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Research

Returning ecological wealth to nonhuman species through design: the case for ecosystemas

Bill Tomlinson [1,2], Bonnie Nardi [1], Daniel Stokols [3], Ankita Raturi [4] and Andrew W. Torrance [5,6]

ABSTRACT. Human population and energy use have increased rapidly in recent centuries. This growth has relied on Homo sapiens appropriating ecosystem services previously shared more equitably with many other species. Envisioning this process as a transfer of ecological wealth among species provides a framework within which to examine human activities. We use this framework to critique the broad endeavor of design, and in particular human-computer interaction design, as it has been pursued by human civilization over the past several decades. We offer a conceptual tool, the ecosystema, that may help enable design processes to support the redistribution of ecological wealth to nonhuman species. The ecosystema is based on the concept of personas: distilled representations of particular user groups that are a key part of many design processes. The ecosystema construct is analogous to a persona, but at the level of an entire ecosystem rather than of a particular human population. This construct could help discern ecosystem level impacts and enable them to influence design processes more effectively. Ecosystemas also may afford greater leverage for effectively managing current environmental crises than existing anthropocentric design approaches.

Key Words: *design; ecosystem; human-computer interaction; personas; sustainability*

INTRODUCTION

Over the past several centuries, the human population has grown dramatically, from less than 1 billion in 1800 to over 7.8 billion people at present (Our World in Data 2020).[1] Human energy use during the same period has increased as well, more than tripling per capita and growing 25-fold in total (Ritchie et al. 2020). Human exploitation of Earth's ecosystems—extracting resources, co-opting ecosystem services, and killing organisms for humanity's own use—has, in large part, made these increases possible.

During the same period, Earth's biodiversity has come under tremendous stress, with extinction rates estimated to have exceeded the background rate over the past 2 million years by roughly 100 times (Ceballos et al. 2017) to 1000 times (Gilbert 2018), with up to 150 species lost daily (Djoghlaf 2007). Even in the absence of humans, it could take 3–7 million years for evolution to restore mammal species richness to prehuman levels (Davis et al. 2018). As humans appropriate ecosystems for their own uses—converting forests to farmland, marshes to malls—many non-human organisms[2] have been crowded out, often resulting in local or global extinction.

Concepts such as ecosystem services (Costanza et al. 1997, Costanza et al. 2014), natural capital (Hawken et al. 2010), and environmental full-cost accounting (Epstein 1996) describe various ways in which ecosystems provide forms of wealth,[3] e.g., energy, habitat, food, building materials, and other natural resources. Viewing human exploitation of ecosystems and non-human species as appropriation of ecological wealth reveals a massive interspecies wealth transfer from non-human species to humans.[4] This concept is similar to, but distinct from, the concept of "human appropriation of net primary production (HANPP)" (Haberl et al. 2014). Whereas HANPP focuses on "total carbon produced annually by plant growth," interspecies wealth transfer encompasses forms of wealth beyond the productivity of the land, including waste treatment, disturbance regulation, and refugia (Costanza et al. 1997).

Rates of interspecies wealth transfer have varied throughout human history, but have trended upward as agriculture (Tauger 2010), industrial processes (Meadows et al. 1972, Stutz 2010, Davis 2016), and energy use (EIA 2016) have proliferated. Expansionist economic models play a key role as well. Capitalism, having outcompeted other economic systems, will likely remain the dominant system for the foreseeable future[5]; its "inherent expansionary tendencies" (Clark and York 2005:391, see also Harvey 2005, Ripple et al. 2017) are capable of powerfully abetting interspecies wealth transfer. As long as economic growth is an explicit policy goal for virtually every national government (e.g., Australian Trade and Investment Commission 2020, Xiang 2020, Biden 2021), interspecies wealth transfer remains a substantial risk, capable of damaging the very ecosystems on which humanity itself depends for survival.

Nevertheless, interspecies wealth transfer may no longer be necessary. Jørgen Randers proposes that human populations are leveling off, projected to peak under nine billion people (Sevaldson 2018). Ecological wealth already appropriated may satisfy many human needs. As Randers describes: "The challenge is no longer production growth—it's distribution" (Sevaldson 2018:296). Humans may become able to maintain a high standard of living without causing undue harm to non-human species.

