APPENDIX 1 Case Studies

Maya Swidden Agriculture and German Allotment Gardens

Q'eqchi' Maya Swidden Agriculture in Belize

This case study is located in the Toledo District, Belize, where there are 42 Maya villages with populations ranging from 70 to nearly 1,000 (mean = 28; Toledo Maya Cultural Council 1997). This area is a wet tropical, evergreen lowland forest (Meerman et al. 2003) with mean annual rainfall approaching ~4000 mm, mostly occurring during a distinct rainy season from June to December. The earliest contemporary Maya villages in the Toledo District date to the late 19th century (Toledo Maya Cultural Council 1997; Wilk 1997, Downey 2015). Bordering Guatemala to the south and west, and the Caribbean Sea to the east, Toledo has been referred to as "the forgotten district" because it was long neglected by the British colonial government. This contributed to the maintenance of a large proportion of the land in the district as property of the monarch of England up through Independence in 1981, when it became property of the government of Belize. The lack of significant private land may have benefited indigenous populations because it made available forested land for swidden farming with little external regulation or oversight.

Belizean Q'eqchi' cultural norms surrounding household-level land tenure dynamics have been explored ethnographically, and historical and political factors have also been studied (Thompson 1930, Wilk 1997, Downey 2010). Throughout the 20th century, Toledo experienced numerous attempts to develop an export economy, including bananas, oranges, lumber, hogs, and coffee. Over the past 20 years, fair trade cacao (McAnany and Murata 2006), ecotourism (Stinson 2013), illegal rosewood cutting for export to China (Zempel 2014); and most recently, oil exploration (Campbell and Anaya 2008) all impacted the region's economy and cultural transitions. Each phase of natural resource extraction was followed by a period of neglect, and this pattern became a cycle in which the Q'eqchi' had periodic opportunities for wage labor, followed by a return to swidden subsistence (Wilk 1997). And while there is some internal migration from Q'eqchi' villages, often seasonally, for wage labor in agriculture and tourism industries, emigration to the United States is less common from Belize than from other parts of Latin America. The study area has also been the focus of intense legal battles with the Belizean government (Medina 2016), and the villages have in recent years been successful as the courts in Belize and the Caribbean Court of Appeals have upheld petitions for community land rights. This has been a significant legal victory with direct implications on community land management and swidden agriculture.

Labor exchange networks in Toledo exhibit unexpected levels of hierarchy and connectivity without top-down coordination. The Village Chairman and a local leader known as an *alcalde* are responsible for the overall health of community lands, but they have rarely monitored day-to-day land use activities (Downey 2010). Other social norms and aspects of Q'eqchi' culture and beliefs suggest that local swidden exhibits a conservative ethos. However, the lack of quantitative data specifically supporting this, and poor models for explaining the dynamics of swidden systems generally, have inhibited the development of an understanding of this coupled human-natural system. Ongoing research by Sean Downey and colleagues (2016-2021; NSF BSC #1553875) is focusing on collecting data and analyzing the coupled dynamics of Q'eqchi' social norms regarding land use

and labor reciprocity. They are also investigating tropical ecosystem dynamics to assess whether local carrying capacities related to maize production are enhanced by human land use activity.

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Urban Allotment Gardening in Southwest Germany

The case study took place in Baden-Württemberg, southwestern Germany (Teuber et al. 2019), the state known for its capital, Stuttgart, with its global corporations, Mercedes Benz, Porsche, and Bosch. Besides metropolitan Stuttgart, the state has several rural districts where so-called "hidden champions" (Simon 2009) – little known companies that are world leaders in their business sector – provide employment and contribute to the development and growth of the German economy. Although Germany is a highly industrialized country that provides its inhabitants with ample food and many opportunities to spend their free time, gardening is and has been an important activity in the daily life of many Germans. In 2016, 8.4 million of the approximately 82 million inhabitants gardened several times a week, and 17.3% worked in the garden several times a month (Destatis 2017, Statista 2018). Several of those gardeners do not have access to gardens at their homes, but lease a garden plot from a municipality. Some of these allotments belong to the biggest German allotment association Bundesverband Deutscher Gartenfreunde e.V. (2019) with almost a million members. The allotments leased at rather low rates are located within an enclosed area in which the local representative of the allotment association is responsible for the enforcement of German law, which requires each gardener to grow food on at least one third of their plot (BKleingG 1983). Generally, each gardener tends to a plot of approximately 370 m², and all plots consist of a small cottage, vegetable patches, flowerbeds and lawn (Bundesverband Deutscher Gartenfreunde e.V., 2019). The overarching allotment association promotes organic gardening management practices. However, each gardener decides individually which practices are used in his/her allotment. In order to investigate these management practices and garden use in German allotment gardens, the ResourceComplex tool was used to identify variables interacting in the individual gardens. Using the variables soil, plants, tools, and knowledge as a starting point, a questionnaire was designed and applied in 6 allotment garden areas located in metropolitan Stuttgart and Villingen-Schwenningen, which is a town in a rural district (Teuber et al. 2019).

