availability depend on the physics of the earth and the atmospheric circulation that control precipitation and, thereby, river discharge and groundwater flow.[39]

Today, irrigation accounts for the largest part of global freshwater domestic consumption (~70 %), and industrial use makes up the remaining 30 %.[40] Beyond these numbers, water serves different purposes and inherits several immaterial connotations. Economically, water is part of nearly every industrial process. Water has a sacred character in almost every culture or religion. Water is vital for recreational programs and is often associated with status, prestige, and/or power. Already, this short enumeration reflects the important roles water plays in every society. It, thus, becomes evident that only integrated concepts that acknowledge the interdependent character of water can help to comprehensively manage it.

In addition, the management of water depends on the character of the available water. Water has an especially high potential for conflicts in times of water scarcity, whether this is due to low rainfall or droughts, poor technical realizations, or gover-

39 Oki and Kanae 2006, 1068–1072.

40 FAO (Food and Agriculture Organization of the United Nations) 1993.

nance and communication failures. This phenomenon leads to prominent, present-day headlines like "Water Wars".[41]

By integrating the two aspects, water inherits both an unstable character and a tendency for conflicts among users. Due to this, a functioning water management system that satisfies all users and suppliers is rarely found. Examples inheriting both the (un-)stable character and the conflict potential of irrigation schemes in semi-arid landscapes are often employed. Examples of stable conditions are: (1) the long discussed governance structures, often called hydraulic civilizations, from Mesopotamia; (2) the vast technological inventions in water supply and delivery techniques by the Romans; and (3) the advanced community based water distribution systems of the Arabs that still partly function today.[42]

The latter case exemplifies that a social (water management) system is most stable when based on prolonged communication; may it be via rules, laws, governance structures, or autarkic institutions. All this communication is represented in cultural values, traditional or technical knowledge, and the affiliated artifacts.

6 Concluding remarks

The socio-ecological concept of Fischer-Kowalski fits reasonably well the aspects and structures of water management.[43] In our case, the 'natural environment' is represented by the hydrological sphere and the 'interaction' is represented by the *management*. Societies perform water management to meet their demands (i.e. water supply) or to handle the surplus (e.g. waste water management). However, besides the basic description, water management is complex and inherits many more processes and functions, if understood as the entire range of management of water, such as: drinking water, food production, fishery, navigation, cult, energy, status, power hygiene entertainment, protection, cooling, and recreation.

Moreover, the technical and practical knowledge and governance structures applied during specific times were developed according to case-related strategies and developments. This implies that water management is always case-sensitive and that inter- and transdisciplinary approaches towards the investigation of water management issues are required.

41 Shifa 2002.

42 Berking, Beckers, Knitter, et al. 2016.

43 Fischer-Kowalski, Mayer, and Schaffartzik 2011, 61–78.

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Textile Revolution

Summary

The article discusses the applicability of the social-ecological model developed by M. Fischer-Kowalski to the topics and methodological approaches of the Research Group A4 Textile Revolution. After some terminological adjustments, we use different disciplinary perspectives to examine the extent to which the model can be successfully used. The diachronic approach and the dynamic character of the innovation process studied pose a major challenge. If at all, the model can be used only to describe separate stages of this process, which can then be compared in a second step. Within the Research Group there was no consensus as to its usefulness – nevertheless, the discussion of the model helped to focus the methodological premises and results of the multi-proxy approach applied.

Keywords: textiles; wool; textile tools; social ecology; social metabolism

Der Beitrag diskutiert die Anwendbarkeit des sozial-ökologischen Modells von M. Fischer-Kowalski auf die Fragestellungen und methodischen Ansätze der Gruppe A4 Textile Revolution. Nach begrifflichen Anpassungen wird aus der Sicht der beteiligten Disziplinen erörtert, inwieweit das Modell anwendbar und zielführend ist. Ein Problem stellt der diachrone Ansatz und dynamische Charakter des untersuchten Innovationsprozesses dar. Wenn überhaupt, so lässt sich das Modell nur auf Stadien dieses Prozesses anwenden, die verglichen werden können. Innerhalb der Forschungsgruppe bestand kein Konsens hinsichtlich seiner Nützlichkeit, doch hat die Diskussion über dieses Modell wesentlich zur Schärfung der methodischen Voraussetzungen und Ergebnisse des praktizierten multi-proxy-Ansatzes beigetragen.

Keywords: Textilien; Wolle; Textilwerkzeuge; soziale Ökologie; gesellschaftlicher Metabolismus

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1 Introduction

Sheep were domesticated in the Fertile Crescent in the second half of the 9th millennium BCE. Like their wild forbears, these first domesticated sheep were hair sheep, as were the early domestic sheep that came to Europe with Neolithization. These animals were kept to provide meat and (also probably from early on) milk. When and where genetic mutation and artificial selection caused sheep with long, spinnable fleece to come into being has long been the subject of debate. The Textile Revolution research group investigated the age and origins of woolly sheep, as well as the process by which their use spread. There can be no doubt but that the availability of animal fibers must have had an enormous impact on the production of woven and knitted textiles and felt materials and resulted in an increase in the variety of such materials. Given the superior material characteristics of wool fibers (better insulation against cold and damp at lower specific weights, good dyeability) compared to plant fibers and their greater ease of processing, it is clear that the introduction of wool constitutes an important innovation in textile production. That this innovation has received far less research attention than other prehistoric innovations, such as pottery production, copper processing or the appearance of the wagon, is undoubtedly due to the fact that it is, to a great extent, invisible in the spectrum of archaeological finds and features.

2 Methodology

The research group *Textile Revolution* engaged in the investigation on a large scale – encompassing a vast geographical area stretching from the Iranian highlands into eastern Central Europe – of indirect evidence pointing to the introduction of wool use. Indications for the beginnings of wool use can take the form of qualitative (morphological) or quantitative changes in the artefacts associated with textile production (spindle whorls, loom weights)[1], but changes in the faunal assemblages of settlements (sheep size and representation, changes in herd age and sex structure) can also be indications of this introduction[2]. Intensified grazing activity can leave anthropogenic traces in geo-archives, although probably not of a kind that can be associated with specific animal species. Each of these categories of indications is associated with a different spatial representativeness, chronological resolution and degrees of causal ambivalence. However, a temporal and spatial correlation of multiple indications is associated with increased probability of a common underlying cause. The research group used an interdisciplinary *multiproxy* ap-

1 Grabundžija and Schoch 2020.

2 Becker, Benecke, Küchelmann, et al. 2020.

proach[3] to detect such correlations. It must be said, though, that the group's researchers do not necessarily expect the emergence of wool production to have left traces of same type or density throughout the entire area under investigation or over the entire period in which the process spread within it, given the vast size of that area and length of the period (6th–3rd millennium BCE) in question.

3 The social-ecological model

Marina Fischer-Kowalski and her colleagues have been developing their social-ecological model since the late 1990s. Their aim is to place interactions between society and nature on an epistemological foundation that is compatible both with the notional and conceptual approaches of the social sciences and with the systemic view adopted in the study of ecology in the natural sciences.[4] The developers of this model have drawn attention to a sort of role reversal in sociological and natural science perspectives: Sociologists traditionally view society as highly complex structure whose interactions play out largely independent of an exogenous environment, the effects of which are generally perceived as disturbances. Conversely, the natural sciences perspectives of physical geography and other environmental sciences view natural systems as highly complex and interlinked entities, while human beings are assigned the role of external actors with a low-level of complexity.[5] The social-ecological model takes up Niklas Luhmann's concept of society as a "system of recursive communication", although Fischer-Kowalski and Erb understand Luhmann's system of recursive communication (society) to have essentially the same meaning as "cultural systems"[6] as this concept is used by historian R. P. Sieferle.[7]

Another key element of the social-ecological model is the notion of "social metabolism", first used by Fischer-Kowalski in 1997. The term describes the flows of material and energy between human populations and their biophysical environment. The metabolism paradigm underlines the idea that the "metabolic equation" applies to human societies as well as to individual organisms, i.e. that material extraction (of raw materials, resources) is associated with a proportional output of material and energy (emissions, waste, heat, etc.).[8]

The social-ecological model visualizes the two areas of nature and culture, each conceptualized as a system, as two overlapping spheres: that of the physical world and that of human society. The notions "population", "artefacts" and "livestock" belong to

3 Becker, Benecke, Grabundžija, et al. 2016; Schier 2020.
4 Fischer-Kowalski and Erb 2006, 34.
5 Fischer-Kowalski and Erb 2006, 35.
6 Fischer-Kowalski and Erb 2006, 37.40.
7 Sieferle 1997.
8 Fischer-Kowalski, Mayer, and Schaffartzik 2011, 97.

the area where these two spheres overlap. Systemic population-culture interactions are described as "direct communication", "program" or "representation", while interactions between population and nature include labor (colonization) and experience,[9] in addition to the direct material flows (metabolism).[10] Fischer-Kowalski and Erb adopt quite a broad understanding of communication, one that can include, for instance, market processes (buying/selling) and institutional decision-making processes. Experiences (of individuals and populations taking action) are represented culturally and become "components of a socially objectified understanding of meaning and knowledge."[11] On the other hand, Fischer-Kowalski and Erb understand culture as the basis for a "program" that guides action in analytical and normative respects. They describe the interactions between "population" and "culture" that are subsumed under the term "communication" as being hybridized with the physical/material, in that they require both human bodies and technical infrastructure. The interactions between human populations and their natural surroundings are also conceptualized as hybrid – labor is at once an "meaningful, intentional process" and one that "develops physical effects".[12] "Experience", on the other hand, is understood as the feedback from natural processes into the human populations, whereby these processes are filtered through human sensory perceptions and interpreted with existing knowledge.[13]

Fischer-Kowalski's social-ecological model was the subject of intensive debate within Topoi Area A, in the context of which it was decided that the terms "artefact" and "colonization" were potentially misleading in the context of ancient studies and archaeology. Some of the researchers in the group expressed general doubts about the conceptual separation, or the possibility of differentiating between "human society" and the "material world". However, Fischer-Kowalski and Erb themselves have responded to this criticism by explaining that this dichotomy is rooted in pragmatic rather than ontological considerations.[14]

9 The term "experience" (*Erfahrung*) is replaced by "events" (*Ereignisse*) in the form of the model published in 2011.

10 Fischer-Kowalski and Erb 2006, 41

11 Fischer-Kowalski and Erb 2006, 42.

12 "'Arbeit' ist ein sinnhafter, intentionaler Prozess und entfaltet zugleich physische Wirkungen […]", Fischer-Kowalski and Erb 2006, 42.

13 Fischer-Kowalski and Erb 2006, 42. This definition of experience fails to convey the complexity and versatility of the term, which Martin Jay's study of "experience" in European thought illuminates (Jay 2005).

14 "Angesichts dieser Dominanz des ‚Hybriden' bei allen sozialen Vorgängen kann man sich natürlich fragen, wozu die dualistische Hintergrundunterscheidung überhaupt gut und notwendig ist. […] In unseren Augen ist dies nicht eine ontologische, sondern eine pragmatische Frage. Letztlich geht es bei Erfolg versprechenden interdisziplinären Ansätzen darum, eine möglichst tragfähige Art von ‚soft coupling' zwischen unterschiedlichen wissenschaftlichen Traditionen bereitzustellen, die es erlaubt, vorhandene elaborierte Theorien und Forschungserfahrungen miteinander in möglichst friktionsfreier und fruchtbarer Weise zu verbinden." Fischer-Kowalski and Erb 2006, 42–43.

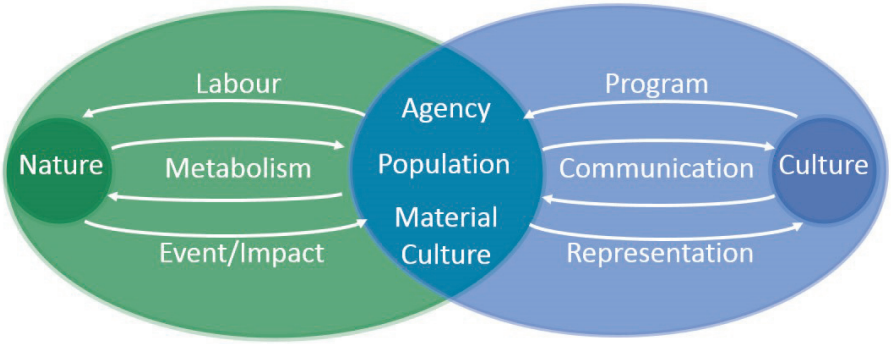

Fig. 1 Social-ecological model.

An in-depth consideration of conceptual underpinnings of the social-ecological model makes it clear that the model does not propose a mutually exclusive dichotomy between nature and culture or between material and immaterial worlds, but rather a "hybrid system" that places Luhmann's model of society as recursive communication alongside social metabolism as a model for (recursive) human-environment interactions in a symmetric relationship.

One result of the discussions of the social-ecological model within Area A was the decision to subsume the terms "artefact" and "livestock" under the term "material culture." The term "agency" was also introduced as the interface between cultural program and labor, representing the sum of all actions by individuals and groups. The term "colonization", potentially misleading in the context of ancient studies, was not adopted. Figure 1 depicts the form of Fischer-Kowalski's social-ecological model as adapted by the A-4 research group.

The next section presents and discusses the initial hypotheses of the disciplines represented in the Textile Revolution research group with reference to the social-ecological model.

4 Initial hypotheses and modelling assumptions

4.1 Phases of the innovation process

For the purposes of our research, the early use of wool is divided into four phases. These do not necessarily represent stages of time in the sense of absolute chronologies, but rather hypothetical stages in an innovation process that did not necessarily unfold in the same way in all regions. We differentiate as follows:

Phase 1. The (initial) use of wool, non-specific.
This use need not involve the production of textiles, a term under which we include both flat textiles (products of weaving, knitting, knotting, felting, etc.) and string-formed products (yarns, twines, ropes). Other possiblities include uses for purposes of insulation (for buildings), for sealing or padding, and as a curative agent or bait.

Phase 2. The use of wool for the production of textiles.
This use entails certain preconditions: to produce a thread that resists breakage, a wool staple length of at least 3 cm is necessary. It is not clear when wool of sufficient staple length can be assumed to have become available.

Phase 3. Production of wool specifically for textile production beyond local needs, which implies a certain degree of producer specialization.

Phase 4. Centrally managed wool production and processing on a large scale (protoindustrial phase).

4.2 Archaeology

This subdivision of wool use into four phases can be illustrated particularly in Western Asia.

In the *first phase (initial phase)*, wool is used sporadically and perhaps in spun or unspun form, i.e. one should not expect to find spindle whorls specifically for wool. Spindle whorls are present, but these were intended for use in the processing of other materials (plant fibers). Spinning is a known technique in this phase, one used to bind plant fibers into threads, increasing their resistance to breakage; thus, spinning was invented prior to the emergence of wool.

In the *second phase (consolidation phase)*, which starts when people begin to use wool for textile production, per-animal wool yields must have reached an adequate amount and the wool produced must have had a minimum staple length of 3 cm. The longer the staple length, the greater the stability of the spun thread. One can assume that artificial selection and human promotion of fleece-bearing animals resulted in a slow but continual lengthening of wool fibers and thus in the continual improvement of the raw material with respect to its utility in textile production. Lighter weight spinning whorls are required to process shorter fibers. Therefore, early wool-spinning whorls should tend to be light-weight and of smaller diameter so that they would spin faster, causing the short fibers to twist more quickly and thus hold the thread together. As wool fibers of greater length became available, the range of whorl weights and diameters that can be used increase. Thus, one can expect to find new forms appearing along with a

greater variability in weights and diameters in this phase.

Once textiles are no longer being produced solely for local use, but also as surplus or export products (*third phase, or specialization phase*), a greater degree of organization becomes necessary. One can expect to see increased standardization of whorl weights and diameters along with an increase in their quantity. Spinning is the bottle-neck in the textile production process – in production based on a division of labor, at least seven people must spin to keep one weaver supplied with yarn.[15] This need not necessarily result in an increase in the numbers of spinning whorls though, as one person can never use more than one tool at a time. Researchers can look for new patterns in find distributions (spinning whorl accumulations in storage spaces, for instance), because spun wool would have to be stored until it could be processed on the spindle.

In the *fourth* phase, the *'protoindustrial' phase*, textile production is centrally managed and controlled. The first written sources providing insight on production quantities and qualities and distribution paths are found in this phase (Late Uruk, Jemdet Nasr and Early Dynastic periods).

At this point, there is little to suggest that fleece-bearing sheep developed independently in Southeastern or Central Europe. The more probable working hypothesis appears to be that woolly sheep spread into Southeastern Europe from the Middle East by way of Anatolia, accompanied by a transfer of the relevant technological knowledge (about the collection and processing of the wool). However, it is not yet possible to determine whether the spread of the fleece-bearing sheep from Western Asia took place during the consolidation phase or not until later, when a form of wool production with a certain degree of specialization had developed. What is clear is that there is no evidence for a protoindustrial phase of wool production in southeast or central Europe during the prehistoric period.

As the discussion above makes apparent, the innovation process leading to the widespread use of wool, given its diachronic dynamics, cannot be depicted in its entirety in the social-ecological model. Rather, a separate model description must be developed for each phase of the innovation process defined above.

