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# Reconstructing Human-Centered Interaction Networks of the Swifterbant Culture in the Dutch Wetlands: An Example from the ArchaeoEcology Project

**Philip Verhagen** [1,*], **Stefani A. Crabtree** [2,3], **Hans Peeters** [4] **and Daan Raemaekers** [4]

1    Faculty of Humanities/CLUE+, Vrije Universiteit Amsterdam, 1081 HV Amsterdam, The Netherlands
2    Department of Environment and Society, Utah State University, Logan, UT 84322, USA;
     stefani.crabtree@usu.edu
3    Santa Fe Institute, ASU-SFI Center for Biosocial Complex Systems, Santa Fe, NM 87501, USA
4    Groningen Institute of Archaeology, Faculty of Arts, University of Groningen,
     9712 CP Groningen, The Netherlands; j.h.m.peeters@rug.nl (H.P.); d.c.m.raemaekers@rug.nl (D.R.)
*    Correspondence: j.w.h.p.verhagen@vu.nl

**Abstract:** In archaeology, palaeo-ecological studies are frequently used to support archaeological investigations, but linking and synthesizing datasets and concepts from ecology, ethnography, earth sciences, and archaeology has historically been rare. While advances in computational approaches and standards of data collection have enabled more collaborative approaches to understanding the past, these endeavors are only now beginning to pick up pace. Here, we propose a method to collect data of these assorted types, synthesize ecological and archaeological understanding, and move beyond subsistence-focused studies to those that incorporate multifaceted economies. We advocate for the use of 'human-centered interaction networks' as a tool to synthesize and better understand the role of culture, ecology, and environment in the long-term evolution of socio-ecological systems. We advance the study of human-centered interaction networks by presenting an archaeoecological (archaeological-ecological) perspective on the Neolithic transition of the Swifterbant culture in the northwestern Netherlands (approximately 4700–4000 BCE). We employed network science to better understand the relationships of animal and plant species to the uses that people made of them. The analysis of the Swifterbant system reveals a highly connected set of interactions among people, plants, and animals, as could be expected on the basis of the hypothesis of an 'extended broad-spectrum economy'. Importantly, this broad spectrum extends beyond the subsistence sphere.

**Keywords:** human-centered interaction networks; archaeoecology; Swifterbant culture; network analysis

## 1. Introduction

Ecosystems as they exist today are the end-result of the long-term interaction between humans as they spread across the globe and the environments they encountered. Indeed, no ecosystems today exist without human influence. To truly understand ecosystems as they exist today, we need to examine how humans in the past modified and changed these ecosystems for their benefit. While niche construction theory seeks to understand how humans modify the environments around them (e.g., [1]), there is a great opportunity for studying the human place within ecosystems using the archaeological record.

One such opportunity to study how humans adapt ecosystems is by looking at the introduction of crop cultivation and animal husbandry (sometimes referred to as 'neolithization'). This process played out differently across the world, yet often societies continued to interact with the non-domesticated ecosystem in addition to their domesticates (e.g., [2]), leading to a richer economic package.

In Central Europe, this process is primarily associated with the spread of the Linearbandkeramik or Linear Pottery (LBK) culture that, from 5500 BCE onwards, introduced

agriculture to most of the area [3]. LBK culture is characterized by drastic socio-economic changes: people started to live in larger houses and larger groups, and introduced a number of (cereal) crops and domestic animals [4] to the region, leading to population growth [5] and changes in the natural environment. LBK culture displays a high degree of social organization, but also shows signs of internal conflicts [6]. Later, around 4000 BCE, crop cultivation and animal husbandry spread farther west and north to Scandinavia and the British Isles, also showing patterns of socio-economic reorganization (see [7] for an overview).

From an ecological point of view, the Neolithic transition in Central Europe did not constitute a dramatic break, ushering in a completely domesticated lifeway, but rather was a gradual addition of introduced taxa to the endemic flora and fauna. The emphasis on subsistence economies in studies of the Neolithic transition tends to obscure the fact that people continued to use the natural environment for many purposes, including for social and religious ones [8]. The introduction of agriculture and pastoralism did not divorce people from the relationships they had developed with their environments; rather, these domesticated taxa augmented the relationships these societies had developed over millennia with the different wild animal and plant species in their ecosystems. While several scholars have argued for the slow transition to the Neolithic [9,10] and the persistence of wild-based lifeways (e.g., [11]), teasing out how these multilayered economies interacted can be challenging, particularly so due to the interdisciplinary nature of the research involved. How can we assess the persistent importance of flora and fauna over time in a principled and quantitative manner?

In archaeology, palaeo-ecological studies are frequently used to support archaeological investigations, but linking and synthesizing datasets and concepts from ecology, ethnography, earth sciences, and archaeology has historically been rare. While advances in computational approaches and standards of data collection have enabled more collaborative approaches to understanding the past, these endeavors are only now beginning to pick up pace. Here, we propose a method to collect data of these assorted types, synthesize ecological and archaeological understanding, and move beyond subsistence-focused studies to those that incorporate multifaceted economies. We advocate for the use of 'human-centered interaction networks' as a tool to synthesize and better understand the role of culture, ecology, and environment in the long-term evolution of socio-ecological systems.

We advance the study of human-centered interaction networks by presenting an archaeoecological (archaeological-ecological) perspective on the Neolithic transition of the Swifterbant culture in the northwestern Netherlands (approximately 4700–4000 BCE). We employed network science to better understand the relationships of animal and plant species to the uses people made of them. Specifically, we aimed to answer the following research questions:

- What relationships between animal and plant species and their uses by humans can we identify in the archaeological record?
- How are these relationships organized?
- What does this tell us about the role of both wild and domesticated species in Swifterbant culture?
- What does this tell us about the changes in human–environmental interactions as a consequence of the Neolithic transition?
- Can these approaches demonstrate changing socio-economic priorities with the advent of domestication?