Although interspecies wealth transfer has had substantial benefits for humanity, such as marked alleviation of human poverty, hunger, and disease, an effort to diminish or reverse it could benefit most non-human organisms. Isolated efforts at ecological restoration have been effective at benefiting specific populations of non-human organisms, such as the restoration success stories described by the U.S. Department of the Interior (2020).[6]

[1]Department of Informatics, University of California, Irvine, [2]School of Information Management, Victoria University of Wellington, [3]School of Social Ecology, University of California, Irvine, [4]Department of Agricultural and Biological Engineering, Purdue University, [5]School of Law, University of Kansas, [6]Sloan School of Management, MIT

Biologist E. O. Wilson has argued in favor of setting aside half of the earth's land areas for ecological regeneration (Wilson 2016). The COVID-19 pandemic unfolding around the world at the time of writing is providing further evidence that declines in the presence or economic activities of humans may foster ecological restoration (Bates et al. 2020, Corlett et al. 2020, Rutz et al. 2020). This evidence is similar to findings regarding the increase in species richness two decades after the Chernobyl nuclear disaster (Møller and Mousseau 2007), as well as the prodigious regrowth of forests in the United States since 1990 (FAO 2020a). Alan Weisman has observed that ecosystems would recover if humans were to disappear (Weisman 2008; the effects of which would be similar to a reversal of interspecies wealth transfer). All of these analyses underscore the benefits species other than humans would reap from the reversal of the current inequity in interspecies wealth transfer.

Humanity would likely benefit from the reversal of interspecies wealth transfer as well. Human well-being depends on ecosystems constituted, in part, by other organisms. Benefits to other species are often benefits for humanity. In addition, deforestation and other forms of ecosystem reduction may be implicated, in part, for pandemics such as COVID-19 (Poudel 2020), with "current evidence indicat[ing] that preserving intact ecosystems and their endemic biodiversity should generally reduce the prevalence of infectious diseases" (Keesing et al. 2010:647).

We recognize that this domain is morally complex. The impacts from encouraging or reversing interspecies wealth transfer fall differentially on various groups of people and organisms; the distributional effects of any new scenario will lead to new and often unpredictable allocation of benefits and costs. Questions such as "how can humanity balance human needs and wants with those of other species?" and "who decides how such transitions occur?" point to the moral/ethical complexity of this domain. Nevertheless, we believe the current system is unsustainable; we believe reversing interspecies wealth transfer would likely be in the long-term best interests of humanity as well as other species.

Over the past several centuries, human design activities have contributed substantially to interspecies wealth transfer. Designs of institutions and infrastructures have allowed increased human cooperation in extracting resources for their own use. The design of technologies has been central to escalating interspecies wealth transfer. Technologies to harness fossil fuels, in particular, have had profound implications for climate change. Information technologies, too, manage and magnify many of the resource flows of which interspecies wealth transfer is composed. These human designs and technologies act as powerful multipliers (Papaioannou and Dimelis 2007), enabling much more dramatic impacts on other species than humans had previously caused.

Earlier analyses (Wilson 1984, Haberl et al. 2014, Bennett et al. 2016, Schwab 2016) have stressed the importance of slowing humans' exploitation of natural capital (Costanza et al. 1997). The interspecies wealth transfer framing presented in this article extends those earlier works by proposing novel approaches to design and environmental policies that seek to enable humans to return ecological wealth to other species, thereby also benefiting their own survival.

In this article, we focus in particular on the design of computational systems. We build on Herbert Simon's classic definition of design being the act of "devis[ing] courses of action aimed at changing existing situations into preferred ones" (Simon 1988:67). Specifically, this work is situated within an ongoing trend toward bringing the design of computing systems to bear on the domain of sustainability (Blevis 2007, Dillahunt et al. 2009, Tomlinson 2010, Raghavan et al. 2016, Nardi et al. 2018, Nardi 2019). Several of the authors are computing researchers and design researchers; as such, we seek to help the disciplines of computing and design more effectively support transitions to sustainability. Although we focus on this specific domain within the design of computational systems, we believe that the approach described here is relevant to many other areas of design as well.