For the initial phase, we must assume that mutations occurring in the biological reproduction cycle of the existing sheep population resulted in the appearance of the new characteristic of coat/fleece that grew to a greater length or that external sheep with this characteristic were introduced to the existing stocks, which would require *communication* with the source culture and the transfer of operative knowledge (*program*). As we assume that during this phase the new raw material, wool, was used in fairly sporadic, non-specific ways, we do not expect to detect any major changes in the *social metabolism* (yet), as this phase would see no substantial change in herd size or grazing needs.

15 Levy and Gilead 2013, 37.

The consolidation phase was accompanied by changes in the *material culture* because the increasing staple length of the wool required the modification of the pre-existing spindle whorls, which were initially optimized for use in processing plant fibers. The experiences acquired through this process fed into the fund of cultural knowledge and, as program, guided the production of whorls better suited for use with wool. This optimization process, which, of course, also involves knowledge about wool collection and processing techniques, can then be passed on via *communication processes* to other populations, possibly triggering a system change from the initial phase to the consolidation phase in that population. Therefore, in addition to assuming that the characteristics of the social-ecological model change over time, we must also assume that models representing successive stages coexisted on different spatial scales.

The specialization phase is characterized by recurring change in the material culture (diversification of spinning whorl forms and sizes) and the representations in cultural knowledge associated with them. We also expect changes in the *social metabolism* though: sheep herds should become larger and their age structure change, resulting in an increase in metabolized biomass, but also entailing the intentional taking into agricultural use of new areas of land (*colonization*), which had previously lain outside the sphere of influence of human *labor* (grazing), and the material flows associated with that (food, manure). We would thus expect to see both an intensification of metabolism and an expansion of *economic spaces*, i.e., a change in the spatial scale.

Thus far, the protoindustrial phase has only been detected in the Middle East. In addition to an enormous increase in herd size (further increase in *social metabolism* and expansion of *spaces* subject to economic use), this phase is associated with a shift of the management of wool production from individual producers to central institutions, which constitutes part of direct *communication* as conceptualized above. The normative aspects of the *program* (production specifications, rules governing pasturing, etc.) increase in scope and complexity as do the quantitative aspects of *representation* (encoding of herd sizes and production quantities).

4.3 Archaeozoology

It has not yet been established when or how sheep with short hairy coats became the woolly sheep that we are familiar with today, nor is it known what triggered this development. Two scenarios are conceivable: a spontaneous mutation of the gene loci responsible for hair formation or a development that was triggered, in the broadest possible sense, by human intervention (*program*). One possibility is that this took the form of an enormous change in the living environment of domesticated sheep, for instance with the spread of sheep, along with other domestic animals and cultivated plants, out of the primary areas of domestication into other regions in the course of Neolithization.

This might have been associated with a change of diet, a different form of livestock keeping (some use of enclosures rather than exclusively free range) or perhaps crossbreeding with animals originating in other regions. Any or all of this could have had an effect, in the sense of an epigenetic modulation, possibly in the absence, initially, of any intentional human intervention. It is doubtful that humans could have deliberately bred for this type of hair, as they would never have seen it before and would not have been at all aware that hair sheep had the potential to develop it. It is possible to detect the spread of domesticated sheep into regions outside of the area of initial domestication using archeozoological methods.

The effects of these changes were obvious enough to make the animals involved become the focus of breeding activities. The selection process, which focuses on the characteristics of the coat, probably unfolded in multiple steps (intermediate stages: hair/mixed wool, mixed wool). It is unclear whether the appearance of woolly sheep constitutes a monotopic event, with subsequent dissemination of the "new" domestic animal, or a polytopic event (*culture*, *communication*). If we assume that wool-bearing animals differ from the previously existing hair sheep in both shape and size, then there is the possibility that these changes in constitution can be detected using osteological methods.

Sheep are domestic animals associated with a large range of uses (e.g. for meat, milk and wool). According to the Payne model, the use of livestock primarily for wool production is associated with a high percentage of adult animals, including many castrated animals, and a similar population structure should be found in the remains of slaughtered animals. Castrated sheep grow to a significantly greater height than female sheep do. Therefore, in addition to the use-specific stock structure, an increase in size of sheep in diachronic comparison can be seen as a marker for wool-oriented sheep keeping.[16] These changes described should be reflected in the faunal assemblages, particularly those from locations or regions where wool had become an important economic factor. One can also expect sheep-keeping to take on greater overall importance with the advent of wool/wool production meaning the representation of this domestic animal among faunal remains should be significantly greater.

If animal management was previously geared primarily toward milk and meat production, the animals would have been slaughtered at a relatively young age. A shift in focus to wool yield would cause herd managers to let the animals live considerably longer in order to maximize the yield. Castration is also a proven method of increasing wool yield. The collection of sheep-related data from sites associated with the time period of particular interest, i.e., the fifth to the third millennium BCE, and from the largest possible geographic region allows to shed light on the issues mentioned above.[17]

16 Becker, Benecke, Küchelmann, et al. 2020, 91.

17 Becker, Benecke, Küchelmann, et al. 2020.

However, there is a time lag between transitions like these and their reflection in the archaeozoological record.

With regard to the social-ecological model proposed by Fischer-Kowalski, one is also faced with the problem, from an archaeozoological perspective, that the anticipated changes in sheep herds (size, animal height and sex composition) and their consequences for the *social metabolism* and the *spaces* used for sheep keeping, can be depicted only by means of a diachronically staggered series of model diagrams.

4.4 Landscape archaeology

Wool's emerging role as a significant social and economic factor results in increased sheep-farming activity. Were this increase in activity restricted to a specific location, e.g. in the vicinity of wool fabrication locations, it would result in a locally restricted increase in grazing pressure. This would result initially in vegetation changes and degradation, and ultimately in soil degradation and erosion. Such changes can be inferred from data collected from appropriate environmental archives. With reference to the social-ecological model, this signifies substantial changes in the *social metabolism, labor* in the form of mechanical-physical effects on the natural environment and possibly repercussions in the form of (irreversible) *impacts* like soil degradation.

Grazing pressure would be mitigated if the intensified sheep keeping was associated with a mobile lifestyle (transhumance, mobile pastoralism), since limited areas would not be grazed as intensively, i.e. the pressures of use would be distributed over a larger geographic area (*economic region*).

Both of these scenarios can be expected to give rise to very different results depending on where the environmental archive analyzed is located.[18]

Pollen data allow researchers to arrive at conclusions about vegetation conditions, and these conclusions can in turn provide indications of human influences, such as pastoralism. Geochemical proxies and charcoal data can yield information about environmental conditions that can, in turn, be associated with natural or anthropogenic processes. This last distinction usually poses a great challenge; in most cases, both natural and anthropogenic factors play a role. These types of data (i.e. pollen and charcoal data, geochemical proxy data) cannot produce evidence for the use of wool, because they can only support indirect conclusions about static conditions.

Is it even possible to draw conclusions about a (socio-)economic development like the beginning of wool usage on the basis of landscape change? Based on insights from archaeological and archaeozoological research, we assume that wool production and wool usage began to intensify in the Chalcolithic/Early Bronze Age. When and where

18 Schumacher, Schier, and Schütt 2016.

this change occurred has not been established. The linkages between wool production and landscape ecosystem described above offer a way to obtain indications that we can use to answer the primary research question: are there spatiotemporal patterns of indications of disturbances in ecosystems that can be linked to grazing? If so, how can these patterns be related to the available archaeological and archaeozoological data? If the large-scale reconstruction of ecosystem disturbances caused by sheep grazing were not undertaken in the context of the multiproxy approach, with the corresponding support of data from archaeological and archaeozoological research and research in ancient Near Eastern studies, it would probably be impossible to arrive at any well-founded conclusions on the basis of the available data.

4.5 Insights from ancient texts

In the structure of the social-ecological model, the information provided by ancient Near Eastern text studies is drawn from written *representations* of economic facts relating to the program and its relations to the area of agency. The cuneiform sources offer information about sheep farming, wool production, dairy production, operation sizes, wool yields and the social groups associated with these activities, but several factors must be considered when interpreting these sources, namely their secondary find contexts, the randomness associated with text preservation and processes of intentional selection. For instance, writing is a phenomenon of urban culture, one that developed directly out of the demands associated with complex economic structures and relates primarily to such structures. The activities of nomadic or pastoral populations are not represented in it, or at most only indirectly.

Hypotheses and knowledge about *early* wool production from the standpoint of the proto-cuneiform texts from Uruk[19] and Jemdet Nasr dating to ca. 3300–2900 BCE, relate to the third and fourth phase of the model described above, since wool is generally considered to have already become a key, perhaps even *the* key economic factor in the period associated with these oldest textual sources. This view is supported by the fact that the sign UDU, which refers to "sheep" or to "sheep and goats" more generally, ranks twelfth in the list of the most common signs and, remarkably, is one of the few signs that are abstract rather than pictographic.[20]

Around 50 "herd texts"[21] document the quantification and/or growth of sheep and goat herds. These texts distinguish terminologically sex, age and reproductive capability of sheep, thus providing evidence of the same differentiated terminology as in texts

19 See Schrakamp 2020 for a more extensive discussion of the evidence from Uruk.

20 Englund 1998, 55, 70.

21 Green 1980; Englund 1998, 146; Szarzyńska 2002; Schrakamp 2020, 208–211.

of the later third millennium BCE.[22] A half dozen of these texts identify sheep explicitly as "wool sheep" (UDU SIKI), making it possible, due to the highly formalized and uniform nature of the texts, to understand the common simple designation of "sheep" (UDU) as also meaning "wool sheep" (similar usage is seen, e.g. in the texts from the 24th century BCE from Lagash).[23] In addition to "(wool) sheep", the earliest texts also mention "fat-tailed sheep" (GUKKAL). A lexical list that teaches, among other things, the vocabulary for large cattle and sheep and goats (*Tributes*), mentions a ratio of male to female animals of 1:10, proportions similar to those appearing in the herd texts. They probably represent the lowest level of the management of sheep and goats, since they record flocks of only 40–60 animals and deliveries of dairy products.[24]

That these animals are "wool sheep" is also suggested by the organization of the economy in Uruk, for which five "offices" are believed, based on textual evidence, to have been responsible.[25] One of these covers the documentation of cattle, sheep and goats, dairy products and textiles, i.e. the management of the herds and their products.

A lexical list (*Vessels*) gives terms for vessels and textiles (including colored textiles), thus shedding light on two areas of cattle and sheep/goat production. This list is therefore associated with one of the five administrative fields of Uruk known from written documentation, which was charged with the administration of cattle and sheep and goats, textiles and milk products.[26] A few tablets reflect a higher level of accountability and record up to 1400 animals, wool, textiles, dairy products, and dung.[27]

Although the administrative texts distinguish between fleece, wool and material or textiles,[28] direct references to wool processing are rare; it is not possible to identify a production chain *(chaîne opératoire)* from animal to garment.[29] In particular, the absence of any mention of sheep shearing is striking, though it could be due to the fragmentary nature of the data or the randomness association with preservation and/or discovery of textual sources. The earliest solid evidence of shearing is found in archaic texts of the Early Dynastic I/II period from Ur, dating to 2700 BCE (?);[30] it remains unclear whether one archaic sign represents a pictogram for combing or carding tools.[31]

The administrative structures appear to be centralized; the titles of the functionaries that appear in the relevant texts also appear in a prominent position among the first entries in a lexical list ("*ED Lu2* A") that is thought to be a list, in hierarchical order, of

22 E.g. Green 1980; Englund 1998, 149; Schrakamp 2020, 209; cf. Steinkeller 1995.
23 See Hruška 1995.
24 Green 1980; Englund 1998, 146 n. 331; Veldhuis 2006, 193–194.
25 Schrakamp 2020, 208.
26 Veldhuis 2006, 187–188.
27 Hruška 1995, 80 n. 35; Englund 1998, 98, 126 n. 267, 147; Szarzyńska 2002, 24; Schrakamp 2020, 211–212.
28 Englund 1998, 70; Szarzyńska 1988; Szarzyńska 1993; Szarzyńska 2002; with Englund 2004.
29 Englund 1998, 152.
30 Charvát 2014, 86.
31 Charvát 2011, 51–52.

all (?) offices and occupations in Uruk.[32] Which institutions were involved in processing the wool, however, is not yet particularly clear.[33]

Thus far, the question of whether transhumance was practiced has not been answered; textual references which might support the assumption of a such a practice for the late Uruk Period are limited in number and extremely doubtful both epigraphically and with respect to their interpretation.[34]

Comparing the information obtained from archaic texts from Uruk with findings from later epochs in the third millennium BCE, one is struck by the relatively low numbers of goats and sheep. The numbers appear quite low compared to the five- or six-digit numbers of sheep mentioned in texts from Ebla in Syria (24th century BCE), from the Akkadian period (23rd–22nd century BCE) and the Ur III period (21st century BCE).[35] Was a "textile industry" still only just starting to develop in the 3300–2900 BCE period?

5 Effects and interactions in light of the initial hypotheses and interim results

This section presents some examples of the effects and interactions suggested by the data and discusses whether and how they can be described in accordance with the social-ecological model.

5.1 Morphological and metric variability of spindle whorls in Southeastern Europe

Results of the textile tool analysis on the Eneolithic and Early Bronze Age spindle-whorls from the investigated region of eastern Central and Southeastern Europe reveal several trends in the course of the 4th and 3rd millennium BCE:[36]

– increased frequency

– increased shape variability

– increased weight and size variability

32 Green 1980, 9.
33 Charvát 2014, 80–83.
34 Green 1980, 16–17, 18, 21; Charvát 2011, 50; Schrakamp 2020, 209–210.
35 E.g. Sallaberger 2014, 106.
36 Grabundžija and Schoch 2020.

The Middle Eneolithic spindle-whorl sample (first half of the 4th millennium BCE) shows the lowest variability in both morphology and weight, with a dominance of low height types. Some of the high and steep-sided types that do occur in this period, but are underrepresented, could be connected to animal-fiber processing. These high and steep spindle-whorl types of moderate weight would provide a smaller moment of inertia, as needed for the spinning of animal fibers. By imparting more twist and not too much tension, they can be associated with shorter wool fibers.[37] They become more common in the succeeding Late Eneolithic and Early Bronze Age assemblages. Exceptionally light spindle whorls of considerable height are not expected in the context of early wool processing. The first wool used for textiles is expected to have limited fiber quality, especially if fine fibers were not separated from coarser kemp, as attested by the preserved evidence from the Bronze Age.[38] In this case very light weight, tall types of spindle-whorls would not give sufficient tension and would not provide enough moment of inertia for the particular fiber quality,[39] suggested for early wool. The settlement patterns and faunal data for the first half of the 4th millennium BCE (Lasinja/Furchenstich/Proto-Boleráz phase) support an intensified animal husbandry with a slight increment in sheep/goat frequency.

The Late Eneolithic and Early Bronze Age assemblages are characterized by the increase in both weight and shape variability. The appearance of new types and the significant height value variability are indicative of technological adaptation to both new fiber material(s) and end product(s). A possible explanation for the continuous growth of spindle-whorl weights could be attributed to improvement in the fiber length over the course of the investigated two millennia. This assumption corresponds well with the development of fibers proposed for the flax plant.[40] The observed dominance of heavy and very heavy types, both in the Late Eneolithic and in the Early Bronze Age assemblages (Kostolac, Vučedol and Somogyvár-Vinkovci contexts), could indicate intensified plying techniques and use of long plant fibers.[41]

The observed trends are considered to relate to two main advancements evident in textile production, relating to changes in the cultural program in terms of the socio-ecological model:

- transitions in fiber procurement (introduction of new raw material(s))
- adaptation of spinning techniques (introduction of new end products)

37 Chmielewski and Gardyński 2010, 877; Laurito, Lemorini, and Perilli 2014.

38 Bender Jørgensen and Grömer 2012, 56; Rast-Eicher 2012.

39 Laurito, Lemorini, and Perilli 2014.

40 Herbig and Maier 2011, 529.

41 Barber 1991, 52; Hochberg 1979, 21.

Changed conditions of textile production are also indicated by several social factors. Specialized activity areas and increased presence of spindle whorls in human burials suggest a mature organization of the manufacturing process, which is supposed to be accompanied by its growing economic importance.

The analyzed data is sufficient to propose an intensified use of two different fiber materials, while the functional analysis of the studied tools, namely spindle-whorls, revealed two independent trends (a decrease in height – diameter ratio and an increase in weight values). The results, however, do not allow for a narrative of socio-environmental causality. For the time being, the interpretation is restricted to the description of observed patterns of change, derived from random samples of successive cultures or epochs. Nevertheless, the end of the 4th millennium BCE could be described as a transitional phase of both intensified production and technological adaptation. Smaller-scale studies on intra-cultural or inter-site dynamics during the respective period could enable further insight into the more exact causes and effects of these technological adjustments within the material culture.

5.2 Social metabolism and landscape resilience

In a diachronic and comparative perspective, social metabolism is revealed to be neither constant nor subject to *continual* change (in the sense of a cultural-evolution perspective) with respect to its type and intensity. The investigation of changes in the social metabolism of prehistoric societies in different regions leads to the concept of the *resilience* or *vulnerability* of ecosystems.[42] The evaluation of existing landscape archaeology studies and field work in northern Hungary, both carried out by researchers of the Textile Revolution group, have failed to provide more than vague indications of increased pasture use and subsequent anthropogenic changes to the landscape within the period under investigation by the research group (5th–3rd millennium).[43] From a methodological perspective, possible conclusions are that livestock keeping in this period was less intensive and on a small spatial scale or that the landscapes in question were highly resilient.