Cooperation within the German allotment areas is limited to the maintenance of pathways and the clubhouse or playground, and voluntary networks that individual gardeners establish. This differs from community gardening, as found in many American cities, where the garden is managed cooperatively (Armstrong 2000, Ghose and Pettygrove 2014). Allotment gardens similar in size, history, and management practices to the ones found in Germany exist in England and France (Nilsen 2014); and in Greece, Finland, Estonia, and Poland (Noori and Benson 2016).

Studies in recent years have shown that the gardener's motives for gardening range from food production to leisure activity. Similarly, the allotment gardeners in southwestern Germany value recreational aspects (Teuber et al. 2019). The comparison of metropolitan and rural allotment gardens showed that food production is more important for the latter (Teuber et al. 2019). The gardeners interested in food production retain the social-ecological memory of food production, as was first mentioned by Barthel et al. (2010) for the Stockholm allotment gardens. Further differences between the regions are the management practices used by the individual gardeners with new methods being more frequently used in the metropolitan gardens.

Both the urban and rural gardening systems have in common that out-of-equilibrium conditions are created by the gardeners within the boundaries of their plots. First, the management practices of adding compost or manure to the plots creates out-of-equilibrium soil conditions in the metropolitan and rural allotment gardens. Further, both systems have a higher biodiversity than the surrounding areas within the towns and cities where the gardens are located, thus creating another out-of-equilibrium space in the cityscape. As food is cheaply available in supermarkets and in farmers' markets in both German regions, even the time spent in the garden can be considered out-of-equilibrium, if one only considers economic reasoning.

Triggers for the establishment of allotment gardens have been times of crisis, such as industrialization, and the post war periods after World War I and II (Nilsen 2014), which led to the formation of the first association in 1921 (Bundesverband Deutscher Gartenfreunde e.V. 2019). Regime shifts in the gardening community might occur if food production becomes less important within the allotment gardening community. If the allotment gardening law were to change in the future, a regime shift in the gardening community might be possible.

Applying the favor/disfavor dichotomy to the two, surveyed regions indicates that, climatically, Stuttgart is more favored. The soil properties of the allotment gardens in both regions are good, so there is no favor/disfavor dichotomy connected to soils. However, the space required for allotment gardens is less contested in the rural region, as there are fewer conflicts of interest between gardens, infrastructure, industry, and housing, making it favored.

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Black Forest Agriculture and Bronze Age Land Use in Southwest Germany

Agriculture in the Heights of the Southern Black Forest

The Black Forest is a mountainous area in southwest Germany covering an area of 6000 km^2 and reaching elevations of 1500 m.[1] Apart from the valleys, the natural conditions are nearly alpine. Compared to the Rhine River valley to the west, the mean annual temperatures are much lower and the mean annual precipitation is significantly higher. In the southern parts, the main geological substratum comprises crystalline rocks, such as granite and gneiss. The soils are usually described as acidic, poor in nutrients, and containing many stones.

[1] This case study is based on fieldwork as part of the research project: Archaeological and natural-scientific investigations on the land use history of the southern Black Forest' financed by the German Research Foundation (DFG).

Historically, the Black Forest is seen as a classic, disfavored region for agriculture. Nevertheless, some authors point to the local existence of soils with a high suitability for agricultural uses (Hädrich and Stahr 2001).