This approach was developed as part of the ArchaeoEcology Project (http://www.archsynth.org/the-archaeoecology-project.html) (accessed on 25 May 2021), a multidisciplinary project led by Crabtree involving archaeologists, anthropologists, human-behavioral ecologists, geographers, and ecologists as a means of moving beyond food-web-based approaches to examine the myriad ways humans have lived in and impacted environments since the appearance of anatomically modern *Homo sapiens sapiens*. Food webs, networks of predator–prey interactions, have been used by ecologists to understand the structure of communities of taxa in various ecosystems worldwide. Yet food webs only examine con-

sumption links, so other approaches are needed to examine those connections that are not related to consumption. As part of this research agenda, several human-centered food webs were developed [2,12,13] and human-centered interaction networks are being examined from diverse contexts, including the Ancestral Pueblo, East Polynesia, and the Martu in Western Australia. In our paper today, we present research from one of our research sites as an example of some of the ways we can use the archaeological record to better understand how humans manipulate ecosystems, and how ecosystems provide opportunities and constraints for societies. The Swifterbant case study is, to date, the oldest that we have analyzed in this way, and was chosen since the archaeological investigations have yielded palaeo-environmental information at a level of detail that is unique for the period. It thus provides a unique window to examine the ways that people have shifted from a purely hunting-gathering lifeway to one involving domestic animals, allowing for a deeper time comparison of human-centered interaction networks in our cross-comparison cases.

## 2. Archaeological Setting

### 2.1. The Neolithic Transition in the Dutch Wetlands

The northwestern part of the Netherlands during the Early Neolithic (approximately 4700–4000 BCE) was a coastal wetland area where people gradually shifted their lifestyle from semi-sedentary hunter-gatherer-fishers to agriculturalists. Animal husbandry was introduced into the area around 4600 BCE [14–16] and cereal crops were cultivated from approximately 4300 BCE onwards [17]. The 'consolidation' of animal husbandry and crop cultivation is thought to only have been achieved around 3500 BCE, making the northwestern Netherlands one of the last regions in Central Europe to adopt a fully sedentary, agriculturalist lifestyle, with an extremely long substitution phase [18,19], although recent zooarchaeological research suggests that, at least for animal husbandry, this consolidation was achieved earlier [20]. This is in clear contrast to the quick transition exemplified by LBK culture farther south around 5300 BCE.

The pace and method of introduction of cereals in the region are still poorly understood. Compared with the areas farther south, only a limited number of crops were introduced (barley and emmer wheat). Local cultivation of cereals before 4000 BCE was doubted until micromorphological soil analysis confirmed the existence of tilled middens at Swifterbant [21,22]. It is possible that the slow adoption of agriculture was the consequence of the specific environmental conditions in the region that offer few opportunities for farming [17,23]. Furthermore, the availability of rich natural food resources in the wetlands may have made a transition to a fully agricultural lifestyle both unnecessary and undesirable—a 'mistake'. However, socio-cultural factors may have been important for the delay as well, especially since evidence for direct cultural influence from the LBK-influenced area farther south is lacking [23,24]. Generalized theories on 'neolithization' [3,14] have not been very successful in explaining why Swifterbant culture was relatively slow to pick up the Neolithic lifestyle in the 5th millennium BCE, but at the same time was not completely resistant to it, as were the cultures of South Scandinavia.

Raemaekers [25] questioned the narrative of an extremely long, 1000-year substitution phase. Recently, he argued that the first phase of animal husbandry introduction in the area did not lead to any significant social changes. In contrast, the introduction of cereal cultivation from 4300 BCE onwards is accompanied by clear signals of social change, such as the introduction of new pottery types and the ritual deposition of cattle horns [26]. The transitional phase would then have taken, at most, a few centuries.

For the purposes of this paper, the actual pace of change is not of great importance. The point made by Raemaekers about social change, however, is central to the idea that the introduction of animal husbandry and crop cultivation did not completely transform the way people interacted with their environment, precisely because it is about much more than simply cuisine. Unlike traditional models of '(extended) broad-spectrum economies' that are based on a narrow view of economic optimization strategies, we want to emphasize that the relationship between humans and ecosystems is much broader than this,

and encompasses the many uses humans have for biota. By moving our focus to categories that encompass the myriad ways people impact ecosystems, we can examine how the Swifterbant people embedded themselves in ecosystems and how domestic animals and crops changed (or did not change) the ways they manipulated and conceptualized their environment.

### 2.2. The Swifterbant Sites

The area around Swifterbant was archaeologically investigated from the late 1960s onwards, and is characterized by an unusually rich set of archaeological [24,27,28], zooarchaeological [29–31], and archaeobotanical data [32–35]. This makes it a perfect case study to explore the relationships between humans, animals, and plants, and to investigate the effects of the introduction of animal husbandry and crop cultivation on these relationships.

The excavations at Swifterbant completely changed the narrative of the Mesolithic–Neolithic transition in the Netherlands. Later research in other parts of the wetlands of the Netherlands confirmed that 'Swifterbant culture' was a unique and distinct regional phenomenon in the coastal zones of the Netherlands and adjacent Germany in the period between 5000 and 3400 BCE, where mixed subsistence strategies were pursued. It was characterized by specific pottery styles [24], stone tools [36], and burial customs [37].