However, there are examples of regions of lesser resilience in which irreversible landscape changes can already be seen in connection with land use, and particularly with livestock farming, in prehistory, although these lie outside of the area that this group is investigating (from the Middle East to eastern Central Europe). For instance, anthropogenic deforestation and moorland expansion on nutrient-poor Pleistocene sandy soils in the northern Netherlands or western Jutland can be linked to settlement and intensive land use by the Final Neolithic Single Grave Culture (c. 2800–2400 BCE) on

42 E.g. Miles et al. 2001; Bintliff 2002; Kalis, Merkt, and Wunderlich 2003; Dusar et al. 2012.

43 Schumacher, Schier, and Schütt 2016; Schumacher, Dobos, et al. 2018.

the basis of palynological data.[44] A particularly striking example for vulnerability of northwest European landscapes is that of the Shetland Islands, which were probably first settled by from populations coming from the Orkney islands at the transition from the fourth to the third millennium. As the excavations and landscape archaeological analyses at the Scord of Brouster on the Mainland have shown,[45] this island was covered by a low-growing birch-hazel woodland when the first settlers arrived there. After only a few centuries of agricultural use (dated field systems), the woodland cover had largely disappeared in conjunction with a rapid spread of common heather (*Calluna vulgaris*), and blanket bogs, of the kind typical of the Atlantic coastal areas of Great Britain, had already begun to form. Thus, in the Final Neolithic (3rd millennium), after only a brief episode of agriculture, the only option available to the population of the island was to increase pasture grazing, particularly of sheep, which prevented regrowth of the woodland and further accelerated the formation of blanket bogs.[46]

5.3 Wool production, pastoralism and social differentiation

Questions about the type, scale and sustainability of change arise not only with respect to the interactions between human populations and their natural environment but also with respect to society, or, in Fischer-Kowalski's model, the *cultural system*. As described above, we expect the phase of specialization to be accompanied by a differentiation into part- or full-time specialists both in the area of sheep keeping and in that of the collection and processing of wool and wool textiles. Along with increasing degrees of specialization, one would expect to see growth in herd sizes and increasing diversification in land use patterns – all the more so given that lands that are of only marginal use for crop farming can still be used as pasture lands. The use of pastureland at greater distances from settlement areas is conducive to the development of mobile forms of sheep keeping, such as transhumance or even pastoral nomadism. It is likely that the increasing mobility of pastoralists would then lead to a consolidation of the social specialization, perhaps manifest in the development of seasonal part-time and full-time specialists.

Effects of specialization in textile production can be detected both at the artefact level (diversification of spindle whorl sizes and forms) and at the feature level (specialized households) in the fourth and third millennium, as described above. Whether and to what extent these indications of increasing specialization can truly be ascribed to the advent of wool as a raw material cannot be determined on the basis of archaeological criteria alone; such a determination would have to be confirmed by archaeozoological data, in line with a multiproxy approach.

44 Andersen 1992; Andersen 1992; Casparie 1992.
45 Whittle et al. 1986.
46 Keith-Lucas 1986.

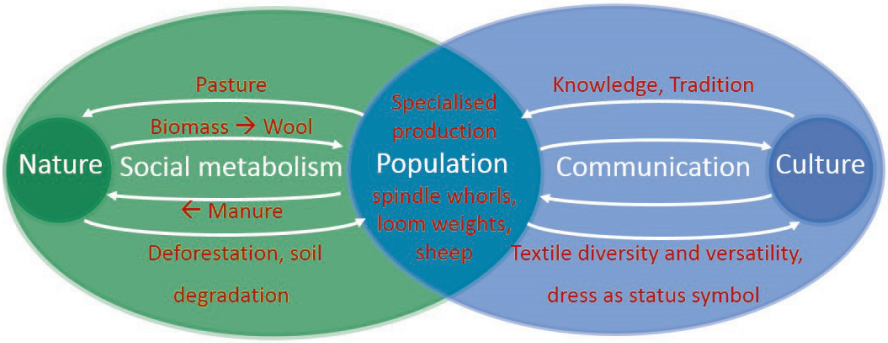

Fig. 2 Social-ecological model of early wool production.

With respect to the social-ecological model, one can expect the use of wool to be associated with other interactions at the level of representation and communication: here, one might think in terms of how value is assigned to new raw material within society (prestige?), or of the potential inherent in the characteristics of the new material and in the fact that wool materials are easier to dye for symbolic representations of status (differences) and identity.

In principle, these interactions between society/culture, economic actions (sheep keeping, textile production) and the social metabolism, presented only cursorily here, can be depicted in the social-ecological model and the systems it conceptualizes. However, here again, one is faced with the challenge of structuring the model in a way that permits the depiction of the temporal dynamics of these processes, extending all the way to partial or complete system change (e.g., development of pastoral societies or centrally managed protoindustrial sheep keeping and wool production).

6 The "Textile Revolution" in the social-ecological model

The discussions above have shown that it is, in principle, possible to depict the initial hypotheses and interactions expected by the research group in the social-ecological model developed by Fischer-Kowalski and her colleagues. Fig. 2 shows some of the components and effects discussed in the model architecture. However, it is also evident that when attempting to produce a more comprehensive presentation of the elements, effects and interactions involved, one quickly runs up against the limits of clarity in visual representation.

The social-ecological model is also able to portray the partially overlapping, partially complementary disciplinary perspectives of archaeology, archaeozoology, geography

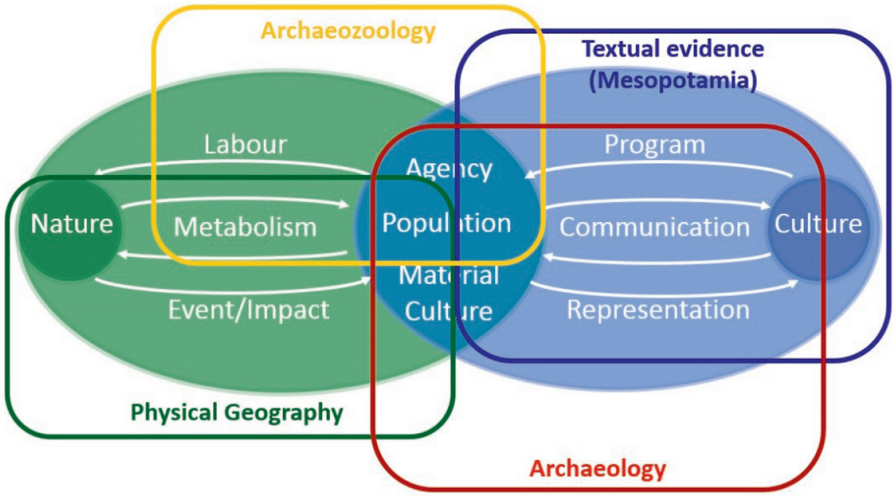

Fig. 3 Disciplinary perspectives in the social-ecological model.

and ancient Near Eastern studies within the Textile Revolution research group (Fig. 3).

However, the presenting the different temporal and spatial scales required is problematic. The central research question of the group is *per se* diachronic in nature, the group's primary objective being to gain a more detailed picture of the temporal and spatial dimensions of the process of innovation and transformation associated with the introduction of the woolly sheep and the development of the production of textiles based on animal fibers, and to contribute by doing so to a better understanding of this important cultural innovation. There are many indications that this process did not follow a linear trajectory through time or space (diffusion model) but played out in multiple, spatially offset stages that might not form consistent sequence even when viewed on a large geographic scale. Moreover, archaeobiological data suggest that it might be appropriate to view the establishment of wool production not as an isolated process, but within the context of a specialization and diversification in Central Europe relating to flax cultivation and processing in the late fourth millennium.[47] Finally, the spread of wool production should probably also be viewed in the context of climate change.[48]

Diachronic changes in natural-physical and social-cultural interactions can only be depicted appropriately in the social-ecological model through the use of multiple diagrams consisting of staggered time slices, since the dynamic state of equilibrium (homeostasis) known from system theory forms an epistemological foundation for the model.

47 Karg 2020, 147–148.

48 Grabundžija and Russo 2016.

As shown above, spatial scaling must also be taken into account in connection with possible or expected changes in the textile production system. It is highly probable that specialized sheep keeping would lead to an expansion of economic space or to the use of marginal lands poorly suited to growing crops. However, this necessarily entails an extension of the spatial range of the social metabolism. If specialized transhumance or even fully nomadic pastoralism develop, then material flows and consequences for natural spaces would have to be considered on two scale levels (agriculturally active majority of the society in areas with favorable conditions, pastoral minority in larger regions).

This temporal and spatial multi-scalar character definitely renders the application of the social-ecological model to the issues discussed here substantially more difficult. However, the model can be applied to individual phases and regions, where it allows differences and developments to be portrayed in diachronic and diatopic comparisons.

7 An alternative view

Although for some in the group, the social-ecological model of Fischer-Kowalski and colleagues offers a workable basis for their research, others see fundamental problems with it. One of the most significant problems is the notion of *culture* used in the model, which appears to include solely that which is mental – ideas, beliefs, etc. This concept of culture does not fit well with current discussions in anthropology, where culture is understood as closely entwined with practices engaged in by humans in their interactions with the material world.[49] If instead, culture includes people's practical actions in and on the material world, it cannot be set apart from other elements of that world. Rather, it would be more useful to dissolve the dichotomy between nature and culture postulated by the Fischer-Kowalski model and acknowledge that 'nature,' as a concept, incorporates both an external physical world and the cultural perception of (parts of) that world with which people interact. Ultimately, this would result in a nearly complete overlap of the two areas ('eggs') in Fischer-Kowalski's model.

An example from our research group may make this point clearer. Our work centers on the woolly sheep, an animal that was not simply there 'in nature' but that came into being through some combination of genetic mutations and human intervention and selection. Both the 'making' of the woolly sheep and the 'final product' itself are an inextricable mix of 'nature' in the form of animals, in this case hairy sheep, and 'culture' in the form of human interventions in breeding, selecting, nurturing, and ultimately use of the product wool. Ideas about textiles and the place of animals in human life

49 See Ingold 2000, 39–43.

surely played a role as well, but they cannot be separated from the practical engagement of people with these animals.

For our research, it is more productive to examine human engagement with the material world and the constraints and possibilities set by that world, than it is to pigeonhole elements of the research into specific categorical boxes, such as those set up by the Fischer-Kowalski model.

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Illustration credits

1–3 W. Schier after Fischer-Kowalski and Erb 2006, 41, and Fischer-Kowalski, Mayer, and Schaffartzik 2011.

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Socio-Ecological Aspects of Iron as a New Raw Material

Summary

This contribution explores the challenges, chances, and limitations of the socio-ecological interaction model for different case studies focusing on the introduction or utilization of iron as a new raw material. The Fischer-Kowalski et al.'s social-ecological model supports interdisciplinary discussions and interpretations of archaeological and physical-geographical data in the research group. The database differs in the single study areas and depends on the state of the art of the region, the methodological approaches, and the material culture under consideration. Nevertheless, by combining the knowledge derived in all regions, we are able to shed light on all aspects of the social metabolism of iron smelting.

Keywords: socio-ecology; interaction model; Iron Age; interdisciplinary research; landscape archaeology

Dieser Beitrag erforscht für verschiedene Fallstudien die Herausforderungen, Chancen und Grenzen des sozio-ökologischen Interaktionsmodells mit Blick auf die Einführung oder Nutzung von Eisen als neues Rohmaterial. Das Interaktionsmodell nach Fischer-Kowalski et al. unterstützt interdisziplinäre Diskussionen sowie die Interpretation archäologischer und physisch-geographischer Daten innerhalb der Forschungsgruppe.

Die Datengrundlage unterscheidet sich in den einzelnen Fallstudien und hängt vom Forschungsstand der jeweiligen Untersuchungsgebiete, den methodischen Zugängen und der verfügbaren Funden und Befunden ab. Durch die Verknüpfung der Ergebnisse aller Fallstudien ist es möglich alle Aspekte des sozialen Metabolismus der Eisenverhüttung zu beleuchten.

Keywords: Sozialökologie; Interaktionsmodell; Eisenzeit; Interdisziplinarität; Landschaftsarchäologie

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1 Introduction

1.1 Objectives

The research group 'Iron as Raw Material' investigates the introduction of iron technology in five case study regions located in the Near East, the Northern Thyrrhenian Sea, the young moraine landscape south of Berlin (the Teltow region), the old drift landscape of Lower Silesia (Poland), and the Baltic region (Fig. 1).

The research group 'Iron as a Raw Material' aims to analyze: (1) development trajectories of the innovation iron smelting and (2) its impacts on natural and cultural boundary conditions. The research group is following a multi- to interdisciplinary approach. This approach allows the consideration of a wide range of different materials and sources, ranging from the Hittite cuneiform texts to the material culture of the Central European Iron Age, to environmental proxy data derived from sedimentological records. Accordingly, different aspects related to the introduction of this new technology – like detailed information on (a) the development of prices for iron in the ancient Near East,[1] (b) technical processes of the smelting process,[2] and (c) environmental impacts of iron production – are taken into account.

The smelting and processing of iron is related to a number of human activities that effect the natural environment, like the exploitation of iron ores and other natural resources (e.g. wood for charcoal production). From a socio-economic point of view, the availability of iron opens economic perspectives and offers competitive advantages. Therefore, the application of a non-dichotomous model describing human-environmental interactions builds a promising theoretical base from which to discuss the research hypothesis of the group in a wider framework. This contribution aims to explore the opportunities, challenges, and limitations of the socio-ecological model of Fischer-Kowalski et al. for the research focus on iron as a new raw material.[3]

1.2 A short history of the spread of iron technology

The production of malleable iron from terrestrial iron ores was preceded in the Near East by a long period that was characterized by a very sporadic use of probably meteoric iron, beginning at the end of the 4th millennium BCE.[4] At the same time, there is also evidence that use may have been made of telluric iron, which admittedly occurs only rarely in nature.[5] The first millennia of iron usage were characterized by the production

1 E.g. Cordani 2016.
2 E.g. Thelemann, Lehnhardt, et al. 2016; Thelemann, Bebermeier, Hoelzmann, and Lehnhardt 2017; Brumlich, Meyer, and Lychatz 2012; Lychatz 2018.
3 Fischer-Kowalski, Mayer, and Schaffartzik 2011.
4 Rehren et al. 2013.
5 Yalçin 2000, 308–309.

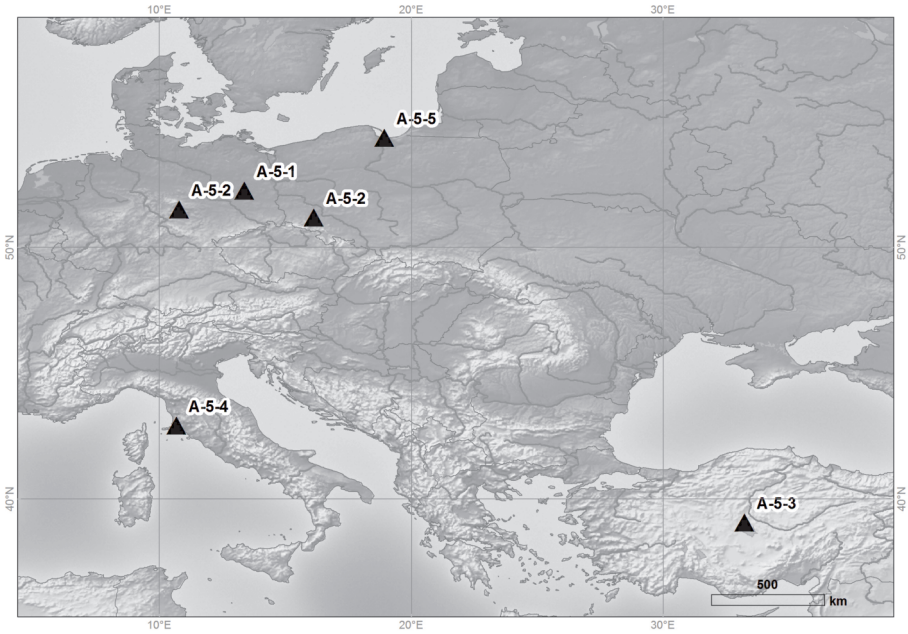

Fig. 1 Location of the research regions of the research group A-5 'Iron as a Raw Material'. The triangles mark the centre of the region of interest. Alphanumeric codes identify the research projects as follows A-5-1: Teltow, A-5-2: Silesia and Southern Harz Forelands, A-5-3: Near East, A-5-4: Populonia, A-5-5: Baltic region.

of various ornamental objects and some dagger blades, which can be regarded as luxury objects and status symbols.[6] Apart from a few iron finds, evidence of iron utilization is found primarily in written sources from the 2nd millennium BCE.[7] It took until the second half of the 2nd millennium BCE until iron products like tools and weapons became available in Anatolia and Mesopotamia.[8] Between the 10th and 9th century BCE, the technique of iron processing (not smelting) probably arrived in the Iberian and Italian peninsulas.[9] Approximately three centuries later, evidence points to an Etruscan exploitation of iron ores on the island of Elba, although it was not before the 4th century that the region of the Thyrrhenian Sea developed to become one of the centres of early iron production in the Mediterranean.[10] In the 5th century BCE, the first evidence in the Black Forest region indicates that the knowledge of iron smelting crossed the Alpine

6 Epimakhov and Koryakova 2007, 189, fig. 5.1; Pleiner 1996, 284–285; Pleiner 2000, 7–8.
7 Pleiner 2000, 8–9; Yalçin 2000, 309.
8 Lychatz 2013, 13; Pleiner 1996, 285–286; Pleiner 2000, 9–10; Yalçin 2000, 310.
9 Álvarez-Sanchís, Fernández-Götz, and Ruiz Zapatero 2012; Lychatz 2013, 14; Pleiner 1996, 287.
10 Lychatz 2013, 16; Pleiner 1996, 287–288; Pleiner 2000, 28–30.

mountains.[11] Contemporary smelting slags and bloomeries from Brandenburg[12] and Jutland[13] point to a rather fast spread towards North Central Europe.[14]

2 The socio ecology of iron smelting

In the following paragraph, the terminology of the socio ecology model is presented, by reflecting specific considerations related to the topic of 'Iron as raw material.'