The vast majority of work in computing and design fields ignores other species and ecosystems beyond their value to humans. We argue that a serious limitation of much current design knowledge arises from its embedding in an anthropocentric framing (Wakkary 2021). Approaches such as "user-centered design" (Usability.gov 2020), and "human-centered computing" (NSF 2020) typically place humans at the center of the design process. These approaches arise from a shared anthropocentric model of the world that puts human needs and wants above the needs and wants of other species. Even holistic approaches to design that build on systems thinking, such as "systemic design," focus on the inclusion of the needs of human communities and consideration of humans' broader social, economic, and political context (van der Bijl-Brouwer and Malcolm 2020). However, a non-anthropocentric framing, in which there is an explicit effort to reverse interspecies wealth transfer, could produce a quite different body of design knowledge that has greater potential to help ameliorate current planetary dilemmas (Burke et al. 2015, IPCC 2021) than human-centered techniques. In this article we delineate the characteristics of this alternative body of design knowledge. Although we focus on the design of computational systems, we believe many of the perspectives that arise in this sub-field of design are relevant to other areas of design as well.

We propose a new conceptual design tool, the ecosystema[7], analogous to an existing conceptual tool used in design. In many design processes, designers use constructs called personas (Pruitt and Grudin 2003, Nielsen 2014). Personas are paper or digital representations of some group of stakeholders that designers use to keep that group in mind during the design process. For example, a design team working on the design of a social media platform may have a persona to represent an archetypal college student user, a persona for a parent of young children, and a persona for a retiree. Each persona would exist on a sheet of paper or digital equivalent. Design researchers have developed processes (see Pruitt and Grudin 2003, Nielsen 2014; also discussed later in this article) for creating personas that accurately reflect the richness and complexity of particular groups of stakeholders. An ecosystema is analogous to a persona, but at the level of an entire ecosystem rather than an individual human. An ecosystema is a tailored description of an ecosystem potentially impacted by particular design activities.

We believe that the ecosystema design tool can allow the needs of ecosystems to be represented more effectively in design processes. In this article, we explore how to build ecosystemas, how they may be used, and future directions for work in this domain. The research described here brings together a range of domains, integrating research in ecology and design with work in social ecology and research in computing and design. Although a real-world deployment of this design tool was beyond the scope of this research, we present the theoretical basis that could enable future deployments of this tool. The broad goal is to elevate ecosystem concerns in the design processes that underlie so much of global human civilizations' activities.

RELATED WORK

Human design processes are critical in a range of ecological contexts, from the design of human habitats (Henfrey 2018), to the design of transformative spaces (Pereira et al. 2018), to the co-design of scenarios with an array of different stakeholders (McBride et al. 2017). Because the design of human technologies and infrastructures multiplies the impact humans have on the ecosystems in which they live, engaging with design processes is of central importance in understanding these impacts.

Various scholars in social ecology have explored the relationship between humans and non-humans. For example, Helmut Haberl and his colleagues examined relationships between society and nature over time (Haberl et al. 2016). Stokols' (2019) analysis of environmental design in the Anthropocene proposed a broader conception of environmental "users" beyond those living or working at a particular site. For instance, relevant user groups might include not only local users of the site but also individuals geographically distant from the site whose health may be impacted, nonetheless, by atmospheric or marine transport of carbon and pollutants from the place of origin to more remote, telecoupled regions (see also Liu et al. 2013, 2015, Stokols 2018 for further articulations of telecoupling and systems integration). The "deep ecology" movement embraces the principle of "biocentrism" or "biocentric egalitarianism" (vs. anthropocentrism) and is premised on the idea that humans must be decentered, or relegated to a less powerful and preeminent role in ecosystems, if those systems and the diverse species that comprise them are to survive and thrive (see, for example, Næss 1973, Lovelock 2000, Devall and Sessions 2007). Biocentrism holds that all life forms have an "equal right to live and blossom" (Næss 1973:96). The field of animal rights law has approached similar issues from a different perspective: attributing legally enforceable rights to non-human organisms and assigning to humans legal obligations to protect the welfare of non-human organisms (Singer 1975, Wise 2000, Sunstein and Nussbaum 2005). Social ecologist Murray Bookchin has written about the evolution from biological and societal nature to "thinking nature" in which humans' reasoning capacities would be applied to ecosystem design in ways that promote more equitable relationships between humans and other species (Bookchin 1996, Bookchin 2005). The ecosystema concept builds on these ideas and broadens this perspective to include the interests and rights of non-human species and ecosystems in design processes.