Over the course of time, the environmental conditions in the Swifterbant area changed considerably due to continuous sea-level rise. Around 4300 BCE, freshwater tidal creeks reached far inland, with marshlands developing alongside the creek levees [34]. The levees supported forests, and provided opportunities for human settlement (Figure 1). From these settlements, the Swifterbant people could exploit the marshlands and forests to fish and hunt, and on the levees they grew their crops and herded their cattle, but it seems clear that the settlements were only seasonally occupied [17].
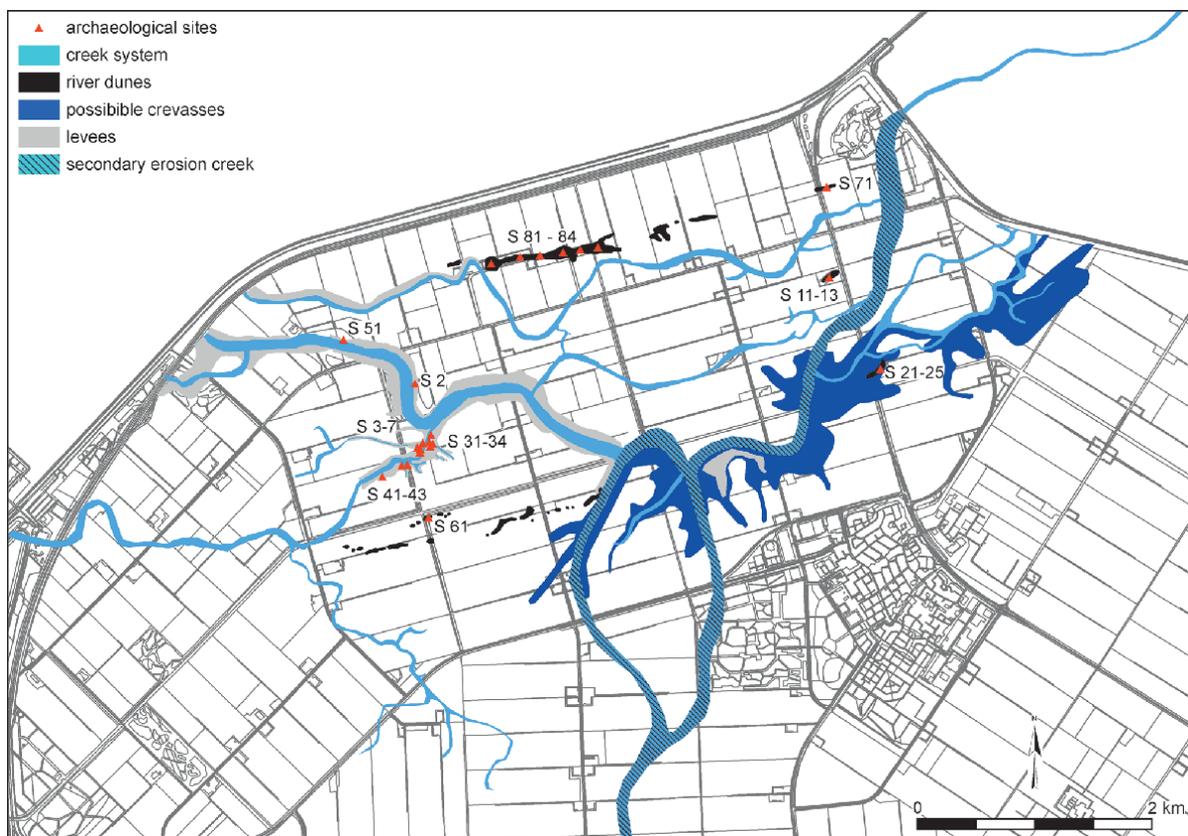


**Figure 1.** Palaeo-geographic reconstruction of the area around Swifterbant (approximately 4300 BCE) and location of investigated sites. Source: [36], Figure 2.2.

Around 4000 BCE, the area around Swifterbant became too wet for habitation and was eventually flooded from around 3700 BCE onwards [38]. The Swifterbant settlements were covered and preserved under peat, estuarine, and marine clays [39,40]. When the polder of Oost-Flevoland was drained in 1957, this fossilized landscape was rediscovered, presenting a unique window into a crucial phase of the human past.

### 2.3. Data Collection

For the current case study, an inventory was made of published archaeobotanical (macro-remains and pollen) and zooarchaeological data from the sites of Swifterbant S3, S4, and S25, and Noordoostpolder P14. This last site is located some 12 km northeast of Swifterbant, but shares many similarities. In total, we have identified 186 species, of which 48 are animal species (see Table 1 and Supplementary Materials S1).

**Table 1.** Breakdown of species by class.

| Class | Number of Species |
|-------|-------------------|
| bird | 13 |
| fish | 15 |
| fungus | 2 |
| mammal | 20 |
| moss | 18 |
| plant | 99 |
| tree | 19 |
| total | 186 |

To develop the use categories to record our data, participants of the ArchaeoEcology Project met at the Santa Fe Institute in 2016 to determine how to assess the uses of various taxa in the past. Here we focus only on biotic remains, necessarily leaving out lithics from our analyses, but as our question is nominally "how do people exploit ecosystems?", it is necessary to remove the abiotic environment as a variable. These identified categories are listed in Table 2 and are intended to be as cross-cutting as possible. In Table 3 we list, in descending order, the counts of representation for each of our use types. Figure 2 shows these results graphically.

**Table 2.** Categories used in this analysis identified by ArchaeoEcology Project members.

| Category | Explanation |
|----------|-------------|
| artifact | anything used to make portable artifacts such as tools, bowls, utensils |
| clothing | includes personal adornment such as garlands and perfume |
| companion | commensal animals and pets such as dogs |
| food | anything ingested for nutrition, including spices |
| fuel | anything used for heat, cooking, illumination |
| housing | anything used for timber, thatch, mats, posts, etc. |
| medicinal | anything ingested or applied for health reasons |
| ornamental | any taxa used for secular aesthetic reasons beyond personal adornment |
| ritual | includes tribute and religious use, monuments, shrines |
| structural | for constructing structures aside from houses |
| trade | anything used as a trade/exchange good, or that was traded/exchanged in from elsewhere |
| transportation | anything used to move across the land/sea such as boats, horses, etc. |

**Table 3.** Frequency of representation for each use type.

| Category | Count | Percentage |
|---|---|---|
| artifact | 43 | 14.3% |
| clothing | 14 | 4.7% |
| companion | 1 | 0.3% |
| food | 95 | 31.6% |
| fuel | 31 | 10.3% |
| housing | 18 | 6.0% |
| medicinal | 64 | 21.3% |
| ornamental | 4 | 1.3% |
| ritual | 12 | 4.0% |
| structural | 15 | 5.0% |
| trade | 0 | 0.0% |
| transportation | 4 | 1.3% |
| total | 301 | 100.0% |
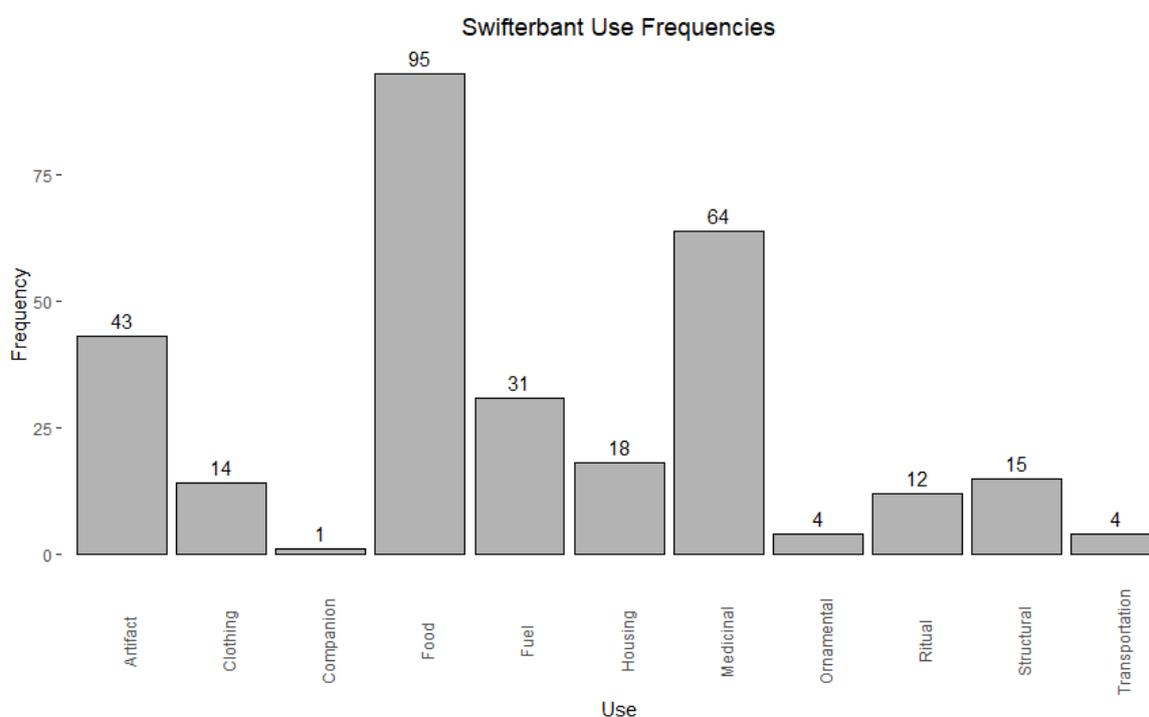