Flint artifacts prove that there was discontinuous land use for hunting or pastoralism in the Paleo-, Meso- and Neolithic times, and pollen analyses show that people changed the forest tree communities for short periods in the Neolithic, Bronze- and Iron Ages; and in Roman times (Rösch 2000, Wagner 2016). From early medieval times onward (Haasis-Berner 2010), archaeological finds and colluvial deposits (Knopf et al. 2012) suggest that humans started to develop and settle the Black Forest systematically.

Since the 1980s, numerous 'stone mounds' of different shapes and sizes have been reported in the area of the town of Titisee-Neustadt. Several thousand of these obviously anthropogenic residues are now documented, mainly on the tops of forested hills and on slopes. Systematic field surveys using LiDAR and mapping were undertaken on two hills near Neustadt, and three mounds were excavated on a hill with an elevation of 1060 m (Knopf et al. 2016). As a result, the stone mounds can be described as resulting from agriculture. The slopes were terraced, and the excavated mounds consisting of irregular stone piles contained remarkable amounts of charcoal. The spatial distribution of the stone mounds suggests that relatively flat areas on the tops of the hills were left open to practice agriculture or grazing. The overgrown areas were cleared of vegetation (by burning the wood), and the stones were gathered. Radiocarbon dating indicates at least two phases of land use, with one possibly starting in the late 15th century CE, but most probably happening in the 16th century, with a second taking place in the 18th or 19th century. The land use can be imagined as a kind of temporary swidden agriculture with breaks in tillage every five or six years, as is known in other parts of the Black Forest (Reif and Katzmaier 1996, Reif and Katzmair 1997, Henschel and Konold 2008). Intensive land use started with a growing population and the introduction of commons. It is interesting to note, that the land use with stone mounds largely coincides with the Little Ice Age (15th - 19th century CE), reflecting challenging climatic conditions for food production.

Classically defined, disfavored topographical conditions were turned into more or less useful sites by investing a huge amount of labor. Social, political, and symbolic factors, however, could have contributed to the cultivation of this so called "marginal" land.

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Bronze Age Land Use And Settlement Dynamics In Southwest Germany

The northern pre-alpine foreland of southwest Germany is a diverse mosaic of geographic landscape units. In an ongoing archaeological-archaeopedological project[2], we are investigating settlement and land use dynamics in three physically distinct areas during the Bronze Age, especially the Middle Bronze Age (ca. 16th – 13th centuries BCE). Based on physical geographic parameters, e.g. shorter vegetation periods, lower average temperature, and higher precipitation associated with increasing elevation, two of them (Baar and Western Allgäu) appear to be disfavored compared to the third (Hegau).

During the Bronze Age, new technologies, such as the pulled scratch plow and the bronze sickle emerged, along with new species of crops and cattle (Behre 1998, Falkenstein 2009). One of the effects of these developments was a general intensification of land use for food production. Larger fields were kept open for longer periods and tilled more deeply, resulting in drastic soil erosion in many places (Vogt 2014, Dreibrodt et al. 2010, Henkner et al. 2017). At the same time, the remaining forests increasingly became open, oak-dominated forests used for grazing (Rösch 2013; Rösch et al. 2014). Another major characteristic of this period was the increasing importance of interregional exchange of copper, tin, amber, salt and other resources, as demands for steady supplies grew along with technological and cultural developments (Woltermann 2014, Kristiansen and Suchowska-Ducke 2015).

[2] "Favour - Disfavour? Development of resources in marginal areas" under the supervision of Prof. Dr. Scholten, Prof. Dr. Knopf and Dr. P. Kuehn in the Collaborative Research Center SFB 1070 RESOURCECULTURES, financed by the German Research Foundation (DFG).