Nature is understood as the perceived natural environment that follows the laws of nature. It sets physical limits for living, and represents the physical space in which early iron smelters act to exploit natural resources. *Labor* is the activity or process of changing nature in order to adopt it to human needs and to accelerate the metabolism between humans and nature. The exploitation of natural resources (i.e. iron ore, wood, construction materials for the furnace like clay or loam, and stones), is brought into focus by discussing the term 'labor' for our group. *Metabolism* is characterized as the direct connection between humans and nature. In terms of our research group, metabolism is the process of iron production, which is determined by the supply and availability of the required resources. If a society fails to organize the supply of resources the production process cannot be further sustained and ceases. The term *event* inherits changes in the natural sphere of causation that are perceived by a society. For instance, the depletion of a natural resource leading to a deceleration or the collapse of the iron production metabolism can be understood as an event.

Central to the model, and essential for our research, is the *material culture*, which comprises the remains of the iron production process, i.e. ores, slags, iron blooms, and iron objects, as well as the remains of workshops and furnaces (Fig. 2). Written and epigraphic sources provide more direct insights into economic and social implications. Sediment deposits allow for the derivation of information on changes in landscape dynamics. These dynamics may correlate with human activities, like the exploitation of natural resources, and are, thus, regarded as a second order category of material culture. The *material culture* informs us not only about the knowledge of people, but also about their relationship to, and their appropriation of, nature. Based on the material culture – as a product of the structural coupling of cultural and natural sphere of causation (e.g. knowledge, innovations, techniques, and the availability of resources) – we are able to analyse particularities in the societies we are investigating.

11 Gassmann 2005; Gassmann, Rösch, and Wieland 2006.

12 Brumlich 2018a, 316–318.

13 Olesen 2010; Olesen 2012.

14 For a more detailed compilation of literature on the spread of iron see Bebermeier et al. 2016.

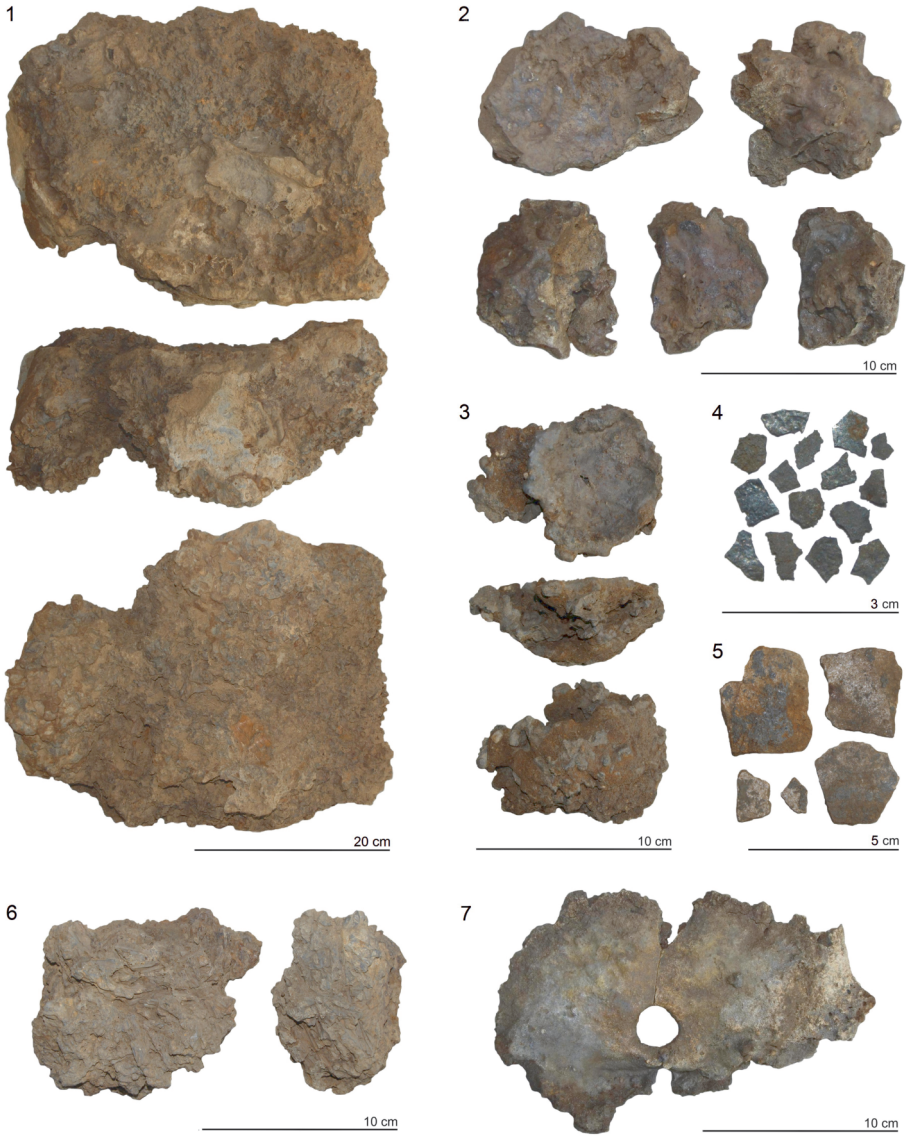

Fig. 2 Material culture of iron smelting and processing from the Teltow region: 1) slag block from a Glienick-type bloomery, 2) fragments of a bloomery furnace shaft, 3) typical calotte shaped iron processing slag, 4) thin hammerscale flakes, 5) splinters of an anvil stone with adhesion of hammerscale, 6) slags with botanical imprints (filling of the slag pit with straw), 7) forge stone fragment with nozzle hole. 1–7 originate from the archaeological site Glienick 2 (Teltow-Fläming). 6 originates from the site Mittenwalde 21 (Dahme-Spreewald). Illustrated finds are dated to the 4th/3rd century BCE .

We understand *culture* as an entity of human created characteristically, intellectually, artistically and formative benefits in a distinct area and period, including arts, language, ethics, religion, sciences, technology, laws, economy, and more.

The term *program* implies explicit and intended concepts of human actions in instrumental-analytical and normative ways that are the result of constant negotiation processes. The program determines the type of labor to be conducted in the natural sphere. Thereby, program functions on different scales. On a micro scale, *program* touches aspects associated with the technological knowledge of iron smelting and the subsequent processing steps, including the exploitation, pre-processing, and production of the required resources. On a macro scale, *program* expresses or regulates the demand for iron as a resource material for tools and weapons of a society. In times of rising armed conflicts, for instance, the increased demand for iron weapons is expressed in the term *program*. *Communication* is the direct link between culture and actors. Without *communication*, there is no correlation between human protagonists, no cultural orientated way of acting, and no means to exchange knowledge. *Representation* is the process of recognition, understanding and recording of an event of the natural sphere into a socially objectified understanding or sense of meaning and knowledge. *Representation* can be regarded as cultural memory of environmental changes that were perceived, and may lead to an adaptation of the program determining labor and metabolism. The perception of massive clearings of forests in mountainous areas due increased demand of wood for charcoal production, can be regarded as an example of the meaning of the term representation in the framework of the research group 'Iron as a Raw Material'.

3 Case studies

The case studies of the research group try to trace the first incidence of iron smelting in the respective study areas (Fig. 1). The applied methodological approaches and the state of research differ from project area to project area. As a consequence, the spatio-temporal availability of data, which can be used to feed the socio-ecological model, is also different in each case study region. In the following, the five case studies will be briefly introduced before the application of the model in the region of the Tyrrhenian Sea is presented in more detail. Table 1 provides an overview of the data sources in the respective case study regions that feed into the social-ecological model of Fischer-Kowalski et al.[15]

15 Fischer-Kowalski, Mayer, and Schaffartzik 2011.

3.1 The West Baltic region: unanswered questions

Little is known about origin and application of iron as a new raw material in the West Baltic region between Vistula and Neman. Although iron object like weapons, tools, and other objects have occurred from the whole period of the Iron Age,[16] research on the beginnings of iron production is still scarce. For the period between the 6th and 1st century BCEE, and also for the following centuries, the question has remained unanswered if the iron objects were produced from local ores or if these objects represent imports. While focusing on this research desideratum, the project carries out basic research on the reconstruction of the development of a local iron production facility in the Baltic region. Collecting enough relevant data to adopt the model for the West Baltic region has not yet been completed.

3.2 Teltow (Brandenburg): early slags and bloomeries

According to recent studies, the Teltow region, a ground moraine landscape in the middle of Brandenburg, was one of the regions that pioneered iron production in Central Europe. After a hiatus in settlement during the late Hallstatt period, the region saw a period of renewed settlement by populations associated with the Jastorf culture during the 5th century BCE (Ha D/LT A). It is highly probable that regional iron production also began in this same period, making it possible to assume that this production was directly related to the settlement activities of the Jastorf culture. The archaeological record for the subsequent period includes many pre-Roman Iron Age settlement sites exhibiting traces of iron smelting and processing, clearly indicating that iron metallurgy was established throughout the area. The production was organized decentrally within the settlements and was predominantly geared towards meeting local needs. The 'Glienick'-type furnace is a characteristic feature of iron smelting in the Teltow region, the reusable bloomeries are free-standing shaft furnaces with a slag pit lined with big stones and a working pit in front.[17]

Environmental conditions in the region were highly favourable for settlement as well as iron production. All the resources necessary were present in adequate quantities and relatively easily available. Bog iron ore, wood, clay and stones are at the top of the list the raw materials required for iron production. Bog iron ore constitutes the fundamental basis for iron production in the region. It has been possible to demonstrate through metallurgic analyses that the bog iron ore present in the region is well suited for iron smelting.[18] Clay and stones were needed to construct the bloomery furnace, wood for the production of charcoal, which served as fuel and reducing agent.

16 Nowakowski 1994.

17 More detailed information in Brumlich, Meyer, and Lychatz 2012; Brumlich 2018a.

18 Metallurgic analyses performed by Bernd Lychatz (Institute of Iron and Steel Technology at Technical University Bergakademie Freiberg).

Fig. 3 Test trench on the Glienick 2 site with two pits filled with different remains from iron smelting and processing (see Fig. 2). The border between dryland and wetland is visible in the background, a typical situation for Pre-Roman Iron Age settlement sites in the Teltow region.

In most cases, only indirect evidence has been found in the Teltow region for the human interventions in the natural environment performed to obtain the raw materials for iron production. For instance, although the presence of bloomeries and iron smelting waste in the settlements indicates that ore extraction did take place, no other traces of this activity have been found. However, direct evidence has been found for the extraction of building clay, in the form of large clay pits at the edge of the settlement Glienick 14 (Teltow-Fläming district), which has been extensively excavated.

There are no known events caused by the use of the natural resources for iron smelting. Proxy data obtained from the sediments of Rangsdorf Lake, for instance, do not support any statements about significant deforestation resulting from the felling of trees for charcoal production.[19] Moreover, calculations to determine the wood demand associated with iron production revealed that this demand was relatively low and could not have had a significant influence on the forest resources. No indications of exploitation of the existing bog iron ore deposits have been found either. Unlike the situation with respect to the island of Elba, described below, one would not expect to find that iron production had any serious impacts in the Teltow region, given the environmental conditions in the region, the resource base and the relatively small scale of production.

At selected settlement sites, field prospecting, geophysical measurements and larger- and smaller-scale excavations were conducted to learn about the local and regional structure of iron production.[20] The archaeological investigations uncovered many physical traces of iron production and processing (Figs. 2 and 3). In the absence of other sources, of the kind available for Elba or the Near East for instance, iron production traces constitute the principal foundation for the study of iron metallurgical activities in the Teltow region (Tab. 1).

19 Palynological analysis performed by Pim de Klerk (Karlsruhe).

20 Brumlich 2018b; Brumlich 2019.

Project region	labor	metabolism	event	material culture	program	communication	representation
Teltow	Exploitation of natural resources (bog iron ore, wood, loam, stones, water)	work force (extraction and transport of bog iron ore, loam, stones and wood; carbonization of wood; well building; processing of bog iron ore and loam; furnace building; iron smelting an processing) → products and waste	–	findings: loam pits, charcoal piles, iron ore deposits, bloomery furnaces, slag heaps, forges, wells finds: bog iron ore, charcoal, iron smelting slag, furnace wall remains, nozzle fragments, charred grains (slag pit filling), iron bloom fragments, anvil stones, forging stones of loam, iron processing slags, hammerscale , iron objects, stone tools (hammer stones, whetstones) environmental proxies: pollen and charcoal from lake sediments (Rangsdorfer See)	knowledge of the use of iron and demand for iron; application of knowledge about iron smelting and processing and its social and economic organisation	improvement of the production process	iron objects
Silesia	Exploitation of natural resources (ores, lumber)	work force (Exploitation of iron ore, loam and stone extraction, [transport,] lumbering, carbonization, smelting) → products and waste	depleation of bog iron ores	ore and furnace remains, slags, ceramic fragments, remains of a charcoal pile and of rectangular stoves	application of knowledge about smelting	Mining and smelting techniques	Cultural development, extension of knowledge

Tab. 1 (Part I) Available information to parametrize the social-ecological model after Fischer-Kowalski et al. in projects of the research group *Iron as Raw Material*.

Project region	labor	metabolism	event	material culture	program	communication	representation
Mesopotamia	–		–	Written and epigraphic sources, metal objects	–	development of prices	–
Elba	exploitation of iron ore, loam and stone extraction, development landing sites	work force for the exploitation of natural resources (lumbering, carbonization, smelting) → iron products and waste (e. g. iron slags and soot) , [transport,]	(air) pollution, erosion, overexploitation and shortage of wood resources	*Ore and slag remains, furnace remains, wracks, (landing and smelting) site pattern, (environmental proxies derived from alluvial and marine sediment archives: charcoal, slags, heavy metals), iron ingots, written and epigraphic sources*	Application of knowledge about smelting, [seafaring] forestry, carbonization, conservation of resources	Political decision to save resources *(senatus consultum)*, supply of armaments, fear of slave revolts	toponyms (e. g. "Aithále" means "The Fuming One"), global literal descriptions of deforestation and erosion (Pliny the Elder, Plato)
Baltic region	exploitation of natural resources (lumber, loam, iron ore) and preparation	work force (exploitation and treatment) → products and waste	–	*ore, roasted ore, slag, furnace remains, iron objects, pits*	application of knowledge of exploitation and preparation of resources as well as operation of the smelting processes	–	–

Tab. 1 (Part II) Available information to parametrize the social-ecological model after Fischer-Kowalski et al. in projects of the research group *Iron as Raw Material*.

Fig. 4 Pielgrzymowice, Lower Silesia (Poland). Slag-pit furnace from the Roman period.

3.3 Lower Silesia (Poland): iron mining in the Przeworsk culture

Iron production in Lower Silesia (southwestern Poland) was investigated in a micro region in the Widawa catchment in the surrounding of the town Namysłów (Opole Voivodship).[21] The data relies on archaeological surveys and sondage excavations at the small village Pielgrzymowice as well as percussion drillings and soil profiles in the vicinity of some prehistoric slag sites. The material culture in this project comprises ex-situ bog iron ore and iron slag samples and the remains of two slag pit furnaces from the Roman period (Fig. 4).[22]

People of the Przeworsk culture in Silesia exploited bog iron ores for iron smelting,[23] which occurred in the valleys of this old drift landscape. These ores developed near the subsurface and were probably explored by soundings with wooden sticks.[24] Therefore, the intensity of labor needed to exploit this type of ore is estimated to have

21 Thelemann, Lehnhardt, et al. 2016; Thelemann, Bebermeier, Hoelzmann, and Schütt 2018; Lehnhardt 2019, chap. 3.4.

22 Thelemann, Lehnhardt, et al. 2016; Thelemann, Bebermeier, Hoelzmann, and Schütt 2018; Lehnhardt 2019, chap. 3.4.

23 Bykowski 1997.

24 Graupner 1982; Evenstad 1801.

been moderate.[25] Overall, the small-scale iron smelting at Pielgrzymowice can be described as a technical process that is insignificant in terms of resource consumption and labor input compared to all other settlement activities (such as firewood procurement, agriculture, etc.).