**Figure 2.** Frequency of representation for each use type.

The assignment of uses to species is mostly based on direct evidence of consumption, the presence of specific artifacts, and evidence for ritual uses from the Swifterbant sites. Because of the lack of evidence for trade and/or exchange of plant and animal species, this use category is not represented in our data set. However, we have attributed various other, not directly attested, uses on the basis of historical and ethnographic accounts, evidence from archaeological sites outside the region, and/or ecological knowledge (see Supplementary Materials S1). In particular, this is true of species that may have been used for medicinal purposes, and for edible species that have not been observed directly in archaeological contexts. However, we do not claim that this inventory is fully exhaustive, or that the assignment of unrecorded uses is necessarily correct.

Food is the predominant use category identified. This is partly a consequence of the focus of much archaeological research on identifying food resources, but it also shows the position of humans as an omnivorous species. The most frequently occurring uses are the ones that are directly related to individual human needs (food, medicine, artifacts, and

fuel). Less dominant uses are associated with collective practices, in particular construction and ritual.

For 53 species (28.5%), no specific uses could be assigned on the basis of the available evidence. This includes species that may not have been used, but were identified in the macro-remains and pollen record as being part of the natural vegetation. Others might have had uses we have not been able to identify, or that could not reasonably be assigned to a specific use. The presence of these taxa, however, help us identify the available biodiversity of the site. If, indeed, 53 species were not used by residents of Swifterbant, this suggests they used 71.5% of the available biota. For comparison, published food webs identify around 25% of available taxa being exploited by humans for food [12], compared with 51.1% in our own data. We are, however, missing a large group of plants, insects, and gastropods in our inventory, making it difficult to make a good comparison with modern-day food webs.

Because of the diverse nature of the data sources, the coupling of species to use categories presented here is only preliminary, and a more elaborate analysis of potential uses is desired for future study. Nevertheless, our inventory should be detailed enough to describe the major patterns of plant and animal use at Swifterbant.

*2.4. Network Analysis*

In order to better understand the relationships between species and their use by humans, we have applied a bipartite network analytical approach. By formalizing the human–environmental interactions as a network, we can quickly extract quantitative measures and visualize the connections between species and use categories.

Here, we specifically employ the use of bipartite networks—which have been used in ecology to model predator–prey relationships and mutualistic networks, such as pollination networks—and are a useful analytical tool for examining the connections among species [41–44]. In bipartite networks, there are two different categories of nodes, and nodes within one category cannot be connected to one another; connections can only exist between categories. In the example of plant–pollinator networks, two flowers cannot directly connect, while pollinators cannot directly connect either. Only pollinators (such as hawk moths) and plants (such as flowers) can directly connect. Our analyses therefore follow precedent in ecology, though we employ bipartite network analysis in a novel way. Specifically, we imagine that the two possible columns in the network are the species themselves as one column, and the uses that humans establish for species are the other. The uses cannot directly connect, nor can the species directly connect, but it is through the intervention of humans that these are connected.

The network analysis was run in Cytoscape v. 3.7.2, employing the CentiScaPe package [45], to focus our metrics on centrality measures using the list of species and their use categories (see Supplementary Materials S2). Each species and each use category thus becomes a node in the network, but links (edges) are only allowed between species and use categories. The program was then used to visualize the results and analyze the following metrics: degree, betweenness centrality, bridging centrality, eccentricity, and eigenvector centrality. These all have specific characteristics that are shortly explained here.

1.  **Degree** measures the number of direct connections between the nodes, so in this case, it shows the number of use categories per species and vice versa.
2.  **Betweenness centrality** is used to measure how essential a node is to the network. In order to 'travel' through the network, certain nodes will be passed more often than others. In contrast to social and geographical networks, where betweenness centrality is often used to identify the persons or places that are in control of (parts of) the network, in our case betweenness centrality can be seen as a measure of how crucial a species is for connecting use categories and vice versa.
3.  **Bridging centrality** [46] combines degree and betweenness centrality: what nodes are highly connected, as well as crucial for connecting the network? Potentially, these are the nodes that connect different clusters in the network.

4.   **Eccentricity** will measure for each node the path distance to the node that is farthest away. A high eccentricity value for a node implies that the farthest node in the network is relatively near, so a node with a high eccentricity is one that is relatively central to the network. In our case, it can be used to understand what species are relatively well connected to different use categories.

5.   **Eigenvector centrality**, finally, can be used to understand the hierarchy of the network by identifying the most influential nodes. Nodes with high eigenvector centrality have a large number of connections, but are also connected to other nodes to a high degree.