This research contributes to the broader field of sustainable design (e.g., Ceschin and Gaziulusoy 2019). Sustainable design has engaged with a range of different efforts to allow for sustainability-related topics to influence design processes. For example, transition design seeks to include "place-based and regional" perspectives in the design process to support approaches to societal change that engage with sustainability, developing new visions, and connecting to existing grassroots efforts (Irwin 2015). Cradle-to-cradle design draws inspiration from biological cycles to reconceptualize design processes (McDonough and Braungart 2002). Researchers in value sensitive design (Friedman et al. 2013) have sought to understand processes by which values such as sustainability may affect design. Perhaps most related to the ecosystema concept proposed here, Friedman and Hendry's "envisioning cards" (Friedman and Hendry 2012) offer a potential mechanism for various stakeholder groups' core values (such as environmental sustainability) and other factors to influence design processes. We believe that ecosystemas are complementary to these approaches, and may be useful both for keeping the needs of specific ecosystems in the foreground of design processes, and by proxy, keeping ecosystem effects more broadly in the minds of design teams.

In the design of computing systems in particular, the use of personas is a common way to represent a diversity of perspectives in the design process (Pruitt and Grudin 2003, Nielsen 2014). Rarely are personas used in ways that relate even indirectly to ecosystem issues. Most relevant to the work described here is the concept of "animal personas" (Frawley and Dyson 2014). Animal personas have been proposed to account for species-specific considerations in the design of online systems used in animal agriculture, such as raising poultry. Non-human personas have also been explored by Tomitsch et al. (2021a, 2021b), with the goal of giving "non-human stakeholders a voice in the design process" (http://designthinkmakebreakrepeat.com/methods/non-human-personas/). Similarly, "canine personas" have been put forth in the emerging area of animal computer interaction, where technologies such as digital emergency alarms, are designed specifically to be used by animals (Robinson et al. 2014).

Raturi (2017) proposed the need for "system personas," a design concept that represents the system that the human is interacting with rather than the human themselves. She developed "farm personas" for the design of digital technologies for sustainable agriculture. Landscapes are increasingly multi-functional: a blend of natural and human-made systems performs a range of functions. For example, grass-fed livestock roam on public grazing lands where the landscape provides habitats for wildlife and food for humans, among many other functions. Stakeholder analysis strategies are evolving to consider ecological complexity in, for instance, land-use planning activities (de Groot 2006).

De Groot (2006) describes how land-use planners can account for ecosystem functions, including their role as a habitat, and in environmental planning, management, and decision making. Reed et al. (2009) provide an inventory of stakeholder analysis methods as part of a typology for natural resource management, expanding stakeholder analysis to include non-human and non-living entities as stakeholders. This work provides a valuable set of methods to consider the influence of ecosystems on decision making, though the focus is still on the humans in the loop.

AN ECOSYSTEMA IN ACTION

Ecosystemas can enable ecosystem-centered design of technologies functioning at the juncture of human-made and natural systems. Just as a persona is not a comprehensive depiction of a particular person, but rather a conceptual lens through which to focus on particular aspects of a design space, an ecosystema is not a full biological description, but rather a construct highlighting aspects of ecosystems relevant to a particular area of work. Just as ecosystems may be spatially nested

(Klijn 1994), ecosystemas could also represent various spatial scales. Ecosystemas could be incorporated into design processes, encouraging efforts to ask useful questions, think about impacts, create empathy, and keep track of complexity.