Iron slags and bog iron ore samples were geochemically and mineralogically analysed in order to derive information on the suitability of the local ores as raw material and the efficiency of the smelting processes in local bloomery furnaces. The crystalline mineralogical composition of local bog iron ores is dominated by quartz and goethite. The waste products of prehistoric iron smelting are typical iron silicate slags.[26] Concentrations of manganese and phosphorus in the slags clearly point to the exploitation of bog iron ores as raw material.[27] However, recent bog iron ores only show an iron content of max. 45.4 mass % Fe (64.9 mass % Fe_2O_3) and thus would not be sufficient for prehistoric iron smelting. [28]

In summary, the project outcomes point to the conclusion that iron production was most probably only focused on local needs.[29]

3.4 The Near East: the beginnings of iron

The project 'The Beginnings of Iron' is focusing on the use of iron in Anatolia during the 2nd millennium BCE and, in particular, during the Hittite period (ca. 1650–1200 BCE). Its main goal is to shed light on the role played by this metal before the beginning of the Iron Age and the spread of smelting techniques in the Mediterranean.

In comparison to the other projects of the research group, which primarily consider archaeological records from a restricted geographical area, this project takes the whole area controlled by the Hittites into consideration. It can be observed that Anatolia was rich in all resources that are necessary for iron production, and they were distributed throughout the entire territory.

On the other hand, the material culture can be reconstructed not only on the basis of iron artefacts and fragments, recovered from the excavations at the capital Hattusa and other Hittite sites, but also, and especially in the light of almost 200 texts contemporary with the period under examination and produced in Anatolia. Such documents, in fact, contain a number of references to different typologies of iron objects, for instance tools, weapons, jewellery, and statues that were used in a variety of contexts and occasions. Therefore, they provide us with plenty of information on different aspects of the cultural

25 Küster 1999.
26 Thelemann, Bebermeier, Hoelzmann, and Lehnhardt 2017.
27 Gordon 1996; Photos-Jones and Atkinson 1998.
28 Thelemann, Bebermeier, Hoelzmann, and Lehnhardt 2017; Table 1 presents a compilation of major oxide concentrations of bog iron ores.
29 Lehnhardt 2019, 293.

sphere: trade, exchange, religion, and prestige, all included in the model under the labels of communication and representation.[30]

Indications about the knowledge of smelting techniques (program) are in contrast less explicit, since texts are almost all related to the cultic sphere. An evaluation of data concerning weights and dimensions of the Hittite iron objects, as they are reported in the textual record, and their comparison with artefacts recovered from the excavations, is one of the challenges the project is facing. The natural sphere is not immediately evident from the text sources themselves; therefore, the data base to feed the natural sphere of causation is weak in comparison to the cultural sphere.

3.5 The (Northern) Tyrrhenian Sea: iron mining and smelting

The project 'Iron Mining and Smelting in the (Northern) Tyrrhenian Sea' deals with the chronology and the reasons of the postulated shift of ancient iron smelting sites from the Tyrrhenian Island Elba to the Tuscan mainland.[31] Within this context, a focus is on the impact of iron smelting and the use of fuel on the landscape of Elba Island. As this project yields the clearest information on metabolism, it is described here in some more detail.

The mining of iron ore and its further processing on Elba Island in antiquity is an undeniable fact, meanwhile, the onset date of iron production is still not clear. Today's research tendencies assume two different age determinations: (1) an early one from the beginning of the 8th century BCEE and (2) a later one starting in the 5th century BCEE.[32] In addition, the abandonment of most smelting sites is not exactly dated. Common age determinations of both onset and decline of major smelting activities on Elba are linked to descriptions of the smelting activities found in ancient texts that only partly fit to the archaeological evidence.[33] Both onset and end of smelting are related to a shift of smelting activities from Elba to sites on the Italian peninsula. Reasons for the shift of the iron smelting sites are manifold and are, on the one hand, founded on political conditions like imminent danger by Greeks, Carthaginians, and/or Romans[34] and, on the other hand, it is hypothesized that an overexploitation of Elba's forest resources for fuel production forced the dislocation of smelting furnaces because of wood shortages.[35] Just as little is known about the abandonment of iron production in the

30 Cordani 2016.

31 The following socio-ecolocial interpretation of iron smelting reflects the state of the art as of 2016. For recent findings see Becker, Eser, et al. 2019b; Becker, Eser, et al. 2019a; and Becker, Conrad, et al. 2020.

32 Piccinini 1938; Bervegliеri and Valentini 2001, 49–56; *vs.* Corretti and Benvenuti 2001; Firmati, Principe, and Arrighi 2006.

33 Serv. *Aen.* 10.174; Strab. *geogr.* 5.2.6.

34 Cf. Maggiani 2015, 363–365.

35 Cf. *inter alia* Nihlen 1960, 8; Forbes 1964, 110; Harris 2013, 178; criticism: Grove and Rackham 2003, 173 – the hypothesis is archaeologically mainly based on an abrupt abandonment of all smelting sites in the mid-1st century BCE E, see Corretti and Firmati 2011.

area of Populonia and the of whole of Italy during the late 1st century BCEE and the upcoming 1st century CE; this date is deduced from a text passage by Pliny the Elder, which refers to an old decree of the senate to abolish mining in Italy.[36]

It is assumed that in antiquity deforestation, subsequent soil erosion, and the (air) pollution from furnaces[37] must have caused an ecological change on Elba Island, which should be mirrored in sediment archives. In addition, it is presumed that the problem of wood shortage is also reflected in the atypical distribution pattern of smelting sites on the island.[38] Although all iron deposits are located in East Elba, smelting sites are distributed all over the island.[39] As a consequence, it is supposed that iron smelting was conducted at locations on Elba where that it was easy and safe, with stable access by boat, access to wood, and running fresh water.

The main project objectives are the creation of a fixed chronology of the era of Elban iron mining and smelting with a start, end, and possible shifting date, as well as the reconstruction of the historical ambiance with the environmental changes in relation to the reduction process of iron. The data sources are prospections, surveys, mapping, and sediments, as well as small scale excavations and soundings.

3.6 Towards a socio ecology of early iron mining and smelting on Elba Island

Data currently available on Elba Island seem to be very promising for an application of the model (Fig. 5). The insularity and the complete abandonment of Roman iron smelting sites on the island not later than the middle of the 1st century CE, make it sound to choose this spatial and temporal frame.

A large range of material culture proves the abundance of ancient iron production on Elba Island. The most obvious markers are different types of slag fragments that are widespread over the island and the few remains of former furnaces consisting of loam and fireproofed stones, which are disappearing more and more. Bigger and smaller pieces of raw ore can be found in the riverbeds and at the beaches of East Elba. Iron blooms, ingots, and forged instruments are sometimes contextualized with fragmented pottery and *amphorae* in excavated workshops, on sunken cargo ships and in tombs. Visible or uncovered settlements are rare, superficial concentrations of sherds and the few stone structures suggest a denser grade of colonization.

36 Plin. *Nat*. 3.138; 33.78.
37 Cf. Vigliotti, Roveri, and Capotondi 2003.
38 Nihlen 1960, 4.
39 Corretti, Chiarantini, et al. 2014.

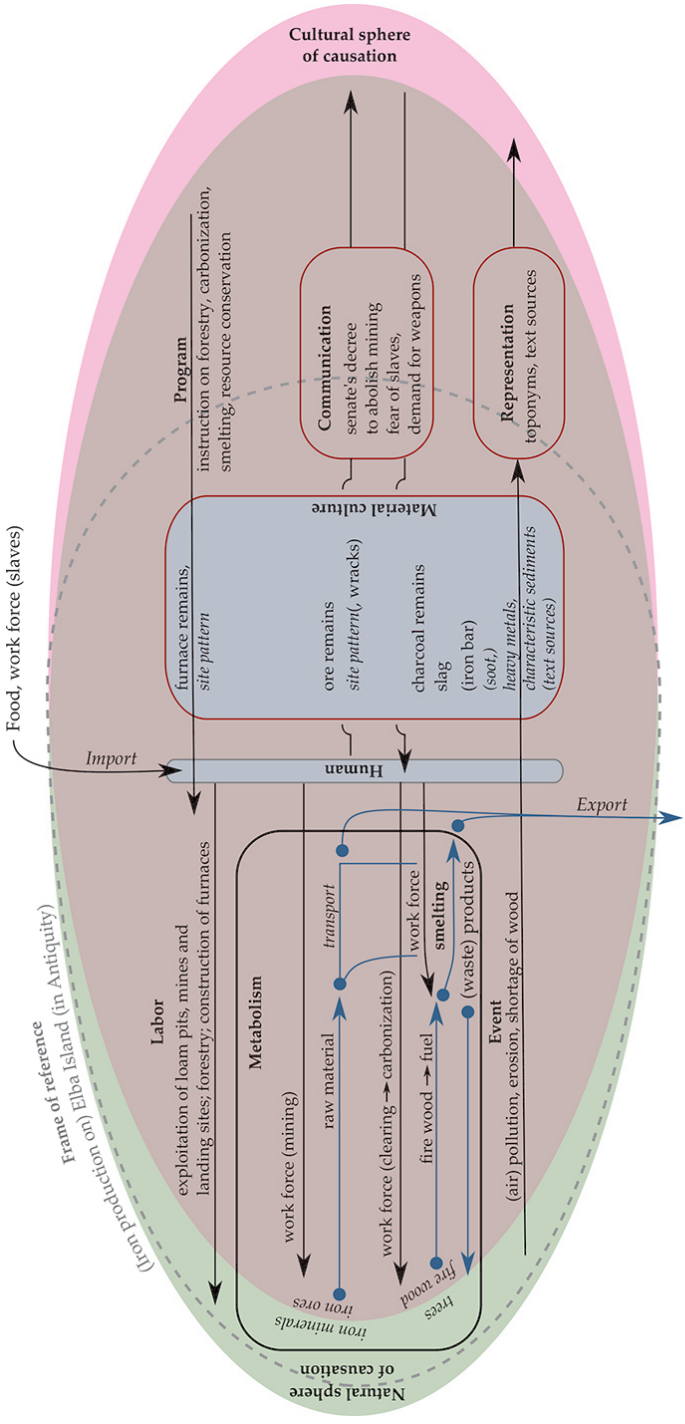

Fig. 5 The social ecological model of iron smelting on Elba Island during Antiquity (frame of reference—dashed oval line): material fluxes (blue arrows) of the iron smelting metabolism (bold box) and immaterial fluxes (black arrows) are highlighted; the sources under investigation in the present project are shown in red framed boxes; material culture *sensu lato* is emphasized.

The distribution pattern of the Roman smelting sites on Elba can also be interpreted as material culture, as the pattern might be represented by a specific means of resource utilization, including the transport of raw iron to places on the island providing the site characteristics required.

Also, sediment archives on Elba Island are in a way material culture that point to iron smelting. Slag and ore fragments deposited in the sediments, as well as the abundance of charcoal fragments in the cores provide clear evidence of iron smelting on the island. Preliminary results clearly indicate that the sediment facies are marked by phases of high erosion after deforestation for charcoal production, altering with phases of stability, with low accumulation rates as a consequence of reforestation or reduced deforestation.

Greek and Latin text sources refer to some aspects of the Etruscan and Roman iron technology; epigraphical evidence relative to iron production or its commerce is non-existent.

For the production of iron, it takes essentially three components: several natural resources, knowledge about the iron smelting process, and the hybrid entity 'human', which combines the other two elements via actions. Then, as now, the nature of Elba Island provides *inter alia*, iron ore deposits, forests, rivers, rocks, clay deposits, and the Tyrrhenian Sea as a transport medium (e.g. for raw ore, smelted iron, and other resources). For the extraction of these resources, humans have to invest energy for lumbering, mining, extracting, charcoal burning, transporting, and so on, corresponding to metabolism. In return for the yielded energy, humans can use nature's provided strategic resources for iron smelting: raw ore, water, charcoal, loam, wood, and fireproofed stones. Besides the consumption of energy, humans leave – next to the aspired products – mostly waste, e.g. slag or charcoal remains, but also air pollutants. With the initiation of iron production, humans had to place more effort into labor (e.g. valorization of nature) like the development of mines, clay-pits and landing sites, forestry,[40] construction of furnaces, shipbuilding for transport, and so forth.

Besides natural resources, which nature offers in a sense of affordances and which have to be first of all just recognized, the knowledge about iron processing is essential. This knowledge reaches actors via communication from their culture (the entity of human-created characteristic, intellectual, artistic, and formative benefits in a distinct area during a distinct period). Knowledge about iron smelting could have arrived to the Etruscans by trade (what is also communication) with other parties, e.g. people of the Middle East or by learning on their own when they, for example, recognized that the smelting of yellow copper ore Chalcopyrite (copper-iron disulfide) to copper delivers

40 Although no information on forestry on Elba Island is available, research from the Tuscan mainland discusses cultivation of tree species for the production of effective charcoal (e.g. Brambilla 2003; Wiman 2013).

another metal, iron. As the term communication also includes political decision making, e.g., the demand for weapons for Roman warfare is relevant for Elban iron such as Populonian's tribute iron to Scipio in 205 BCEE[41] or the communication about the fear of slaves[42] after the slave revolts in the Late Republic.

The instructions on iron smelting, on carbonization of wood, or on forging for the purpose of manufacturing raw iron, ingots, and instruments builds a program. The program of forest resources utilization and conservation on Elba Island is proposed to be inherent in the specific smelting site pattern.

At last, nature influences events by changing tipping points of process onset. For instance, the overexploitation of mountain forests to supply charcoal for the furnaces reduces vegetation cover and causes injury of the soil surface, and by this, increases exposure of the soil-to-soil erosion.

If the overexploitation of forest resources and, e.g., the soot emission of the furnaces are recognized and understood by the hybrid entity human, as well as are transferred into a social context like a written source, they are constituted as representations. In the case of Elba Island, the overexploitation of wood is deviated by the atypical pattern of smelting sites and the change in meaning of the island after the abandonment of smelting (for example by the construction of *villae maritimae*). Events of landscape dynamics are represented in different ancient text sources – although not relating to Elba Island directly – as accelerated soil erosion after clearing in Classical period Attica[43] or flood events after deforestation in the Roman era.[44]

4 Insights/summary

The single projects of the research group contribute in different levels of detail and on different aspects to the model. The scale of iron production, the state of research, and the material culture under consideration are identified as triggering factors for the parametrization of the model. In the project regions situated north of the Alpine Mountains, local iron productions are investigated mainly on the basis of the material culture related to the *chaîne opératoire* of iron production (Tab. 1). This source type allows us to directly obtain data on technical aspects of the smelting process (knowledge); the utilized natural resources; the scale of the production amount; and allows us to derive conclusions on labor (exploitation of natural resources), the efficiency of the iron-smelting metabolism, events (the depletion of a resource), and the cultural program followed in respect to iron production. In contract, it is challenging to get information on economic

41 Liv. 28.45.15.
42 Cf. Corretti and Benvenuti 2001.
43 Plat. *Krit.* 111a–e; cf. Weeber 1990, 21.
44 Plin. *nat.* 31.53.

and social aspects of iron production based solely on the remains of the material culture. Therefore, written sources, which built the primary source type under investigation in the project, about the possible beginning of iron smelting in the Hittite civilization have proven to be highly significant. In contrast, these texts do not refer to aspects related to the natural sphere of causation.

For the project focused on iron production in the Northern Tyrrhenian Sea, material culture and written sources are available to gain information about the social ecology of iron smelting. Iron was produced for export and not only for local demands. These prerequisites built the basis to derive a data base, which allows us to equally consider the natural and cultural sphere of causation in the sense of the socio-ecological model.

One challenge we have faced when discussing the model was how to define the frame of reference or the system under investigation. That was, for instance, illustrated in the example of the Tyrrhenian Sea, in which for the natural and cultural spheres of causation different system boundaries were considered: while the production process is located on the island of Elba, to a certain degree, aspects like *program*, *communication*, and *representation* have to be understood under consideration of the Etruscan Empire as a broader reference frame (Fig. 5). In summary, the application of the model seems to be most favourable when the research is founded on an interdisciplinary data base incorporating material culture and written sources, as well as paleo-environmental records, as it is the case for Elba Island. For this region, the application of the model facilitates the researchers to link interactions between the natural and cultural spheres of causation and to embed them into a wider causal network or socio-metabolism.

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Some Central Points in the Discussion of the Application of Fischer-Kowalski's Nature-Culture Model by the Topoi Research Group 'Economic Spaces'

Summary

The topoi research group 'Economic Space' has used archaeometric ceramic analysis as a tool to analyse space related economic structures in different projects ranging from the Neolithic to the middle ages. The paper gives an insight in the group's discussion of the Nature-Culture-Model developed by Fischer-Kowalski and analyses whether it' criteria and structure is of value for the groups research approach.

Keywords: economy; archaeometry; pottery analysis; nature; culture

Die Forschungsgruppe ‚Ökonomische Räume' des Exzellenzclusters Topoi hat in einer ganzen Reihe von Projekten, die vom Neolithikum bis in das Mittelalter reichten, mit Hilfe archäometrischer Keramikanalysen raumbezogene ökonomische Strukturen untersucht. Der Beitrag fasst die Diskussion der Gruppe über das Natur-Kultur-Model nach Fischer-Kowalski zusammen und beleuchtet aus verschiedenen Perspektiven den Wert für den Forschungsansatz der Gruppe.