It should be pointed out that these network metrics are designed for the analysis of one-mode networks [47,48]. It is therefore common practice to project bipartite (two-mode) networks to one-mode for analysis of one of the node types involved, which inevitably leads to loss of information. Furthermore, the metrics for projected networks then tend to overestimate the connectedness of the nodes [49]. A number of alternative strategies have been proposed to deal with this effect [49,50] that use specific assumptions about the functioning of social or ecological networks to measure the interactions between nodes in bipartite networks [44,50–52]. Our networks, however, are not truly dynamic social or ecological networks since the taxa themselves do not interact and will not actively form ties over the network. We have therefore only analyzed the (static) connections between uses and taxa, for which standard network metrics provide sufficient information. We do, however, acknowledge that the development of analytic techniques specific to our networks could be a fruitful topic for future research.

## 3. Results

Our analyses suggest that, much as with ecological networks, we find a natural structure that emerges between the two columns of our network and, as with ecological networks, a fair amount of modularity exists within the structure. Specifically, there is overlap among functionally similar species (such as woody species for construction) that help to structure the network. This emergent structure in these analyses, and the similarity to ecological networks, suggest that how the Swifterbant people used taxa follows underlying properties of the ecological networks they embedded themselves within. Further, the use of both wild and domesticated taxa is integrated within the network—there are no subsets of the network that form domesticated taxa. We explore these results below.

For each metric, the results for the top 25 nodes are summarized in Figures 3–7. A visual representation of the network structure is given in Figure 8.

### 3.1. Degree

The nodes in the network that have most connections are use categories rather than individual species (Figure 3). Many species can serve a particular use, whereas individual species mostly have a limited number of uses. The degree of the use categories is equal to the numbers given in Table 2 and Figure 2, showing that the bipartite network structure is strongly dominated by the food, medicinal, artifact, and fuel categories. The species with most uses (five or six) are predominantly trees, cereals, and reeds, with only *Equus caballus* (horse) featuring as a wild animal with five uses.
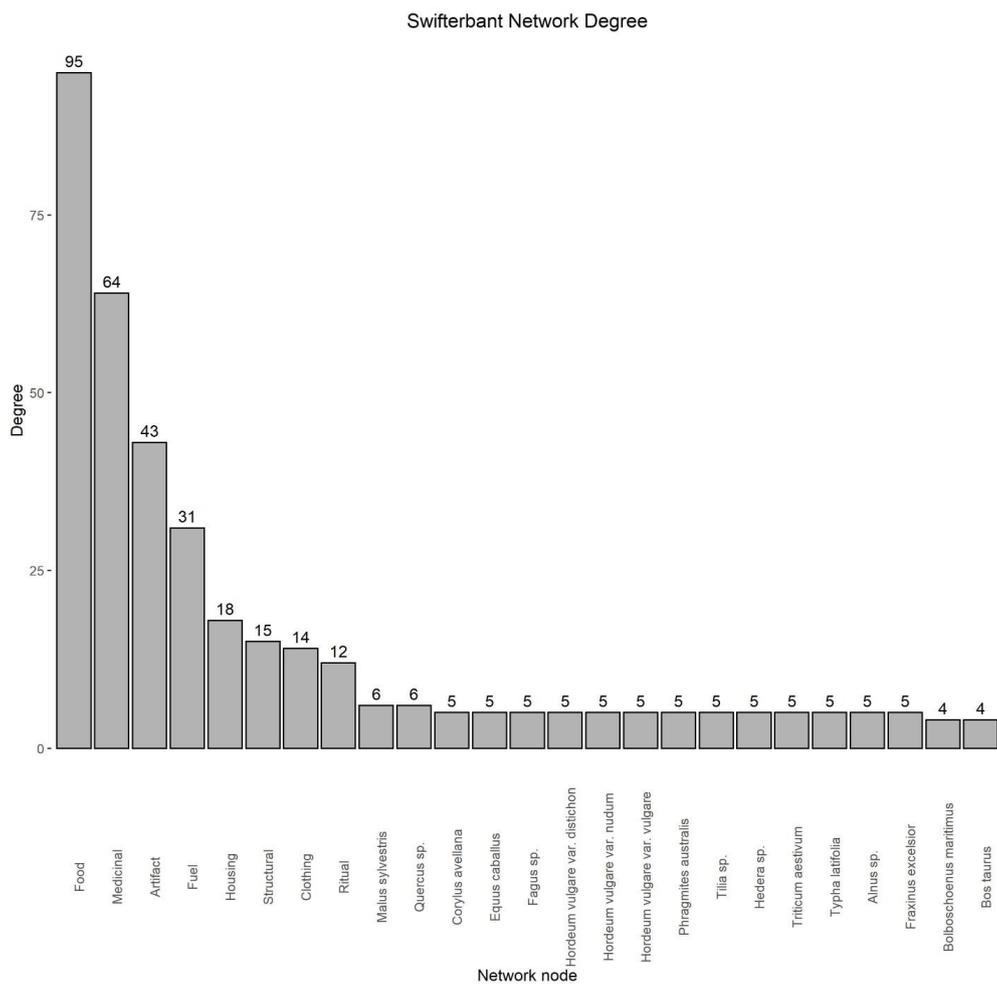
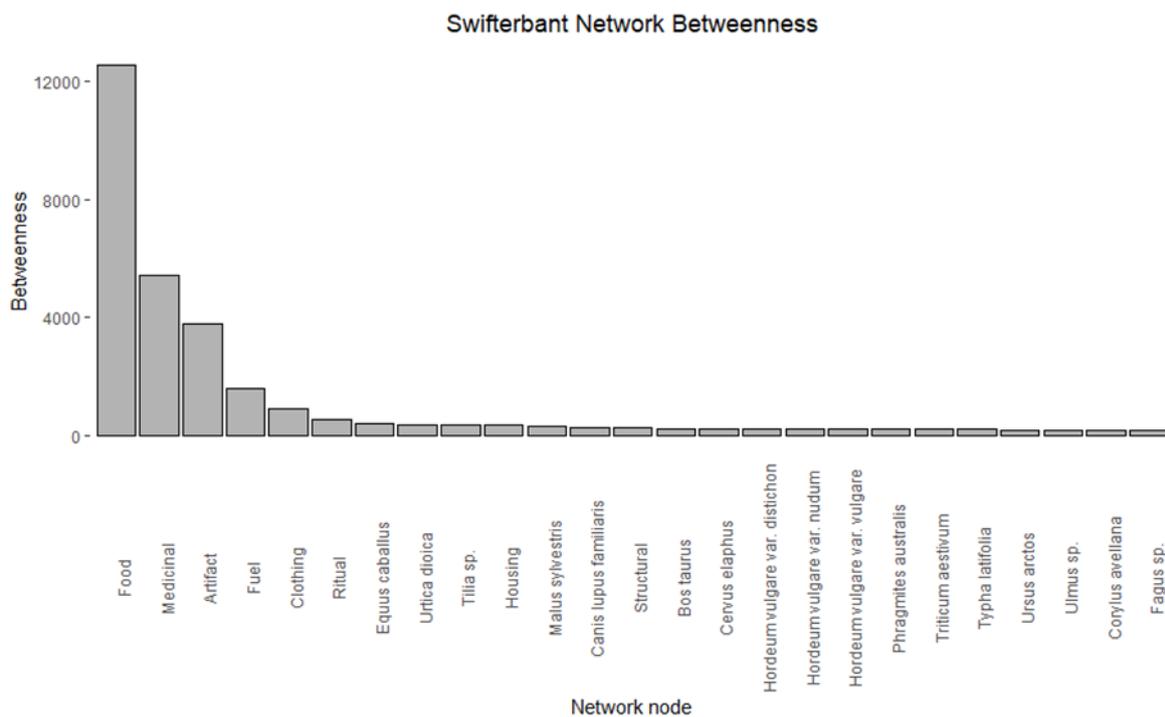**Figure 3.** Network degree (top 25).
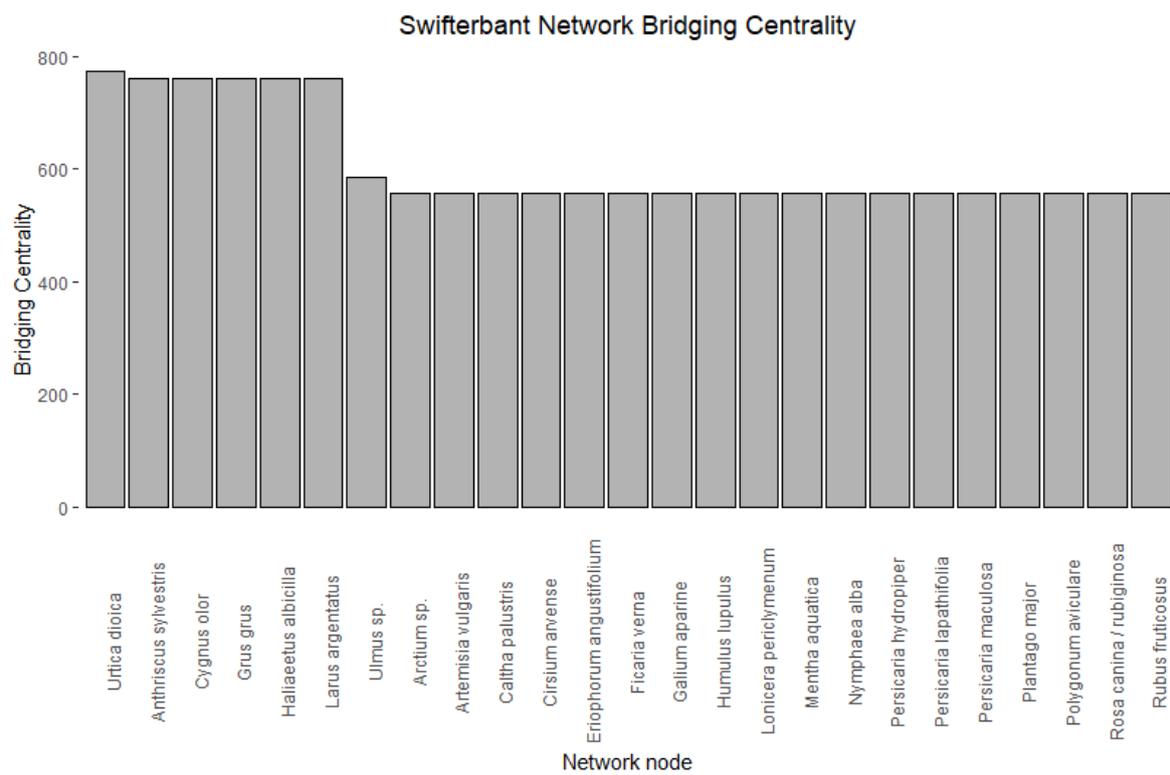