The spatial distribution of archaeological sites seems to attest to the importance of such exchanges: many sites from the later Early and Middle Bronze Ages are situated on hills or outcrops, often referred to as "hilltop settlements," along larger river valleys. Their actual function as permanent settlements is often debatable, as is their exact age, but it seems clear that they were in some way involved in the structuring of exchange networks (Köninger and Schöbel 2010). During the transition towards the Middle Bronze Age, changes occurred in the distribution of settlement types. Earlier (ca. 18th and 17th centuries BCE), "pile dwellings" on the lakeshores had become the predominant settlement type. Some of these were quite heavily fortified, which seems to identify them as junctions or nodal points within the interregional exchange network (Köninger and Schöbel 2010). During the Middle Bronze Age, the lakeshores were quite suddenly and almost entirely abandoned. This was usually related to a phase of deteriorating climate and rising water levels, which lasted for several centuries and prevented resettlement of the lakeshores until the 11th century BCE (Menotti 2001; Magny 2004). At the same time, the number of inland settlements (around the hilltops) multiplied. This is most evident in the Hegau next to Lake Constance and might, therefore, be seen as a direct reaction to rising water levels. However, it can also be seen in the allegedly more disfavored landscape units of the Baar and Western Allgäu further inland. Climate change and the resulting disappearance of the ephemeral lakes alone cannot explain why settlement of these remote regions should have intensified. Instead, other factors must have played a role in this dynamic, perhaps adding to the hardships already imposed by climate change. In a cultural system that increasingly focused on long-distance exchange networks, the connective topography of certain regions could obviously have become a key resource: in the Baar, the great Danube River springs, and it also connects to the northern part of southwest Germany, while the western Allgäu comprises the main watershed between the Danube and the Rhine River systems, connecting both.

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Coastal Aquaculture

Clam Gardens on the Pacific Northwest Coast

Beyond the soils and landscapes of upland environments, human cultures have had complex relationships with aquatic resources and the boundary between land and sea throughout the Holocene, for example, through the creation of clam gardens. Over the past century or so, the development of the aquatic sciences and soil sciences as independent disciplines has largely prevented the application of soil and landscape concepts in aquatic environments. However, collaborations over the past two decades have begun to bridge these fields by adapting soil and land management practices and perspectives to subaqueous landscapes (Kristensen and Rabenhorst 2015). This may ultimately bring modern territorialities of aquatic resources more in line with those of prehistoric Holocene peoples, at least some of whom actively managed "clam gardens" as complex adaptive systems long before the advent of modern aquaculture.

On the North American Pacific Northwest Coast, tribes of the Kwakwaka'wakw Nation built clam gardens by rolling cobbles and boulders from existing clam beds, piling them in bulwarks near the low-tide line. This caused sediment to accumulate on the shoreward side of the bulwark, building a terrace that was exposed at low tide and covered by shallow water at high tide. This allowed the expansion of optimal soils for clam beds near settlements. Clam gardens were maintained by continuing to move exposed rocks and other debris to increase the available sandy habitat for clams, by practicing selective harvesting to maintain clam populations, and by regularly disturbing the soil using digging sticks to improve soil conditions.

The Kwakwaka'wakw had a basic, useful soil taxonomy, calling black and rotten-egg smelling soil *kwen'xlis*, which would produce unpalatable clams called *ya'yeks* (Deur et al. 2015). These soils have only recently been recognized as "monosulfidic materials" by modern soil taxonomists (Wessel and Rabenhorst 2017). The Kwakwaka'wakw would dig these soils to aerate them and to allow the silt and clay to be carried away by the tide, preventing the formation of *kwen'xlis* and maintaining sandy clam habitat.

Individual clans claimed clam gardens and maintained them for generations, with a belief that the clams were related to humans and would make themselves available for harvest if cared for. Some members of these tribes still harvest clams at these gardens, though no longer build or actively maintain them for artificially high carrying capacities for clam communities (Deur et al. 2015). Clam gardens originated at least as early as 1000-1700 years ago on Quadra Island in British Columbia, Canada, indicated by optical luminescence dating of core samples (Neudorf et al. 2017). Clam gardens improved food security and built more resilient coupled human-ocean systems, improving marginal environments with a territoriality that identified the value in cultivating this land (Jackley et al. 2016).

Achieving this type of territoriality, which allows the active management and improvement of marginal, submerged land for aquaculture, has been a challenging task in many parts of the modern world due to the public trust doctrine, which dates to the Roman Empire and was subsequently adopted by English common law and modern nation states. Under this doctrine, submerged lands are held by the government for public use, particularly to preserve the navigational use of the waterways. Many possible submerged land uses involving private property rights are generally prohibited by this doctrine (Rindner 2011). This may actually decrease the

resilience of modern settlements by preventing the adoption of aquacultural practices that helped to maintain prehistoric peoples for centuries. Nonetheless, recent legislative changes in some parts of the world are expressing a territoriality that values private management of submerged lands, enabling their creative use as community resources (Beck et al. 2004).