Keywords: Wirtschaft; Archäometrie; Keramikanalyse; Natur; Kultur

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1 Introduction

The major project of the research team 'Economic Spaces' analyses economic activity in space through pottery, with a view to identify aspects of its production, distribution, and consumption as they are visible in site formation. In terms of methods and organization, the team works together and relies on comparative methods, drawing on a number of individual projects from very different regions of the Old World, including different eras with widely varying socio-economic and political forms of organization. The identification of production areas relies on typological and stylistic analysis, but even more importantly on archaeometric analyses. This type of analysis allows the types of clay, temper and other additions, firing temperatures, the malleability of the clay, and the modelling to be established using methods from the natural sciences, which can identify specific technological 'finger-prints' reflecting different production methods. This, in turn, allows various aspects of the production process to be isolated and analyzed. The devices used can also, in certain cases, testify to post-depositional changes.

Pottery is an ideal material for dealing with 'economic spaces' since it is among the most common types of material preserved at archeologically recognized sites and is, thus, present in statistically significant quantities. Areas and places of production can be identified and recognized archaeometrically and studied because – after firing – the material itself cannot be recycled; mixed messages are, thus, excluded by the nature of the material. Although individual pieces can be discarded or repaired, in general, the material cannot; thus, the objects tell their own stories.

2 Our approach

The research team divides economic activity into four stages, which are treated with different degrees of attention:

- production,
- distribution,
- consumption, and
- taphonomy.

Each of these stages can be situated graphically in the model proposed by Fischer-Kowalski so that, initially, each of the individual elements of the Nature-Culture model

can be presented separately. Of particular interest is the separation of *program* and *representation*, as consciously applied concepts separate from *communication,* as a largely unconscious process contributing to the formation of ideas.

Dealing with the *production* of pottery, *program* is the concept designating how a pottery vessel should look and how it is to be produced. This 'mental template' has significant cognitive implications, which are nevertheless difficult to evaluate; yet, these arbitrary features can be perceived and their distribution in space registered. The preferential choice and acquisition of raw materials can also belong here. Ordinarily, however, when dealing with clay, the choice of the materials is dictated by available resources and should, thus, be understood under *metabolism*. *Representation* is the means by which effect and message are embodied in the vessel itself and, e.g., determining how the vessel is to be understood semiotically. *Communication* allows us to recognize links through time and space, tacitly revealed through technical changes and stylistic aspects of pottery production and consumption; both intended and unintended consequences, conscious and unconscious designs, can also have an impact on the perception and evaluation of vessels.

The dialectic of these processes emerges from the *distribution* and *consumption* of pottery vessels. At this stage, one can enquire whether the intended reception of the vessels as produced is actually perceived in the same fashion when consumed – or whether consumption leads to changes, whereby *communication* and *representation* are confused. Psychologists and archaeologists have come to use the term 'affordances' to designate specific potentially interactive aspects of shapes (such as, e.g., handles), the purpose of which is inviting or easily recognized and exploited. Other possible applications of affordances can be concealed or go unrecognized. When the potential of the object is denied or not appreciated, the value of the affordance either disappears or takes on a new meaning. This depends not only on understanding unspoken tacit views, but also on the relationships between producers and consumers. It seems evident that when families or neighbors produce and use pottery, the communication is reduced to virtually nil, except when reciprocating foreign motifs on their local production. When, on the other hand, foreign wares arrive in distant lands, the 'exotic' understanding of value may fully eliminate any potential original meaning. As these issues are potentially speculative, simply confirming as many empirical points as can be positivistically registered is probably an important aspect of this work.

In our view, the central part of the graphic image of the model where nature and culture interact is the domain of *material culture* and *agency*. Each of these stages must be analyzed separately. Production itself should be located here, as well as distribution and some concrete steps of the consumption process.

The intervention in nature through *labor* involves the extraction of clay and other materials (temper; water; fuel, including wood, peat, dung, reeds, and bushes; etc.)

required for *production*. In a fashion that is determined in the specific form of the execution (carelessly or consciously), the ideal concepts of the *program* are transformed into reality as the raw materials are formed in the hands of the potter. Through enactment, this 'non-discursive embodied knowledge' takes shape. In certain cases – e.g., red-figured or white-grounded Attic wares – clear conceptual worlds may determine the *program* of both the craftspeople and the consumers dealing with the pottery. In most cases, ordinary table and kitchen ware involves 'non-discursive knowledge' embedded and embodied both in *production* and *consumption*. The choice and use of clays reflect such un- or sub-conscious conceptions, potentially leading to the formation of habits, which might on occasion be *program*.

Events can also determine changes in program, such as exhaustion of a clay deposit, heavy winds with an impact on wood supplies, or a drought hitting access to water both for pot-making and the entire community. Curiously through, ordinary wind and rain, taphonomic shifts in the material through erosion, etc. should probably also be located in *metabolism* – yet *metabolism* should also include the movements of the rivers depositing clay and the extraction of the clay by humans. The matter of deforestation or the mere search for fuel in arid regions may not influence nature alone, but may also lead to normative attitudes governing access to raw materials. Thus, metabolism, agency, and program come together.

Distribution exploits and develops the existing potential of the landscape, but interventions in the sense of *labor* are generally relatively limited, restricted to the use of water courses and favorable overland routes. Even in the case of the widely disseminated Terra Sigillata, distribution was largely done within the limits of the limes and the defensive road network.

For each individual project, understanding the landscape and its potential is probably more useful than the search for concrete cases of effects in the landscape.

Consumption, *labor*, *metabolism,* and *event/impact* are criteria that can only indirectly aid the analysis. Traces may reveal the places where certain goods were stored or consumed, how they were produced, and the impact on the environment their production may have had, but this will rarely offer definitive material. *Metabolism* and *events* are, however, probably decisive for *taphonomy.*

Above, we noted that when a foreign object arrives in another culture, it can lose its original intended meaning and gain another unintended meaning, potentially related to the appropriation of the object. This is part of a social process involving different cultures. For the archaeologist, it is also part of 'taphonomy' – the physical processes whereby an archaeological site is created (including the deposition and further fate of pottery vessels) – since the foreign vessel is part of the history of the development of the site. Yet this entire process is much more complex. When discarding rubbish, the activity is necessarily similar, but may not be associated with meaning. However, while

the ultimate fate of objects deposited in tombs belongs under taphonomy, the initiation of, e.g., a funerary pyre is a conscious act of *consumption* and *communication* tied to a specific taphonomic process ensuing from the deliberate and conscious use of certain objects for the ritual (which may also include feasting). Thus, the history of the site must be understood both socially and geologically – with any conclusions drawn about the development of the site being relevant to the interpretation of the social history of the site.

By contrast, e.g., the shifting of finds under the influence of erosion in an abandoned village probably belongs more properly under *metabolism,* in an unconscious sense of the unintended results of human activity. This particular case is important for the archaeologist to recognize and understand, but less relevant to the discursive nature of the pot itself in terms of 'economic spaces'. The excavation of clay and the exhaustion of reserves is also an issue of metabolism – but probably of limited relevance, aside from realizing that people generally chose clay that was easily available. This latter point is significant as it reflects an attitude that the resources did not determine the choice of habitation places, but rather the clay resources around the places of habitation were exploited (which differs substantially from the importance of, e.g., copper, salt, or iron, which were mined and became trade-goods).[1] Thus, in terms of the research agenda of the groups, the importance of *metabolism* (understood as human interventions in the environment) is rather limited in the periods and regions treated. However, securing fuel and water in arid regions admittedly had an impact on both the environment and human behavior.

Within our framework, the model can aid us not only in understanding human action in Antiquity, but can actually contribute to the discourse of the research team. This is best understood through the archaeometric analyses.

The concrete procedures lie at the intersection of our research program, the issues to be investigated, and the scientific approach adopted. Our results, as archaeologists – e.g., the chemical compositions and the localizations of the places of production – are *represented*. The continuous, initially unreflected discourse about the concept and result-producing methods form *communication*. The measurements lead to the discovery of the proportions of the naturally present chemical compositions and the properties of the material selected by the ancient potters, wiht which the pottery was produced, and the *program* delivers the classification framework for the organization of the results.

The model can, thus, be used as an auxiliary aid in structuring the relationships between the research questions, research sources, and the concepts upon which they are built. It is useful to have the individual steps in the areas of production, distribution,

1 Of course there are other situations, like in the case of the Roman terra sigillata-production e.g. in Rheinzabern, but these are not studied for this project by any members included in the group.

consumptions, and taphonomy identified as these are of some importance and, thus, easily recognized and analyzed. This entire structure fits in quite well with the *chaîne opératoire* concept – widely used in archaeology.

Analogous to our division of the four stages, as applied to the model, it would probably be best to add a temporal axis to the model by creating slices of time, whereby, the various shifts could become graphically recognizable. The same applies to the lack of a possibility of inserting spatial and cultural differences; however, a new graphical presentation of the model would be required for each culture, and reproducing this for each period recognizable at each given site or region, creating an image of 'economic space' for each culture at one point in time. Obviously, such a feature would become too complicated when trying to account for competing cultures (as in the case of the Nabateans and Romans in the centuries around the beginning of our era), as represented through pottery.

3 Case studies from the projects of the research team

The various projects of the research team take us through several millennia, from the Neolithic to the Middle Ages, and each project belongs to its own zone and level of development. To discuss the model we want to introduce five of our projects.

3.1 Corneşti-Iarcuri

The Middle and Late Bronze Age (ca. 1600–800 BCE) site of Corneşti-Iarcuri, surrounded by several ramparts in the Romanian Banat, is one of the largest prehistoric settlements in Europe. Given the enormous size of the settlement, our project aims to establish whether or not there was evidence favoring a centralized production of pottery in Corneşti. The abundant local sources of raw material provided the necessary material, but their uniform quality has hitherto meant that the specific deposits used have not as yet been identified. The same applies to fuel, as – in contrast to today – there must have been forests in the surrounding area. Clay was deposited by different types of waterways, some of which will also have supplied water while the settlements were in use.

At Corneşti, the technology of the pot-making seems to have been consistent from the Middle Bronze Age through the Late Bronze Age, but the materials used changed, potentially signifying that part of the *program* was maintained (in terms of communication) and part was altered (through changing sources). In this sense, the choice of clays would not be considered to be part of the *program* based on ordinary archaeological analysis. This question demands further attention, but the issue may not be resolved, as the

sources of the clay have not been identified. Furthermore, in the Late Bronze Age, it can be shown that there was a certain low-level regional exchange of pottery. Nevertheless, it can be suggested that most of the vessels were locally made. Unclear is whether there were potters active in the different parts of the settlement, or whether production was more centralized. Furthermore, the actual archaeological fieldwork has not hitherto revealed how usage differs from quarter to quarter and from house to house.

3.2 Lossow

Another example is Lossow, a Late Bronze Age and early Iron Age fortification (ca. 1000–600 BCE) with a large settlement and a cemetery outside the walls that served as a cult place, at least in certain phases of its usage. It is part of a group of fortifications specific to a local culture in Northern Germany and Poland. Their role within the settlement system and their significance in the political hierarchy are not yet sufficiently understood to allow firm conclusions about the prevailing sociopolitical relations. In a way, Lossow is an outstanding place due to a large number of ritual shafts within the fortification that are more or less unparalleled in the other sites.

A great number of 'turban rim bowls', a very specific type of bowl with specific demands in the way of production, have been analyzed from Lossow (fortification, settlement, and cemetery) and 20 other sites in the surrounding area, with the aim of establishing whether production of this highly specific pottery was centralized at the outstanding site of Lossow. As at Cornești, clay deposits, wood, and water are available at each of the sites whence the samples were taken.

The analysis of the raw materials used for the pottery reveals that the raw materials differ from site to site, so that there is no hint whatsoever of centralized regional production that can be linked to local, regional, or supraregional distribution. On the level of production and trade, no central function of Lossow could be identified. Typologically, all the settlements shared the same pottery type and similar value systems, but they produced the pottery themselves.

A surprising result emerges from the comparison of ceramics from the settlement and from the cemetery of Lossow. The raw materials used clearly differ, leading to the hypothesis that the vessels, including some 'turban rim bowls' from the burials, may have been produced individually as a part of the burial rites.

In the case of Lossow, it would seem that the pottery had some regional function in *representation*, but that the production and distribution *program* was localized. It would appear to be clear that the 'turban rim bowls' represent some common feature shared amongst the dead and the living in a community larger than any one single site (i.e., *program*). Furthermore, the production – using different firing temperatures and different materials – would suggest a distinction (*consumption*) that is related to burial rites, but

one which may also reflect a domestic role (*agency*). Further investigations may reveal more.

3.3 Musawwarat es-Sufra

The Meroitic sacral site of Musawwarat es-Sufra in the Sudan lies in the desert roughly 30 km from the Nile River. Most of its standing monuments date from the Meroitic period (300 BCE to CE 350). Evidence for pottery production comes from a secular quarter of the so-called Great Enclosure, a unique complex of temples which seems to have functioned as a pilgrimage center as well. In one of the huge courtyards of the enclosure, a pottery deposit was identified and investigated. Current excavations produced some 25 000 sherds and substantial production debris, as well as tools that had been used in the production process, such as stamps for decorating the typical Meroitic fineware.[2] In a nearby room, the lower part of a potter's wheel, i.e. the wheel bearing, had been found.[3]

Re-investigations of this room resulted in the discovery of a basin constructed of stone slabs and mortar, which may also have been used in the production process. ^{14}C-dates attribute the pottery production in this place from the 1st century BCE to the 1st century CE.[4] Next to wheel-made coarse ware, a very specific fineware was evidently manufactured at the site, accounting for about 10 % of the sherds in the deposit. Archaeoceramological analyses aimed to characterize the local production, both in terms of its output and its conditions.[5]

A comparison of the clay used in the Meroitic vessels and samples obtained in a raw material survey in the vicinity of the site showed that a major part of the pottery recovered from the deposit was indeed produced from wadi clays of local origin. This pertains to both wheel-made fineware and wheel-made coarse ware.[6]

An unexpected result of the project was the discovery that a small proportion of handmade coarse wares, amounting to about 1 % of the overall pottery corpus, was made from clays of non-local origin – meaning that they were imported to the site.[7] This pattern contradicts the common assumption that handmade pottery was produced and consumed on a household level, while sophisticated finewares derived from centralized production and were distributed over long distances.[8] At Musawwarat, the opposite seems to have been the case. So far, no exports of the typical Musawwarat pottery could be identified in any other contemporary site, suggesting that the production was

2 Näser and Wetendorf 2014; Näser and Wetendorf 2015.
3 Edwards 1999.
4 Näser and Wetendorf 2015.
5 Daszkiewicz and Schneider 2001; Näser and Scheibner 2013; Daszkiewicz and Wetendorf 2014.
6 Daszkiewicz, Wetendorf, et al. 2016.
7 Daszkiewicz and Wetendorf 2014.
8 E.g. Costin 1991.

really only to serve the site itself. This is clear from a comparison with the results of archaeometric analyses on pottery from sites throughout the Middle Nile valley.[9]

The next question concerned the conditions of pottery manufacture in Musawwarat. Clay was locally available, as was water, which derived from *hafirs*, monumental water collecting and storage installations at the site.[10] The archaeometric analyses suggest that animal dung served as fuel.[11] Since no kilns were found, it is assumed that the pottery was fired in open bonfires under quite basic conditions. All in all, the in-depth study combining archaeological, achaeoceramological, and ethnoarchaeological approaches and analyses has revealed an unexpected pattern of production and consumption, which calls for a careful evaluation of more generalizing assumptions about the degree of centralization and organization of pottery production.

In this case, *metabolism* is present through the creation of the reservoirs that maintain water, which would otherwise have run off. However, the water in the reservoirs will also have served humans and animals, as well as the manufacture of pots. The issues of *agency*, *production*, and *consumption* figure in the manufacture of pottery in a cult center, especially as there are no indications of diffusion beyond the site. Since the handmade coarse ware need not be understood as an issue of *representation*, it must be understood in terms of extra-local production and local discarding (i.e., *production* and *consumption*).

3.4 Petra

A very different model can be seen in Petra. Petra was the final station along the incense route by which incense was conveyed from Oman, South Arabia, Eritrea, and/or Somalia into the Roman Mediterranean. Petra owes its origins to the era of the consolidation of Hellenistic kingdoms, when the nomads began to settle down. The Nabatean Kingdom was annexed by Rome under Trajan. The pottery of the last century BCE and the first century CE would appear to reflect a social response to the encroaching power of Rome (*agency, program, communication*, and *representation*). Petra was built in a very dry area, so that specific water management installation had to be constructed in order to secure the water supply. Clay was locally available. Our questions included whether the widely distributed Nabatean pottery was largely manufactured in the Petra region and distributed from there, and whether the decorative program was also centralized. Thus,

9 A seminal corpus of reference for comparison is the "Sudan Database" (SDB) containing the results of archaeometric analyses of pottery found in archaeological work and raw materials from this region conducted by Małgorzata Daszkiewicz since 1991. The SDB currently comprises 1235 entries deriving from ceramic fragments dating from the Mesolithic to the Medieval period and 120 entries relating to analyzed raw materials.