**Figure 4.** Network betweenness (top 25).

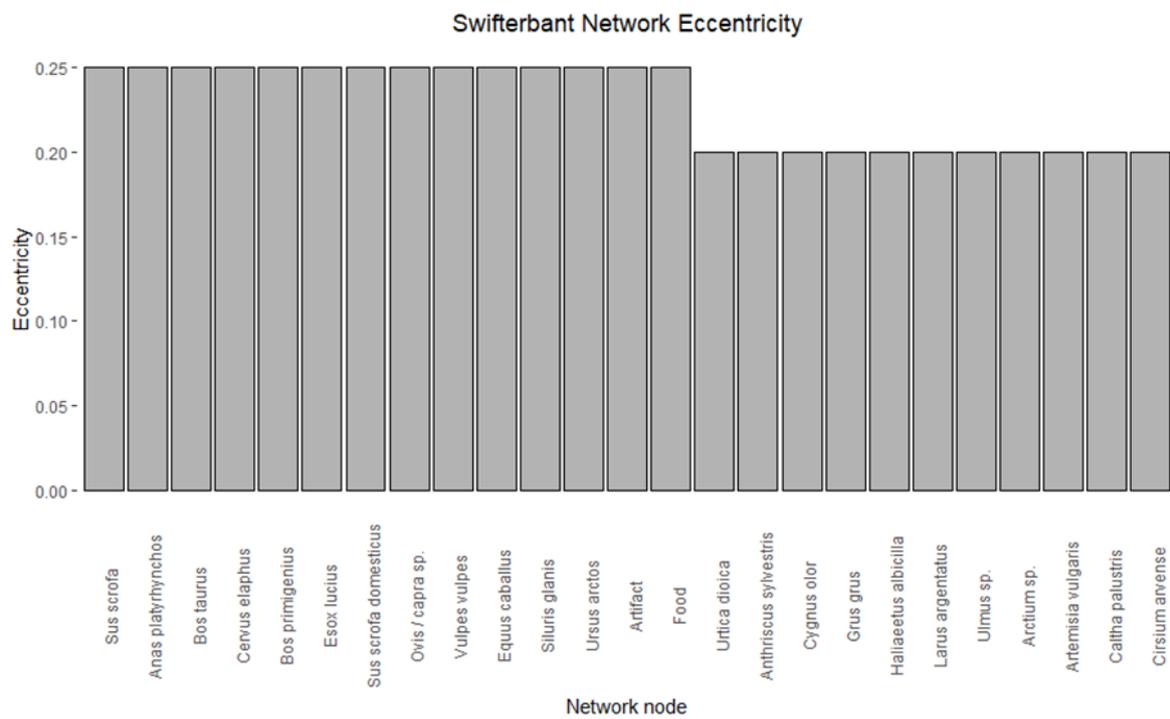**Figure 5.** Network bridging centrality (top 25).