In the following example, we work through how ecosystemas could inform the design of technology used by practitioners of regenerative agriculture. An emerging area of design research and technology development supports a transition to not only sustainable, but also regenerative, agriculture (Raturi and Buckmaster 2019, Basso and Antle 2020), in which software offers agricultural system stakeholders the capacity to manage complexity across scales. In the past decade, there has been a push to adopt regenerative agricultural practices such as reduced tillage, planting of cover and forage crops, integration of pollinator habitats, and use of biological controls that aim to improve soil health and water quality, to increase biodiversity and sequester carbon (Swinton et al. 2006). The regenerative agriculture community seeks to provide a range of ecosystem services, recognizing that shared threats to non-human species and ecosystems are intertwined with threats to agriculture and human food security. The provisioning of ecosystem services through agriculture may enable a reversal of past environmental harm that would benefit human and non-human species alike. Thus, there is keen interest in the design of ecosystem incentive schemes and policies, practice verification systems, and digital tools to enable farmers to participate in digitally mediated payment exchanges, integrated technology, policy, and regenerative agriculture research (Swinton et al. 2007).

Digitally mediated ecosystem service marketplaces (ESMs) integrate lessons learned from the payments for ecosystem services (PES; Kronenberg and Hubacek 2013) and global carbon marketplaces (Corbera 2012), offering a mechanism for financial incentives for farmers to adopt regenerative practices. Ideally, an ESM would enable a farmer to submit farm data demonstrating how their agricultural practices impact an ecosystem and its inhabitants. These data would be used to verify whether the agricultural practices truly render ecosystem services.

ESMs, like other software, are designed with a human-centered approach, which places the focus of design activities on human needs, goals, and desires. This approach may include interviews with farmers and the creation of personas representing archetypal farmers allowing ESM designers to create functionality that enhances farmer experiences and the usability of the tools, increasing the likelihood of technology adoption. Given that the point of an ESM is to verify services to an ecosystem, we argue that a key stakeholder is missing from this design process: the ecosystem itself. An ecosystem-centered approach could include the use of a framework of ecosystemas to represent critical local ecosystems impacted by agricultural practices, and representation of native insects, animals, plants, and other organisms living within the ecosystem. Ecosystem-centered design could include animal personas (Frawley and Dyson 2014) to represent preferences and constraints faced by livestock and wild animals, and farm personas (Raturi 2017) to represent the agricultural systems represented in ESMs. In concert, these personas capture the range of actors and systems that should inform the design of an ESM. If only user personas were included, the ecosystem and native inhabitants of the ecosystem the farm purports to service would be voiceless.

Ecosystem-centered design of an ESM

In typical human-computer interface user research, the designers of an ESM might interview farmers and visit farms to develop empirically grounded farmer and farm personas. The design team may gather data about the conservation areas within the farm as well as the ecosystems the farm impacts. These systems include ecosystems in and around the farm, that is, ecosystems the farm is a part of, those spatially adjacent, and ecosystems downstream. An ecosystem-centered design process would include interviews with farmers and visits to the farms, as before, but also collection of data about ecosystems in and around the farms. In this example, an ESM design team creating ecosystemas would consult experts in local ecosystems and in regenerative agricultural practices such as members of the U.S. Department of Agriculture's Natural Resource Conservation Service who could advise on ecosystem service incentive programs. The team might consult extension educators focused on topics such as cover cropping, soil health, and water quality (e.g., Purdue Extension, https://www.extension.purdue.edu/) who could advise on how agricultural practices relate to improved environmental outcomes. They might speak with federal, state, and county government agents working in agencies such as the Department of Natural Resources or the U.S. Fish and Wildlife Service who have expertise in environmental regulatory requirements as well as non-profit advisors who could provide guidance on current practices around supporting the "rights of nature" in human design activities (e.g., Terra Ethics Alliance, http://terraethics.com/). The team could consult local and Indigenous community groups who could advise on the history of local ecosystems including traditional protections and practices.

Consider the design of a hypothetical ESM, "CarbonMarket." The ESM design team would create a collection of personas representing farmers, farms, organisms, and ecosystems, to develop empathy and understanding about how they all interact.