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Maryland Oyster Management and Barren Bottom (Chesapeake Bay, USA)

In the Maryland portion of the Chesapeake Bay (United States), classification of what may be considered marginal or disfavored submerged land underscores the dynamic and subjective nature of favor and disfavor. Maryland's eastern oyster (*Crassostrea virginica*) population has historically been managed utilizing the designation of 'barren bottom' (Kennedy and Breisch 1983, MD DNR, 1997). This terrain ranges from soft, easily penetrable muddy sediment, to hard scoured sand, to less commonly, but still possible, oyster shell left as remnants of an earlier, much larger oyster population. Though the content of 'barren bottom' varies, the designation is typified by a general absence of living oysters (Kennedy and Breisch 1983). Recognized as disfavored to some, this estuarine bay bottom is highly valued by certain groups and holds higher import than what the label of 'barren bottom' suggests.

While unlikely habitat for large numbers of wild oysters, barren bottom hosts several species of clam (*Mercenaria mercenaria*, *Mya arenaria*, and *Tagelus plebius*) that, in addition to filling an ecological role, provide a source of income for commercial clammers (Baker and Mann 1991, Homer et al. 2011, MD DNR, 2018). Sand and mud sites that typify barren bottom also provide nursery habitat, foraging grounds, and overwintering locations for blue crabs (*Callinectes sapidus*), another commercially important species (Dittel et al. 1995, Seitz et al. 2001, Seitz et al. 2003). Barren bottom exclusively is the area available for private leasing for oyster aquaculture. Oyster aquaculture, the farming or cultivation of oysters, has existed in the Chesapeake for several centuries, but was a limited industry in Maryland until legislative changes in 2009-2010 (MD DNR 2010, Webster and Merritt 1988). Even so, over a century of regulatory changes center upon barren bottom, highlighting the irony that what is deemed disfavored terrain continues to be socially, politically, and ecologically valuable and favored.

Conflicting claims to barren bottom are further complicated when considering the changes in the environmental and cultural aspects of the Chesapeake Bay as a complex adaptive system. Maryland's oyster population is a small fraction of its historic size due to a combination of inputs, including habitat loss, overharvest, oyster disease, and eutrophication; all exacerbated by warming water temperatures (Fulford et al. 2007, Kennedy and Breisch 1983, Wilberg et al. 2011, Mackenzie and Tarnowski 2018). As ecosystem engineers and providers of numerous ecosystem services, oysters play a large role in their systems, and their population decline contributed to the Bay's current regime and recurring dead zones (Dybas 2005, Coen et al. 2007, Diaz and Rosenberg 2007, Grabowski and Peterson 2007, Dumbauld et al. 2009,). Accordingly, a dramatic increase in the number of oysters – through both restoration projects and oyster aquaculture – is viewed by many as the potential key to a healthy Bay, though that remains a lofty goal (Fulford et al. 2007, Mann and Powell 2007, Beck et al. 2011, Bricker et al. 2017). Paired with other actions, oyster restoration efforts could lead to a new regime and state of the Bay, however, the socioeconomic implications of such a shift may not be welcomed by all. As rights to submerged land continue to change, questions of best use and equity are raised. Through ongoing work to understand participation in oyster aquaculture in Maryland, the impact of expanded no-harvest sanctuaries and privatized aquaculture leasing on local livelihoods is being investigated (2016-2018 Maryland Sea Grant SA75281600D; 2018-2020 NSF BCS1822266).

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Table A1.1 Summary of Case Study Data Evaluated Under the Rubric of Complex Adaptive Systems Criteria