10 Näser 2010; Näser and Scheibner 2013.

11 Daszkiewicz, Schneider, et al. 2015; Daszkiewicz and Wetendorf 2017.

we have the elements for an analysis, but only further research and access to further material (from other projects) will allow us to complete the process. A graphic using time slices might betray changes in the decoration and technology that might feed into an interpretation about a changing *program,* which could be reinforced should additional details about the clay be established in the coming years.

3.5 Olbia

The city of Olbia, originally a Greek colony, survived into the Roman era. In the 3rd century CE, the polis was destroyed twice during the so-called Scythian or Gothic wars and abandoned for some decades. At the end of this century, Olbia was rebuilt in an ancient fashion with a reduced *chora* of 5–10 km². The area was taken over by settlers of the Chernyakhov culture, who settled in former villages of the *chora* and all over the area in the late 3rd century CE. Water supply, clay sources, and wood (as fuel) were not a problem in this region; kilns for pottery production are known from Olbia. The project analyzed grey ware in time slices: on the one hand, the phase of Olbia and its *koine* of the 1st to 3rd centuries CE and, on the other hand, the pottery of the Chernyakhov culture. In the first phase, grey ware was mainly made with the same calcareous clay (CC1), probably at one place of production (as a hypothesis, one can assume in Olbia itself). Evidence of clay type CC1 at several sites indicates the distribution of this pottery throughout the polis and its *chora*. In the second phase, various non-calcareous clays were used. The pattern of production and distribution varies significantly; each village had its own production detected by specific local clay compositions and there is hardly any evidence of the distribution of ceramics.

Thus, one can recognize that the two different cultural groups had very different approaches to production and consumption. It is possible that in both instances, there was a subliminal *program*, but one based on very different premises in each of the two cases. This is doubtless of social importance, since it reveals the difference between urban and rural mentalities, while unfolding in the same place. Historically and culturally, it is not insignificant that the urban surroundings had no impact on the behavior of the intruders. In this case, comparing the time slices would be meaningless without taking into account the architectural context. Whether the model could aid us in understanding these cultural contrasts would be an extremely important point, for the archaeologically recognized 'economic spaces' do offer a meaningful contrast, whereas the model seems to be based on one single culture, which effectively renders comparison impossible or means that the model is not suitable to studying a succession of different cultures in one space, while potentially allowing for insights in the case of cultural successions (as at Nabatean Petra and the surrounding area).

The projects, thus, reflect very different socio-economic systems at very different

levels of development. The accessibility of the raw materials required for pottery production differs from case to case, ranging from easy access to precarious situations where securing the raw materials is associated with strenuous efforts.

4 Analytical value of the model

As such, the proposed model is an ecological model, whereby culture determines how individual societies relate to the world. Since the Neolithic of the Near East (beginning more than twelve thousand years ago), the activities of human beings have continued to have a gradually and increasingly substantial impact on the actual geomorphological world, more so than before that time. One obvious result is that since the end of the Palaeolithic the environment has been correspondingly less important in determining human behavior, with the environment becoming merely the stage upon which human history unfolds. This tendency is clearly socio-economic, with implicit economic forces generally having a far-reaching impact on human behavior, well beyond the impact of the explicit political forces.

The case of Petra takes us through the transformation of a station on the caravan trade in incense, into an outpost of the Roman Empire, and later to a forgotten ruin. The monetization of the incense trade allowed Petra to grow, while Rome gradually consolidated its hold on the east, yet the advent of Islam rendered incense irrelevant. Here, many different political and economic tendencies played a role, some implicit market forces (incense trade) and others explicit political forces (consolidation of the Nabatean Kingdom and later Roman annexation). The pottery reflects one part of this tale, particularly that of the era when the independent Nabateans were establishing themselves as a sedentary kingdom, and shows the interrelationship between identities and economy.

Significantly, however, the tendency for gradual inclusion has not been linear and many geographical regions have only gradually been drawn into the mainstream, long-term tendency towards production economies in complex sedentary societies. Significantly, real differences become apparent when examining regions in which two successive cultural groups occupy the same place, as at Olbia (a polis with a changing cultural environment) and at Petra (where the prelude to Roman conquest had very different results). In these examples, the role of social organization on 'economic spaces' is evident. The case of Olbia underscores that accessibility to raw materials is irrelevant to the socio-economic organization unfolding in an identical landscape with a different cultural *milieux*. In this sense, an ecological approach could be a useful angle from which to approach our material, as the ecology could testify to the cultural change.

However, with the concept 'economic spaces', our interest centers on the degree to which 'economic' forces are expressed in our material. Thus, our concern is primarily

the relationships between social structures affecting human behavior (the right-hand side of the model), rather than the relationship between society and nature (the left-hand side of the model).

The peculiarity of this model is that although we live in a world where it is assumed that universal supernatural economic laws apply to all human activity, economic behavior is not paramount in the model. This is naturally refreshing and certainly provides an opening for archaeology to isolate aspects of these developments.

Since the Fischer-Kowalski model is largely an ecological model, economic activities such as production and trade can be fitted into it, but they are not the primary concern. However, in a discussion with her, she said that she views trade routes as part of 'economics', which was drawn in from above (and outside the simplified form of the model). In this sense, the model is not explicitly designed to understand human economic activities, so much as to relate the human and human culture to the landscape that humanity uses a stage.

In economic terms, the usage of the term 'labor' is irritating, as it obviously is not connected to the labor concepts of economy, or only loosely. The dilemma can be overcome by dispensing with the word labor and using the term 'human interventions in nature'. For the ancient world, labor is better placed in company with 'agency'. This would, however, create a problem for us, as material culture is certainly a product of labor and must be fitted anew into the model. In this sense, remodeling the model would lead to a completely different version.

For the production of pottery, the analytical value of the model is always given in cases where clay, fuel, and water are difficult to find. This is true for fuel in arid areas (Musawwarat and Petra); the use of dung as fuel means that the pastoral groups have a role, providing perhaps also milk, meat, and leather, along with dung. Dung is associated with animals requiring grazing or fodder. It is also of great importance for pottery production in areas short or completely devoid of flowing water and, thus, dependent upon rainfall. The example of Nabatean ceramics shows that it is likely that a specific clay was needed to produce this extremely fine ware. Additional, environment-related efforts had to be taken into account to supply the producers with the right clay.

In all these cases, the cultural *program,* in this case, better 'the culturally anchored, embodied knowledge', can only be realized when there is an adequate supply of labor available to secure the supply of clay, fuel, and water. Events like dry periods can directly influence pottery production – the whole *chaîne opératoire* requires a sophisticated approach to nature.

For the analysis of distribution, the model is of particular value, as it offers the comparison between the infrastructure potential of the landscape and social and political spaces. Which distribution area was chosen: the one that allows you to go the longest distance in the shortest time the landscape allows? Or did people accept longer times

for their trade paths to reach areas that were less accessible? In comparing these two concepts of 'economic space' and working out the specific role of social, political, and ritual space, one can identify relevant questions and approaches, revealing that the model can serve as an inspiration.

For consumption, our sources allow two quite different insights. One concerns the manufacture of vessels for funerary pyres, where vessels seem to be made *ad hoc* for the pyre; whether the vessels were used for human (as opposed to divine or post-mortal) consumption during the ceremonies is probably a highly important aspect. At Musawwarat, analyses have provided insights into an unexpected production scenario of fineware pottery under the harsh conditions of the local environment. An answer to a question, however, always triggers the next questions: we must now ask, why the *program* of the Meroites accommodated local production, in contrast to importing fineware pottery from one of the urban centers along the Nile, and what the apparently reversed scenario of production and (non)distribution – with handmade wares being brought in, and wheel-made finewares being manufactured locally – can tell us about the representation of pottery in this specific context.

The model can be of the greatest value when dealing with taphonomic processes that influence the features in which pottery is found. Here, however, the whole model has to be filled with a different meaning, since many taphonomic processes are devoid of human influences, so that earth worms and rabbits, thaw-freeze-cycles, soil chemistry, vegetation cover, etc. become more important than humans – that is, until recent times. Modern agriculture is important because of its influence on the environment, with the resulting erosion processes and soil degeneration. More important, however, is how modern agriculture led to the uncovering of many archaeological sites and, thus, the birth of European archaeology. Yet, this aspect is not in the focus of the group either.

Summing up, the model can be applied successfully by the group to systematize observations on the interactions of potters and traders with the environment. The interpretation of the observations is, in general, beyond the model. The lack of a time scale implies that there is no real developmental possibility in the model. Beyond that, it seems to be restricted to one society and, thus, it is not necessarily helpful for interactions, especially where the social interaction (as at Olbia and Musawwarat) is actually part of the bigger research question.

Applying a more differentiated perspective, another view of the model can be developed, as the 'dissonance' given at the end of our paper may show.

5 Final remark: A dissonance

Excellence clusters bring many people from different fields together. These people do not necessarily all agree on a common framework. In our case, the model that underlies most of the contributions to this volume derives from a dispute internal to geography, namely, how to integrate physical and human geography into one and the same field, as well as into one and the same research project.[12] Archaeology crosses these divides as well and has taken different directions in trying to resolve this issue, from siding with the natural sciences (e.g. in processual archaeology), to making a place firmly in the *Geisteswissenschaften* (e.g. in traditional, culture history-oriented archaeologies and in post-processual approaches).

A group that focuses on the archaeometric analysis of pottery could position itself in the middle ground, straddling the divide by relying analytically on natural science procedures and ending up with a synthesis in the humanities. However, the basic model into which the present contributions are set leans strongly towards a systemic, natural science-based view of the world. Societies are considered to work coherently as machine-like entities or as organisms with a metabolic function, where extractions from an independently existing 'nature' are reworked and non-necessary matter is returned to this nature. Such a framework may be appropriate for (post-)modern conditions where capitalist production and the primacy of instrumental reason fuel a powerful machine that is currently destroying our external environment.

Is such a model universally applicable to culture and nature, or even to a small subset of culture? What is the status of the model's abstractions from concrete cases? Some members of this research group think that it is here that the approach does not provide a good fit for the group's goals, namely, the analysis of spheres of pottery production. Let us start with the major entities. Metabolism assumes an organic whole that is involved in exchanges of matter. Coherence, similar to an organism, is a necessary precondition for metabolic processes, even if they are only understood metaphorically. What is this organism in the case of pottery production though? A group of potters and the conditions of their material existence? If so, that should include their subsistence activities and, therefore, a simple archaeometric research agenda would not be sufficient for the requirements of the model.

The model conceptualizes labor as the goal-oriented extraction of matter from nature. This constitutes another problem, since it assumes that instrumental reason underlies interaction with natural resources. However, it is well known from all kinds of ethnographies that many groups consider the extraction of ore, and other materials from the earth to be a dangerous infringement, assaulting the earth and wounding it.

12 See Wardenga and Weichhart 2006.

The process of extraction is, therefore, often ridden with fears of punishment, so that ritual and magic are used to appease the powers of the earth. To apply such a situation to pottery production: the variable 'labor' in raw material procurement would have to include research on the ritual labor that is associated with such extractive work. Where is this kind of labor located in the model? Does it belong to the 'cultural' realm, which is conceived of as entirely immaterial and, therefore, unable to include these relations of production? It is worthwhile to point out that especially societies with limited hierarchical structures tend to conceive of work in a ritual sphere, and production, allocation, and consumption are not independent but dominated by rituals and beliefs.

Indeed, the underlying dichotomies of the model make it a reductionist scenario with respect to past realities. Nature vs. culture, material vs. immaterial, and metabolism vs. communication become elements of a strictly dichotomous world that includes a few bridging processes whose internal functioning is supposed to be: (a) the logic of instrumentalism, where we are concerned with the material world and (b) the logic of information transmission in the sphere of the immaterial. The complex intersection of material and immaterial worlds has been treated in depth, for example, in Daniel Miller's work and that of many other scholars.[13] They argue for the inextricable ontological unity of what we traditionally split into nature and culture.[14]

One of the most problematic elements in the model is the notion of a 'program,' the idea that action and thinking have a temporal structure in which thinking precedes action. Certain kinds of analytical philosophy may hold on to such an idealist view of the human capacity to act. However, this schematic view does not concur with practice theories in the social sciences, nor with concepts of action in the various technology-oriented approaches such as the actor-network theory (ANT).[15]

Borrowing from this model might be useful, especially for those processes in pottery making that have consequences for the environment, such as deforestation. However, the multifarious (past and present) modes of pottery production would need to be vastly reduced to fit into the model. In systemic terms, it breaks down the multiple variables that impinge on production, distribution, and consumption of pottery even further than does 'ceramic ecology';[16] an approach that has been criticized as technological and environmental determinism.[17] Reduction of complexity is one essential task of scholarly work that aims at explaining real-world processes; however, one can go too far down that road.

13 Miller 2005.

14 Descola 2013; Latour 1993.

15 ANT and the various strands of relational or symmetric archaeologies lean towards the opposite extreme by expelling intentionality and premeditated action altogether from their interpretive repertoire.

16 Matson 1965; Kolb 1989.

17 Gosselain 1998.

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Conclusions: The Applicability of a Socio-Ecological Model to Landscape Archaeological Research

1 Introduction

The various landscape archaeological projects discussed in the preceding chapters were tasked to investigate the applicability of the socio-ecological model outlined in the introduction to this volume. The goal of this endeavor was to explore the general applicability of this model for questions about human–environment relations. The attempt of the model to offer a comprehensive explanatory framework is especially useful in exemplifying discipline-specific positions and perspectives for the complex relations between human activities, social processes, and landscape dynamics. Discussions on the nature of the research subject arose that lead to new questions and new ways to approach such research objectives. Leaving the discursive meta-level and focusing on the specific project-related questions and problems, it becomes evident that the general and broad definitions of the socio-ecological model are not comprehensive enough for the constitution of one common research framework. This does not imply that the search for such a meta-theoretical model is useless.

As discussed at the outset of this volume, interdisciplinary landscape archaeological research has been undertaken in various fields of the Topoi Excellence Cluster under the umbrella topic of "Spatial Environment and Conceptual Design." In the following, we compare different viewpoints on the socio-ecological model of the various research projects reported in this volume. Three main challenges to the generalized application of the model are clearly discernible: space, time, and connectivity.

1.1 Space as a phenomenon of dimensional difference and discrepancy in resolution

The first phenomenon projects invariably tried to come to terms with is spatiality. Comparing spaces can involve entire regions, or, more frequently, localities. On both scales,

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problems with the underlying model became apparent, but to varying degrees. Näser et al. (project A-1) selected a range of study sites from a large territory. They did so to investigate aspects of marginality in their different dimensions. Regions reach from Spain to the Jordanian desert and from Turkey to the Ethiopian highlands. Based on a comparative approach, they discuss different varieties of colonized areas and colonizing intentions, as well as settling strategies. Comparisons of this kind are challenging, and the authors conclude that the application of the socio-economic concept is hampered by the lack of sufficient data indicating explicit past human-environment interactions.

Bernbeck et al. cover different dimensions of non-sedentary past societies, with a set of case studies reaching from Egypt to the Eurasian steppe and from Ukraine to Turkmenistan. They identify variable kinds of non-sedentary societies but comparisons between them are rendered difficult by the case-specific character of the landscapes. Entities considered in case studies sometimes have a regional, sometimes a place-specific character, and are highly different in terms of their temporal rhythms; three aspects that impede comparison between the individual case studies. To cope with the character of different spatial dimensions of the sites investigated, comprehensive criteria were identified to enable a comparative political ecology of mobility patterns in non-sedentary societies.

Berking et al. investigate different approaches of water management at several locations across the Mediterranean in order to examine whether locally used means were on-the-spot inventions or were introduced through the diffusion of knowledge or by immigrating people. Data considered is of a point-pattern but also of areal character, complemented by data of a larger scale character such as government structures and legislative texts.

In Schier et al., the spread of the wool-bearing sheep and related innovations was investigated in a region reaching from the Iranian plateau to Southeastern Europe. The long-term perspective reveals that different types of socio-ecological interactions occurred in one and the same period. The group observed that with the intensification of socio-ecological metabolism, economic regions expand by enlarging stationary pasture farming as well as non-sedentary pasture farming. As a consequence of the large spatial scale and the individual local dynamics, the authors regard an overall applicability of the socio-ecological concept with caution. However, the socio-ecological concept is applicable to individual phases and areas.

In the contribution of Bebermeier et al., the introduction of iron as a raw material is investigated for a variety of regions from early appearances in the Near East to Phoenician iron smelting in the Northern Thyrrhenian Sea, to central European iron smelting processes in the drift landscapes south of Berlin (the Teltow region), Lower Silesia (Poland), and the Baltic region. Iron smelting was carried out in different landscapes, allowing a comparison of diverging intensities of socio-ecological metabolism.

It needs to be remembered, however, that the introduction of iron smelting in each of the cases took place at different times and under different environmental conditions.

For the investigation of economic spaces in the contribution of Meyer et al., study sites across Europe and Northern Africa were considered. The spatial dimension of socio-ecological metabolism focuses on the economic aspects of space while ecological implications remain largely excluded. In the context of these investigations, marked distinctions between heterogeneous cultural contexts demanded a high resolution of cultural interaction data. Similar to the other case studies, this group concluded that the vast spatial extent of the investigated area and sites was problematic.