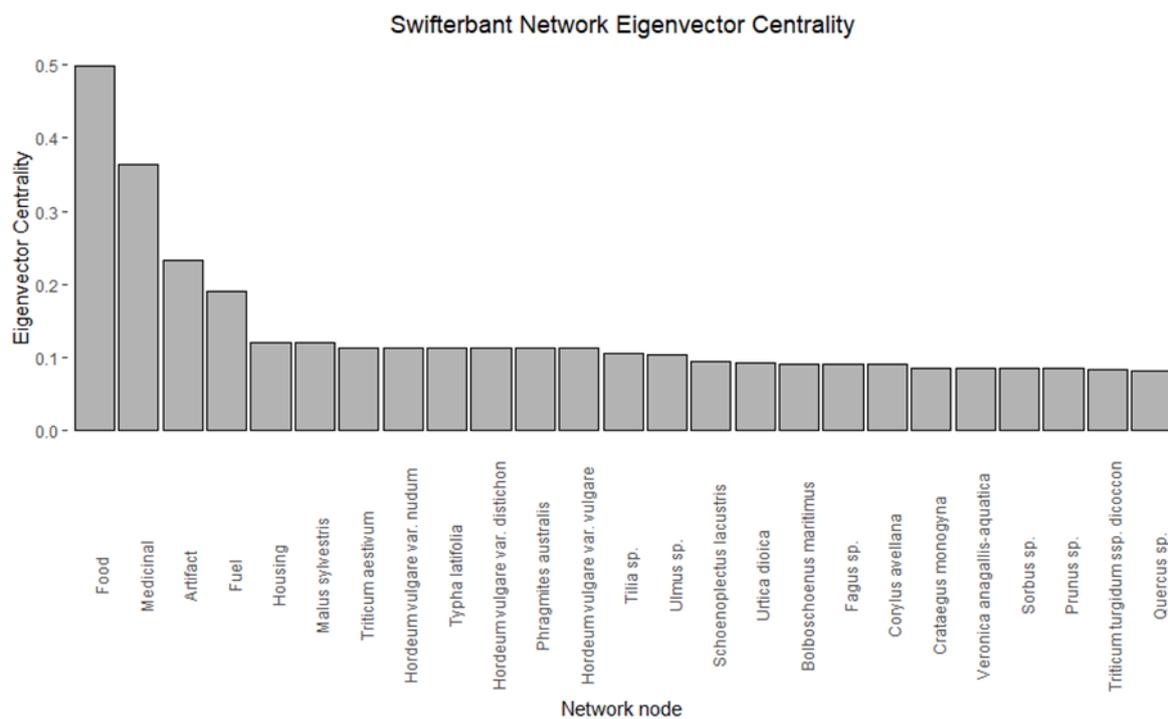**Figure 6.** Network eccentricity (top 25).

**Figure 7.** Network eigenvector centrality (top 25).

### 3.2. Betweenness Centrality

For betweenness centrality (Figure 4), the use categories are ordered similarly as for degree, showing the high importance of the use categories for connecting the network. Looking at individual species, betweenness centrality is high for trees, cereals, and large mammals. Other relatively high-ranking species have in common that they have atypical use combinations, so they are the ones that provide specific connections between parts of the networks. The dog (*Canis lupus familiaris*) is a good example of this, as it is the only species that can be considered a companion. Similarly, *Urtica dioica* (stinging nettle) links artifacts and clothing. However, the high rank of some of these nodes is somewhat deceptive, since there exist more ways to 'traverse' the network, but these are simply not as direct.

### 3.3. Bridging Centrality

Bridging centrality (Figure 5) prioritizes species that directly link important use categories. Therefore, we find several bird species at the top because they link food and artifacts, but nothing else. The top species are all species that would not normally be considered important from an archaeobotanical point of view.

### 3.4. Eccentricity

The differences in eccentricity values (Figure 6) are minimal, with only two values present in the top 25. Large mammals are important, but *Urtica dioica* and various birds are present as well. All in all, this points to the fact that the whole network is fairly well connected, with no clear 'hubs' and no clear outliers.

### 3.5. Eigenvector Centrality

The use categories with highest eigenvector centrality (Figure 7) are, unsurprisingly, the ones that have the highest degree and betweenness centrality, even when the ordering is slightly different. The most important species are trees, cereals, and reeds. These can all be used for construction and as fuel, as well as having additional uses as food, medicine, or artifacts.

## 4. Discussion

The network analysis metrics applied consistently prioritize species with multiple use categories. Some species occupy special positions within the network because they are the only ones directly linking our various use categories. However, the use network is on the whole well-connected, with few obvious 'hub' species, pointing to the functional similarity of many taxa that can be used for similar purposes. Of course, this does not mean that uses could not have been very specific, but there is little reason to suspect that the Swifterbant people were highly dependent on specific key species to maintain their way of life. This confirms the idea of a 'broad-spectrum economy' in a resource-rich natural environment that extends beyond the sphere of subsistence.

### 4.1. Network Structure

Visual inspection of the network (Figure 8) supports the conclusion above: the network is fairly well-connected. However, some use categories are clustered, in particular housing, structural, transportation, and fuel. This is, of course, the consequence of wood being used for all of these purposes. The 'socio-cultural' sphere of clothing, ornamental, and ritual is also clustered, and dominated by mammal species.

The medicinal and food spheres are characterized by a substantial number of species that have no other uses attached. In particular, this is true for most fish species and many herbal plants. Many plants, however, have both medicinal and food uses.

Artifacts, while often acting as a bridge between the different spheres of use, are also connected to a number of single-use species, in particular birds.