Criteria	Q'eqchi' Maya Swidden Agriculture (Belize)	Urban Gardening in SW-Germany	Agriculture in the Black Forest	Bronze Age land use in SW-Germany	Clam Gardens on the Pacific Northwest Coast (Canada)	Maryland Oyster Management (Chesapeake Bay, U.S.)
Nature of land use investigated (contemporary or archaeological)	Contemporary	Contemporary	Archaeological	Archaeological	Archaeological	Contemporary
Favorability/ unfavorability (defined exogenously, endogenously, or both)	Defined both exogenously and endogenously: unfavorable for swidden cultivation (Atran 2002) due to high annual precipitation and soil leaching; favorability has previously been defined historically and relatively. Q'eqchi' communities tend to view land use more favorably	Defined exogenously: Stuttgart has a more favorable climate than does rural Villingen-Schwenningen (Baumüller J 2008; DWD 2018); no difference in soils (Teuber et al. 2019); spatially, the rural region is favorable due to less contested spaces	Defined exogenously: Black Forest as a classic unfavorable region (soil, temperature, precipitation); some resources (wood, metal ores, control of trade etc.) important, therefore favorable aspects; depending on time, scale, and specific culturally determined resource use	Defined exogenously: considering the relative suitability of areas for Bronze Age agriculture, emphasis on social/immaterial needs (including burial/ritual sites, trading routes etc.) in the assessment of a landscape's favorability.	Defined exogenously and endogenously: First Nations that practiced clam garden aquaculture saw these areas as favorable and able to be improved; most modern societies view these areas as unfavorable due to legal/cultural traditions inherited from Antiquity.	Defined exogenously and endogenously: oyster leases are limited to areas designated as 'barren bottom', a classification that originated with the Yates Survey in 1906 (Kennedy & Breisch, 1983) and typified by a lack of oysters, thus, seemingly unfavourable; today a contested space for multiple public fisheries, private aquaculture, and even nearby landowners
Scale of the investigated system in space and time (small: local/months to years; medium: regional/years to centuries; large: geographic units/decades to millennia)	Small: approximately 12 villages, 700 people, 77 km^2, and ~150 yr history.	Small: 2 towns, 6 garden associations, 167 gardeners, 2 yr investigation, history of garden associations dating back to the World Wars	Medium: Field work in ca. 100 km^2 around one town (Neustadt) and probably a dozen farms, focus in time ca. 400 yrs (1500-1900 CE), in Early Modern times, ~1000 people	Large: three levels of spatial scale: (i) individual settlements with their daily activity zones of several km^2, (ii) local networks of several (cooperating?) settlements, spread over a few dozen km^2, and (iii) regional networks of	Medium: largely restricted to the Pacific Northwest Coast, particularly in the Broughton Archipelago and islands between Vancouver Island and the continent (Deur et al. 2015), managed by clans from	Medium: the Chesapeake Bay estuary spans 11,600 km^2; Maryland oyster management includes several centuries of public and private (aquaculture) fisheries in the northern portion of the Bay; fisheries vary in size and now include ~3,000 commercial watermen and fewer than 500 individuals licensed to harvest aquaculture oysters; 69 individuals involved in Maryland fisheries were interviewed, participant observation was conducted with over 100.

				settlements in larger landscape units of several hundred km²; temporal frame: Bronze Age (~ 2150 - 800 BCE) with emphasis on the Middle Bronze Age (~ 1650 - 1250 BCE).	1000-1700 years ago to ~1930s	
System boundaries (clearly defined and understood or poorly defined)	Clearly defined: household organization and intra-village ties are very important; regional and global connections also important, particularly due to government, NGOs, churches, and international development efforts; the region is being affected by climate change -- precipitation is becoming more difficult to predict which is impacting crops	Clearly defined: Nested system of (i) the individual garden managed by a gardener(s); (ii) the gardening association each garden belongs to; (iii) the overarching German allotment garden association which issues rules and regulations according to German law; each garden as an intricate system of humans and nature	Clearly defined: household and farming organization for single farms, network with other farms and relation to town, probably clearly defined within rules and norms how to live and farm; religious boundaries (Christianity); physical boundaries by topography and climate	Poorly defined: system boundaries are based on modern assumptions due to the lack of specific historical data	Clearly defined: (i) individual clam gardens, defined by a bulwark at the seaward side and the shore on the landward side, and bounded by water depth (ii) organizational and archaeological, with a single clan generally maintaining one garden or area of gardens, (iii) contemporary, where these are maintained and well delineated as public trust resources that the public can use for recreational clamming during the correct seasons	Clearly defined: the Chesapeake Bay is an extremely dynamic estuary experiencing wide-ranging salinities (0.5 ppt/freshwater in its upper tributaries to 30 ppt/saltwater near its mouth at the Atlantic Ocean) as well as seasonal hypoxia and anoxia; political and management boundaries are also well defined in the sense that Maryland fisheries management oversees Maryland waters of the Chesapeake Bay.
Adaptation (individual or community level adaptation or	Individual & community adaptation: Q'eqchi'	Individual & community adaptation: individual	Individual & community adaptation: expansion of	Individual & community adaptation: evidence for	Individual & community adaptation: land tenure	Both: Individuals within Maryland fisheries regularly adapt to dynamic system conditions and respond to sociopolitical inputs