1.2 Time: Time spans and processes of varying diachronic resolution

Temporality also played an important role in the various approaches that sought to test the applicability of the socio-ecological model. Here again, differences in resolution – scales of time and rhythms of change – came to be regarded as important and often insurmountable issues for a successful comparative analysis. The age of the different study objects included in Näser et al.'s research spans times from the 5th mill. BCE to the 1st mill. CE. Consequently, the need for the inclusion of diachronicity is emphasized for the application of the socio-ecological concept.

In Bernbeck et al.'s contribution, the chronological framework of the different cases starts with the Epipalaeolithic and ends in the Iron Age (9000–300 BCE), focusing on the migration rhythms of non-sedentary societies. The authors assume that the socio-ecological concept permits only a rudimentary grasp of diachrone dynamics, and suggest an alternative concept of temporality that focuses on short, medium, and long-term processes from two perspectives: etic and emic.

The different water management systems investigated by Berking et al. were implemented between the Bronze and the Middle Ages and have been locally used until present times. The analysis of objects from different periods is required to understand whether the implementation of the specific techniques and management structures was developed locally or was due to the diffusion of knowledge. This differentiation between innovation diffusion and local invention could not be clearly ascertained.

In Schier et al., the temporal span of the investigations ranges from the 6th to the 3rd millennium BCE. Analyzing the diffusion of the invention of wool-bearing sheep required a conceptualization of time as internally coherent temporal slices. The researchers identified four major successive phases in order to capture changes in the size of the flocks, size of the individual animals, and the age and sex composition of flocks. As outlined by Schier et al., the socio-ecological model is not entirely appropriate for a full understanding of diachronic dynamics. Therefore, they suggest a discrete application of the socio-ecological concept for each phase of the innovation process.

Bebermeier et al.'s research focuses on the implementation of iron smelting technology and is thus chronologically confined to the (Early) Iron Age. However, as a result of analyses of the process of inventions, it was clear that the overall project needed to include a diachronic component, also accounting for a temporal offset in the development between the different study regions. As a consequence, each stage of the invention of iron smelting requires the application of its own socio-ecological concept.

The time span of the investigations of economic spaces in Meyer et al. ranges from the Neolithic period to medieval times. Economic actions are analytically separated into the into four steps of production, distribution, consumption, and taphonomy. Each of these processes is described separately and embedded into a distinct socio-ecological concept. The lack of a time axis in the socio-ecological concept is bypassed by a time-slice application of the concept to the respective processes.

Our various discussions have ended in the conclusion that time and temporality are two extremely difficult issues to deal with because our analytical approaches have become more and more precise. Time, chronology and temporalities remain crucial but controversial issues we need to deal with. A unified perspective is not to be expected in years to come.

1.3 Connectivity – The exchange between societies whose dynamics might follow different patterns of space and time

For Näser et al., social exchange is difficult to trace since the degree of physical remains available for investigation differs strongly, due to the specific character of each Research Area including different utilizations of environmental resources. A conceptualization of the underlying model is problematic due to difficulties of differentiating processes of labor and metabolism. Additionally, many pieces of data of explicit past interactions, constituting the main parameters of the model, are not available in the archaeological record, prohibiting investigations of connectivities; estimates might be possible but often lack a sound empirical basis. Therefore, these authors conclude that the model is not able to consider inter-social processes adequately.

The theme of connectivity in Bernbeck et al. is described by comparing the different etic and emic characteristics of short- to long-term processes. In contrast, Berking et al. focus on comparing the gains of inventions and the lifespan and implemented technical measures that contributed to the connection between different cultures at various times and with different natural environmental settings.

Schier et al. show that the spread of the wool-bearing sheep necessitates the spread of knowledge associated with this animal, hence a social exchange. As said, exchange systems can only be investigated within discrete time slices of before/after conditions. The moment of, and the processes involved in, social exchange need an extended model

version that offers approaches that join two socio-ecological systems.

In the contribution of Bebermeier et al., aspects of connectivity are illustrated in the developmental trajectories of the innovation of iron smelting. Here, research investigates specific patterns of socio-ecological relationships that emerged. Meyer et al. have another focus. Differences in production, distribution, consumption, and taphonomy of ceramics allow researchers to assess and model different areas and their socio-ecological relationships in discrete time slices, similar to the project on the "wool-bearing sheep".

2 Critiques and problems: the way forward

2.1 Time is implicitly integrated

The model of socio ecology is process oriented; hence, time is always already integrated. But implicit time turns into a problem when different process domains are compared such as variable spatial organizations of people or the diffusion of innovations within a society. Both may be related to the same cause, for example the implementation of terraces in a landscape, but their pace may be different. The necessary resolution for a disentanglement of variable temporal rhythms is not always accessible in historical and archaeological sources. In the end, this all boils down to a simple and well-known issue: dynamic processes cannot be observed by archaeologists. By definition, archaeologists investigate the static materiality of the past, not living people, animals, plants, or geomorphological processes. Dynamics, therefore, remain a black box. Stage-like evidence must be gathered and precisely dated in order to *infer* dynamic change. A secondary problem is the distance between such stages as we normally assume a uniform speed of change between them, even though this may be wrong. Accelerations and decelerations can only be identified within ever smaller temporal frames.

2.2 Time is continuous

Applying the socio-ecological model to landscape archaeological objectives requires reliance on a background model of objective time as a natural, continuously progressing phenomenon. Cause and effect of processes influencing human-environment relationships and social dynamics are external factors that can be explicitly defined in the present, by which we do not imply any determinism. Hence, we always observe meta-stable situations and conditions whose characteristics, a specific parameter setup, are the result of a system's history. In this regard, the level of meta-stability is closely related to the scale of a system and the process domain one focuses on. This becomes problem-

atic when one refers to diachronic analyses in landscape archaeological research. Due to the character of the source materials, conducting diachronic analyses in landscape archaeology normally means comparing materials whose characteristics indicate their connection to a discrete time-slice. Comparisons are made between differences of some elements during times n and n+1, and potential differences are recorded; this is only possible for those elements where changes are observable. Hence, a time-slice-oriented approach of diachronic research cannot follow the trajectories of change and might be misleading in: (a) overestimating the influence and importance of changes in parameters, (b) overlooking less sensitive elements of the system that might be the main driver of the change, and, consequently, (c) underestimating or misinterpreting the processes that caused the changes of/in material culture and impacted the environment. Additionally, the development from time n to time n+1 is an interpretation of the investigating researcher and, therefore, strongly related to her/his understanding and definition of, and focus on, the participation processes. The socio-ecological model cannot solve this standpoint problem. Nevertheless, in combination with an explicit application of the principle of uniformitarianism, it is helpful in developing and *communicating* contrasting and complementary scenarios in order to gain a better understanding of past conditions.

In summary, any location in the model possesses its own specific rhythms and speed of change. This makes the integration of an already highly problematic transformation of time-slices into the historical fluidity of change even more complicated. Uniformitarianism may help in the analysis of geomorphological processes. However, the application to rates of genetic change in domestication or genetic modifications during the intensification of agriculture and herding that accompany late prehistoric periods in the Middle East, for example, are unlikely to be modeled along such predictable lines. Predictability of human interference in nature is even less plausible. Another major issue that likely transcends the applicability of the temporal dimension of the model are scalar differences, a problem that will be addressed separately below.

2.3 Space

Space can be conceptualized as a tool to investigate processes that influence natural as well as social aspects. In such a framework, space can only be regarded as a measure of differences of geo-spatial locations. Questions about space are closely related to questions about time, and challenges are similar. Concerning processes, space and time only differ in their dimension; one could think of them as interrelated scales in a Cartesian coordinate system. Accordingly, space (like time) can be considered as a continuous element that is implicitly integrated in the process-oriented model of socio ecology.

Of course, space is far more complex than this. Nevertheless, as is obvious from

the different projects discussed, there is no common denominator of what particular features are necessary for a more human-centered definition of space and how such a perspective is able to integrate the different discipline-specific viewpoints. This becomes especially evident in the different methodological prerequisites of natural science and humanities approaches employed by research projects described here.

A conception of nature as a space of resources is at the base of the socio-ecological model proposed here. From it, relations of appropriation between human groups and nature are reconstructed which we have called 'labor'. However, this should not misguide us to think that the theme taken up in any specific case can enlighten us about relations between people and their spatialities. While some Eastern European or Near Eastern groups may have become nomads and thus largely reliant on the production and extraction of raw materials produced by sheep, wool included, this particular selection is only one, albeit an important, aspect for their spatial needs, namely pastures. However, nomads may have developed many other kinds of spatial needs such as hunting grounds, access to water sources, or the right-of-way to move around. These do not all depend on herding. The socio-ecological model discussed in our contributions must be understood to be selective by design. The selective application of the socio-ecological model, therefore, stands in contrast to the holistic aspirations of its basic structure.

The marginality projects in Näser et al. come closest to holism as used in the model, simply because many basic resources in regions such as Jawa, Resafa, and Petra are so scarce that large-scale, only partially overlapping catchment areas for water, lithic raw materials, and other elements of the cultural realm are necessary for simple survival.

2.4 Connectivity

Aside from the issues that arise from the conceptualization of space and time, there is another challenge put forward by all contributions to this volume: how to conceptualize connectivity. While the original model outlines relations between constituent parts, these relations are more or less dense in the research presented here. Connectivity between 'nature' and social groups may be high in the example of iron processing in the Tyrrhenian region since intense labor is mobilized to extract massive amounts of ore and turn it into useable materials. In other cases, appropriative labor may be much less developed, with lower mutual effects on the relationship between people and their natural surroundings.

Connectivity is mainly about the density of relations in a network. However, the quality of such relations merits close attention, as a comparison of our case studies demonstrates. First, the physical forces regulating flows of matter underlie the same laws in the present as in the past so that the principle of uniformitarianism can be applied. Such laws are much less widespread in the realm of living species, particularly in

human relations and historical processes. Second, and as a consequence of this, we face a certain asymmetry of the socio-ecological model as applied in this volume: the degree of predictability and calculability of connections or of diachronic processes and cause-effect relations is much easier to comprehend for the sphere of 'nature' than for cultural elements. In the realm of communication and other links between material culture and non-material culture, predictability (and, thus, the general assessment of presumed systemic relations) depends on: (a) the degree to which activities are driven by means-ends considerations, often invoked in our contributions or (b) routine human practices that have become an unquestioned asset of a culture over time. These two elements constitute a complex web of predictabilities that is intertwined with the vagaries of contingent actions of humans. Differences between single projects and complex research groups in this realm are due to the problems investigated; the successful upkeep of an irrigation system is dependent on both knowledge about when water flows, as well as on the specific needs of land and plants to be irrigated, but it is also a matter of social conditions, often in the form of a 'water bailiff'. Means-ends relations tend to be strongly developed in such an area. On the other hand, an intermittently practiced craft, such as pottery production in households, can be more open to ideological concerns. A greater distance or sheer economic calculation significantly diminishes predictabilities in the model.

A specific problem in the realm of connectivity are inter-societal contacts. How do we conceptualize and analyze contacts and changing socio-ecological conditions of two societies that follow different strategies in appropriating environmental resources to sustain a living? The investigation of innovation diffusion or trading contacts necessitates the integration of several socio-ecological models for one and the same case since an external influence, in this case the contact to another culture or social entity, influences each individual socio-ecological system. For material exchange, often in the form of a trade in goods, an integrated application of the model seems possible, although it is not employed in the case studies presented here. However, a great deal of inter-societal contacts is primarily of a non-material nature and mutual influences can only be observed when they leave material traces – and these mostly only mirror the consequences of exchange. Hence, the effect of inter-societal connections and their influence on the functioning of any specific socio-ecological system can only be exemplified under what Binford once called the 'Pompeji premise', the ideal condition of a sudden and highly unusual event that, while killing all life, leaves everything else complete and in place.[1] Under normal circumstances, it is only possible to refer to *before* and *after* conditions of contact between socio-ecological systems and assess the importance of such relations, while the process-related dynamics and their influence on specifics of the system remain in the proverbial black box.

1 Binford 1981.

2.5 Material vs. immaterial objects

The socio-ecological model as introduced by Fischer-Kowalski is set up as a conceptual framework for modern sociological research;[2] as a consequence, changes are needed to make it applicable to long-term histories based on environmental and archaeological data. It includes aspects that can be investigated and recorded physically, such as material processes and flows of matter. The analysis of texts and images – as secondary representational sources – is another dimension aiding in the understanding of cultural contexts. Additionally, social research can rely on oral interviews with different actors and stakeholders to understand cultural contexts to avoid misinterpretations stemming from too much reliance on secondary sources. Obviously, the tool of interviews is not applicable in archaeological investigations and most historical investigations. Therefore, the application of the socio-ecological model to historical and prehistoric contexts encounters the problem of not being able to include internal views to the extent suggested by the Fischer-Kowalski model.

In this book, the problem of the relationship between material culture and the larger natural sphere, on the one hand, and 'culture' as ideational, on the other, has been dealt with in two ways. Many examples locate themselves firmly on the side of analyzing the relations between material culture and natural conditions, to the detriment of an inclusion of norms and ideas that drove the actions of people in the past. Other contributions have attempted to include internal views in their relations to material culture and agency, but have neglected the ecological aspects, such as Bernbeck et al. Furthermore, especially when relying on textual evidence, the analyses of corpora of written documents for economic considerations build only a small sphere of what the socio-ecological model understands as 'culture', as explored by Becker et al. and Näser et al.

The division of the 'cultural sphere' in this model into an immaterial and a material world would seem to be in need of further discussion – the model fits easily with a source constellation in archaeology, with its material basis for the reconstruction of whole cultures; but it can neglect the often tightly knit whole that is 'culture'. Another issue is the evidentiary basis that serves the reconstruction of prehistoric and historical conditions. The further we move back in time, the less secure we can be that our insights are representative of the whole of a past society and culture.

2.6 It is all about scales

On the level of processes and their understanding, time and space share basic characteristics; they are dimensions along which temporal dynamics and spatialities (networks,

2 Fischer-Kowalski et al. 1997.

surfaces, etc.) of the case studies can be mapped. We have been investigating these records in terms of: (a) their patterning, which provides us with information about the pace and spread of certain phenomena and (b) their resolution, i.e. the amount of information accessible to us in relation to the dimension of the temporal or spatial domain.

Taking the two aspects of patterning and resolution together, one specific character of space and time that causes many of the problems for investigations of landscapes in archaeology becomes evident: *scale*. Research on a phenomenon such as the triggering of the textile revolution, seen from the perspective of the spread of the wool-bearing sheep, whose spatial domain is a supra-regional or even continental level, is certainly different from an investigation of the changing shape of a spindle whorl within the layers of an excavation trench. Nevertheless, they are taken to describe the same general process: the spread and diffusion of an innovation throughout space and time within and between societies. Hence, what scale really describes and refers to is the adequate material to answer certain hypotheses, but not the characteristics or effectiveness of processes. Interpretations are related to the *scale* the material refers to. Extrapolations of findings are valid only on the scale of the investigated material.

Time and space, but of course also connectivity as an element of time-space dimensions, are in need of scalar specifications. One of the problems of the socio-ecological model that dominates our contributions in this book is a preference for the large scale. There is an easy reason for this. Ancient technologies and ancient demographic densities were not prone to destroy large swaths of natural environment; rather, natural processes were likely to impinge on human groups, setting a temporal as well as spatial agenda for these groups. When we investigate the mutual relations between nature and human activities in the deep past, a measurable impact on natural conditions is likely to be the result of small-scale, repetitive, and routinized processes. Salinization, deforestation, extermination of overhunted species, and erosion due to agricultural intensification are all the result of long-term processes. However, these temporally large-scale phenomena are accumulations of small scale quotidian practices, from irrigation without drainage as the instigator of salinization, to charcoal production as a major reason for deforestation.

The complex interdigitation of scales is what we might call a 'scalar leap': how and when do small-scales and presumably inconsequential processes, whether natural or human actions, transform into large-scale changes? Conversely, we might ask when and how large-scale phenomena change smaller routines and structures. The latter, for example, the moving out of a desiccated landscape, may seem to be an evident response to environmental problems. However, we are also concerned with thresholds of change. Many environmental changes probably occurred without fundamental consequences for past societies, as they were resilient enough to endure a certain degree of detrimental alteration of their living conditions.

Scalar leaps are those points in the dynamic relationships between nature, mate-

rial culture, ideas, and human groups where we need to assess closely in which of the components of the socio-ecological model we can identify changes in resilience and vulnerability, leading to a re-arrangement and re-scaling of the adaptive cycle itself – or even to its decomposition. Such scalar effects are not necessarily always processes of decline and degradation; the interpretation of scalar leaps as advantageous or detrimental depends on our own perspective. Traditionally, the development of a highly productive sedentary village life with agriculture and herding has been seen as a major positive development in human history offering surplus production, leisure, and the development of entirely new technologies such as the wheel, animal traction, the plow, or pottery. Recently, however, ecological understandings have sprung up in which 'late Neolithic resettlement camps' are seen as ecologically impoverished and overly specialized, disease-prone entities that needed a constant influx from the outside in order to subsist in the long-run.[3]

Going back to the application of the socio-ecological model in landscape-archaeological research – using it as a meta-theoretical tool to connect our different research questions, problems, and results – we need to state explicitly what scale we are referring to when conducting such research. At the same time, we need to exemplify at which point our detailed investigations produce new insights for our hypotheses. This is what we gain when using the socio-ecological model: hypotheses, connecting aspects referring to space and time.

3 Scott 2017.

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