In the socio-cultural sphere, we again find a substantial number of 'single use' species, in particular small mammals used for clothing. The large mammals constitute the main bridge to other uses (food and artifacts). We must keep in mind, though, that for many social uses (in particular trade/exchange and ritual), evidence is completely lacking, even when these uses can be considered plausible.

Large mammals and birds are most integrated in the network. Domestic animals (cattle, pigs, and ovicaprids) are especially important in this respect and occupy a similar position to large wild mammals. Cereals (*Hordeum vulgare* and *Triticum turgidum* ssp. *dicoccum*) also play an important role in the network by providing construction materials and fuel in the form of straw.

### 4.2. Cereals

When we remove the introduced species (cereals and domestic animals) from the network, its structure does not fundamentally change (Figure 9). In particular, the introduction of cereals would not seem necessary from a subsistence-economic point of view, an observation that has been made previously [18,23]. From an ecological point of view, agriculture may only have had a limited impact on the ecosystem [53]. Some weeds (ruderals) and small animals (rodents, birds) may have profited from the cultivation of cereals, but these were not new additions. As a consequence, it would seem that cereal cultivation could have been introduced at low socio-cultural and ecological cost. Perhaps it was not necessary for subsistence, but it did not hurt, and did not fundamentally change human–environmental relationships at Swifterbant.

An additional consideration is the supposed semi-sedentary nature of the settlements at Swifterbant. Seasonal relocation to the 'uplands' (at least 25 km inland) may have been necessary because of winter flooding of the levees [34]. This assumption is, to some extent, supported by isotope research on burials showing a higher proportion of terrestrial proteins than can be expected from a wetland environment alone [54,55], but it is hard to interpret the dietary implications of this. In any case, the 'inland' system would have had different characteristics from the wetland system, coupled to less available plant food resources in winter. This becomes clear when we run the analysis for such a 'winter habitat' (Figure 10). Aquatic species are not available, which leads, when coupled to the reduced availability

of green plants, to a much more limited spectrum of foodstuffs dominated by wild and domestic mammals.



**Figure 8.** Visualization of network structure. Domestic species are visualized by larger circles.

**Figure 9.** Visualization of network structure without domestic species.



**Figure 10.** Visualization of network structure for the 'winter habitat'.

It can be assumed that long-term storage of food—for example by smoking of fish and meat or by collecting non-perishable foodstuffs such as hazelnuts—would have played an important role in winter subsistence. Growing cereals that can be easily stored and transported may thus have provided an additional way of dealing with potential food shortages in winter, and in that sense may be seen as part of a strategy to further widen the food economy spectrum. However, it is clear from the zooarchaeological assemblages that hunting (and presumably fishing) in the wetlands was also carried out in winter [53]. The distance is not prohibitive in this respect.

### 4.3. Animal Husbandry

Domestic animals take a central position in the system and 'compete' with wild mammals as providers of food, but also of tools, clothing, and ornaments. For example, teeth of both wild ungulates and domestic animals were used as beads and hangers and were found in burials at Swifterbant [56]. This 'non-food' usage of large mammals was as important as their use for subsistence. Domestic animals have the advantage of being reliably present when needed, playing the role of both fridge and toolbox on four legs. They most probably would have followed the Swifterbant people when they moved inland in winter [53]. From an ecological point of view, cattle and ovicaprids do not just use available pasture, but also actively create and maintain it. Since grasslands are also attractive to wild animals such as elk and deer [53], the domestic animals thus may have also helped to attract more of these.

Much of the debate on whether Swifterbant culture fully adopted the 'Neolithic' lifestyle hinges on the relative presence of domestic animals in bone assemblages. While LBK assemblages often show them taking up to 90% of the total, in Swifterbant assemblages they typically do not exceed 50%, which is often seen as a critical value [3,10]. It should, however, be pointed out that the successors of LBK culture further south (Rössen and Michelsberg cultures) show a reversal when compared with LBK, with bone assemblages indicating an increase in wild animal proportions [14]. In addition, within Swifterbant sites there are clear differences in the proportions of domestic animals [10,25]. These differences are thought to reflect adaptation to local environmental conditions.

Raemaekers [25,26] further emphasizes that the incorporation of domestic animals into the ritual sphere only took place a few hundred years after their introduction as sources of food and artifacts. Depositions of aurochs horns seem only to have been followed by similar depositions of cattle horns after 4000 BCE [57]. This observed role of wild animals in ritual deposition points to their importance in the belief systems of Swifterbant people, and may therefore have delayed the replacement of wild animals by domestic ones.

## 5. Conclusions

In this paper, we applied a network analytical approach to understanding human–environmental relationships in Swifterbant culture. The main advantage of this approach is that it allows us to bring together archaeological, zooarchaeological, and archaeobotanical data in a single network of interactions. This overview of human–environmental interactions is extremely valuable to visualize and interpret the complex relationships involved at a relatively high level of abstraction. Entanglements and vulnerabilities within the system can be identified, either through visual inspection, or by calculating appropriate network metrics, and comparisons between systems can easily be made.

The analysis of the Swifterbant system reveals a highly connected set of interactions among people, plants, and animals. The system relied on the inclusion of many species, without any of them playing a dominant role for specific uses, as could be expected on the basis of the hypothesis of an 'extended broad-spectrum economy'. Importantly, this broad spectrum extends beyond the subsistence sphere. Nevertheless, some use groups relied on the same set of species. A central role can be assumed for wild and domestic mammals, which were used for food, clothing, tools, personal adornment, and rituals. Trees, on the other hand, played a central role in construction purposes and the making of tools. Other

species were only single-use. This is true, in particular, for fish and herbs as sources of food, small mammals that were used for clothing, and herbs used for medicinal purposes.

The analysis does not provide direct answers to the reasons for the slow transition to agriculture at Swifterbant. Cereals seem to have had only limited importance as a food resource, and may have been grown as a back-up food source for the winter season. Domestic mammals, on the other hand, occupied a more important role in the system, supplementing wild mammals as sources of food, tools, and clothing.

This work exposes how the modern ecosystem is itself the end product of hundreds of generations of human–ecosystem interaction, and demonstrates how to use archaeological and past ecological data to provide a better understanding of the ways in which people and ecosystems interact [58]. This paper represents the first of a series of papers from the ArchaeoEcology Project aiming to understand the archaeoecology of multiple systems worldwide. Future research will not only investigate system-specific cases, as we have here in Swifterbant, but will work to compare between regions to demonstrate the human place in ecosystems worldwide.

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