adaptation through policy, or both)	households as primary unit of social and economic decision making; health and wealth as important measures of success.	gardeners decide management practices; local gardening association influences decisions; success is measured through yield and taste of products	agriculturally used areas; investment of labor; success measured in wealth (size of farm and amount of land)	frequent interregional trade during the Bronze Age in SW Germany points to swift distribution of ideas and technologies as means for adaptation	maintained by lineages from nearby settlements; management information passed orally and via experience; success measured by both obtaining a good harvest and by leaving enough clams behind to maintain the population	(regulatory restrictions, catch limits, etc.) by adhering to fluctuating rules and laws; job satisfaction and the ability to feed one's family define success
Out-of-equilibrium conditions within the studied system (yes or no)	Yes: swidden systems worldwide suggest increased biodiversity (Balée 2006), and possibility of increased hunting returns in swidden fallows due to increased food sources for prey, source-sink dynamics, or sustainable off-takes (Bird 2015).	Yes: the gardeners are creating locally enhanced carrying capacities; highly diverse plant communities in the different gardens lead to a high plant biodiversity and in turn create habitats for fauna	Yes: woodland is turned into fields, meadows and bushland; forested areas massively declines; energy input by man-power for clearing forest/building terraces etc.	Yes: deforestation, plowing, manure management, building burial mounds etc. changed the appearance of landscapes; to maintain these states or to minimize undesired effects, a constant input of energy was applied.	Yes: clam populations were maintained at higher than natural levels by creating habitat and managing populations; clam gardens require construction and maintenance; moved boulders and cobbles change the sediment regime to build the platform; regular digging prevents sulfide accumulation and washes away fine particles, maintaining sandy habitat	Yes: the current reduced oyster population may be an out-of-equilibrium condition created by combined inputs of overharvest, habitat loss, and oyster disease (Wilberg et al., 2011) exacerbated by warming temperatures (Mackenzie & Tarnowski, 2018); progress in storm water and runoff management and increased inputs of oysters via restoration and aquaculture may contribute to a path toward an alternate state (Fulford et al., 2007).
Social and natural feedback effects within the analyzed system (yes or no)	Yes: Swidden fields are placed intentionally with respect to historical forest	Yes: gardeners increase soil fertility, which enables them to grow a diverse set of	Yes: most probably new cultivated land was used due to rights of ownership, but	Yes: Socio-cultural and technological developments (growing demand for	Yes: larger clam populations would have positive water quality and	Yes: policy changes in 2010 reorganized submerged land classifications to create larger no-harvest oyster sanctuaries, reduce available bottom for public oyster fisheries, and expand the potential

	use, local norms regarding nominal land 'ownership', past productivity, and expected future benefits; visible spatial mosaics	plants, which provide habitat to fauna, which increases the biodiversity of the area; combination of up to 100 gardens with different management practices in one association creates a mosaic of plant and animal communities	also commons existed which had to be dealt with by agreements (which parts of the mountains & terraces could be used when); feedback dynamics possibly caused by climatic problems/crop failure/erosion problems that led to adjustment in the use of the mountain fields and terraces	fields, lumber and fuel) are likely reasons for intensified land use and erosion, especially during the Early Bronze Age (Henkner et al. 2017, Dreibrodt et al. 2010; Vogt 2014). Soil degradation may then have encouraged a shift towards more extensive land use and the settlement of former "marginal" areas. Consequently, expanding settlement networks would have become more complex as well, potentially promoting socio-cultural changes in turn.	habitat impacts for the ecosystem at large and would improve the resilience of the coupled human-ocean systems; larger clam harvests would support larger human settlements, who would be better able to maintain large clam gardens.	development of oyster aquaculture; more oysters in the water, presumably increase many ecosystem services, and a much larger number of active oyster aquaculture operations, which also could enhance ecosystem services.
Evidence of emergence (local interactions, self-organization into hierarchies, unexpected/unex-plainable system-level properties) within the investigated system (yes or no)	Yes: village labor exchange networks exhibit unexpected levels of hierarchy and connectivity without top-down coordination	Yes: local networks between the gardeners within an association; regional networks between the spokesper-sons of each association; a (flat) hierarchy exists between the individual	Yes: system is dominated by local interaction of the farmers; differences between "richer" and poorer" farmers (amount of land use and invested labor); centralized control (or at least agreements) necessary for commons.	Yes: settlement networks may be clustered around local or even regional nodal points (e.g. within trading routes) and could comprise a differentiated set of settlement types (along with burial sites,	Yes: landforms and large clam populations emerge from the clam garden management; communities located near highly productive clam gardens would have experienced greater food security and may have	Yes: recent, locally increased submerged aquatic vegetation (SAV) populations may be an emergent property due to (i) better storm water, pollution, and nutrient management at local and watershed levels and (ii) potentially increased ecosystem services provided by oysters via restoration and aquaculture, though the relationship between oyster aquaculture and SAV is debated (Dumbauld & McCoy, 2015; Ferreira & Bricker, 2016; Orth et al., 2017).

		gardeners, the spokesper-sons of the association they belong to, the regional networks and the country-wide garden association.		functional places, etc.) which may have organized themselves; no clear evidence for any kind of centralized decision making in SW Germany during the Bronze Age.	grown larger over time.	
Alternative regimes possible (yes or no)	Yes: transition to a grassland regime due to cattle ranching in combination with political and economic factors; villages exhibit varying degrees of socioecological resilience due to variation in environmental and geographic recourses, and historical and social factors	No (and Yes): Due to the German law, allotment gardens do not currently exhibit alternative regimes; but, food production becomes less important due to the availability of cheap fruit and vegetables in supermarkets & farmers markets	Yes: creation of mountain fields and terraces might have been caused by a regime shift (growing population); with a change in the 20th century to less agriculture and more handicrafts, industrialization, & tourism, the mountain fields & terrace system was abandoned; the traditional, big farms in the region have existed since the 15th century and point to the resilience of the system	Yes: marked shifts between lakeshore/ wetland and inland/ terrestrial habitats from the Early to Middle and Middle to Late Bronze Age; differences in local chronologies of cultural and land use changes may indicate varying levels of resilience	Yes: with a lack of active management, soil conditions change, clam populations decline, and other organisms increase in abundance, leading the system to shift from productive clam beds to muddy and sulfidic flats	Yes: local water quality has improved in some places; major storm events can dramatically revert local improvements back to what may be considered a largely unfavored state; sociopolitical inputs may lead to an alternative regime in which there is no public oyster fishery
Are there triggers (material or symbolic) in the investigated system (yes or no)	Yes: material improvements in road infrastructure trigger regime shifts towards market integration (Chomitz and Gray 1995); recent legal decisions in favor of community land rights	Yes: World Wars as historic triggers to start urban gardens in Germany due to food shortage; provisioning of a healthy free time activity during industrializa-tion promoted	Yes: population growth leads to more demand for food; more manpower enables forest clearing for fields; the Biblical duty of Christians to tame the wilderness (forests and mountains) as a symbolic trigger.	Yes: material trigger "Bronze metallurgy" led to a reevaluation of areas; Middle Bronze Age abandonment of the lakeshores is usually correlated with climate deterioration and rising	Yes: the European-inspired legal system made management strategies illegal; recently the National Park Service has considered allowing subsistence clam gardening in some areas, and many	Yes: both material (climatic/weather) and symbolic (policy) triggers may affect the system. Major weather events can destroy or alter estuarine habitat and coastal communities, and extended weather patterns during a single season can hinder recruitment and survival; the system has been affected by far-reaching 2010 policy changes designed to catalyze oyster aquaculture and trigger a regime shift into a self-sustaining oyster population.

	could be symbolic triggers for the development of novel forms of community land management	among others by factory owners (Nilsen 2014, Keshavarz and Bell 2016); recent symbolic triggers: wish to be outdoors and experience nature		water levels	states and the US Army Corps of Engineers have implemented systems of permitting and promoting bottom management for aquaculture; a material trigger is the initial moving of stones to build the bulwark	