1. User personas: The primary user group of an ESM is farmers because they provide data for verification to the marketplace in order to receive compensation. The CarbonMarket design team might identify farmers already practicing regenerative agriculture as early adopters. These farmers would be familiar with conservation cost-share or incentive programs, and use some form of digital record keeping to track their progress toward achieving ecosystem services. Another user group might be ESM credit purchasers. These users, who are being matched with farmers in ESM transactions, could be individuals and corporate buyers. Thus user personas would represent both farmers (i.e., the ecosystem service providers), and those looking to purchase ESM credits. These personas would be designed through user research, for instance, interviews with farmers and credit purchasers. These personas advocate for the humans in the design process, guiding the design team toward improved usability and positive user experiences.
2. Farm personas: The process for verifying an ecosystem service ranges in specificity depending on the service. For instance, verifying that a bird habitat is successful can be as simple as monitoring and counting birds. In contrast,

protocols for measurement, monitoring, reporting, and verification of improvements to soil organic carbon are still being developed with many competing efforts as soil science research improves (e.g., the FAO 2020b). Thus, use of farm personas (Raturi 2017) would enable the CarbonMarket design team to consider how different types of farms could be represented in an ESM and to catalog agricultural data collection and reporting practices that farmers use to monitor ecosystem services.

3. Ecosystemas: Ecosystems naturally service themselves. The construct of an ecosystem service exists in the context of agriculture in two forms: first as an act of repair, and second as an act of prevention. In an act of prevention, a human seeks to prevent future harm, e.g., planting a cover crop to prevent or reduce nitrogen leaching. In an act of repair, a human seeks to undo a prior harm, e.g., repairing loss of biodiversity due to habitat destruction through creation of new habitats by planting native species and creating conservation areas. In designing an ESM, an ecosystema would be used to ensure that when a designer conceives of a service, they take into account whether this ecosystem service would truly enable ecosystem restoration. Thus an ecosystem used in the design of an ESM like CarbonMarket needs to contain guidance about the relationship between regenerative agricultural practices and ecosystems.

An example ecosystema

Each of the adjacent and overlapping ecosystems that are directly impacted by the farmers' management decisions may be represented via an ecosystema. For example, at a Midwestern farm, these could include native wetlands in and around the farm; a perennial stream running through one of the pastures; a coniferous forest adjacent to the ranch boundary; and the soil microbiome that underlays the entire ranch. The CarbonMarket design team will need to determine the set of ecosystems to turn into ecosystemas. One approach begins with cataloging all major natural ecosystems that intersect with each of the farms managed by farmers participating in the ESM user research. The CarbonMarket design team now has a set of candidate ecosystems that can be abstracted into an ecosystema.

Figure 1 introduces a prototypical example of an ecosystema based on the archetype of a wetland in the American Midwest. This ecosystema includes specific considerations for the impacts of agriculture because it would inform the design of an ESM used by farmers and others. We propose six components in an ecosystema, as demonstrated in Figure 1:

1. Images of wetlands are chosen to evoke a designer's imagination of what it may be like inside the ecosystem, thus situating them in the context of the ecosystem. The images are of real wetlands, though together they illustrate features of a wetland archetype. In the example of Figure 1, photos of the Pinhook Bog, among others, are used.
2. The characteristics component describes how the ecosystem naturally functions to provide the designer with an understanding of how humans interrupt the self-servicing characteristic of ecosystems. In Figure 1, we supplement a textual description with a diagram that illustrates a range of related ecosystem types (that are abstracted into the ecosystema).
3. A user story introduces the history of the ecosystem, including a description of the effects of climate change and conservation efforts. Because this ecosystema is to be used in the design of agricultural technology, content related to human impacts is centered around the effects of agriculture.
4. The inhabitants component informs the designer of the range of native species living within this ecosystem, providing a summary of key non-human organism stakeholder groups. If, for instance, a species is endangered or faces potential harm, we suggest designers use a persona devoted to the organism itself, similar to user and animal personas.
5. The challenges component warns against the negative impacts an ecosystem faces as a result of human actions. In wetland ecosystema of Figure 1, we describe challenges beyond direct farmer actions, including second-order, third-order, and indirect effects on the ecosystem.
6. The desires component describes concrete ecosystem services that are needed to offset the effects of human intrusion. This includes services to combat effects resulting from global human-induced challenges such as climate change, to specific ecosystem services to repair harm or prevent potential harm caused by agricultural activities.

Ecosystemas to inform the design of an ESM

A good ecosystema ideally cultivates empathy toward ecosystems, encouraging technology designers to consider how their tools may impact nature. A good ecosystema effectively advocates for ecosystems, pushing designers to critically consider the potential for technology to encourage ecosystem protections and respect for the rights of nature.

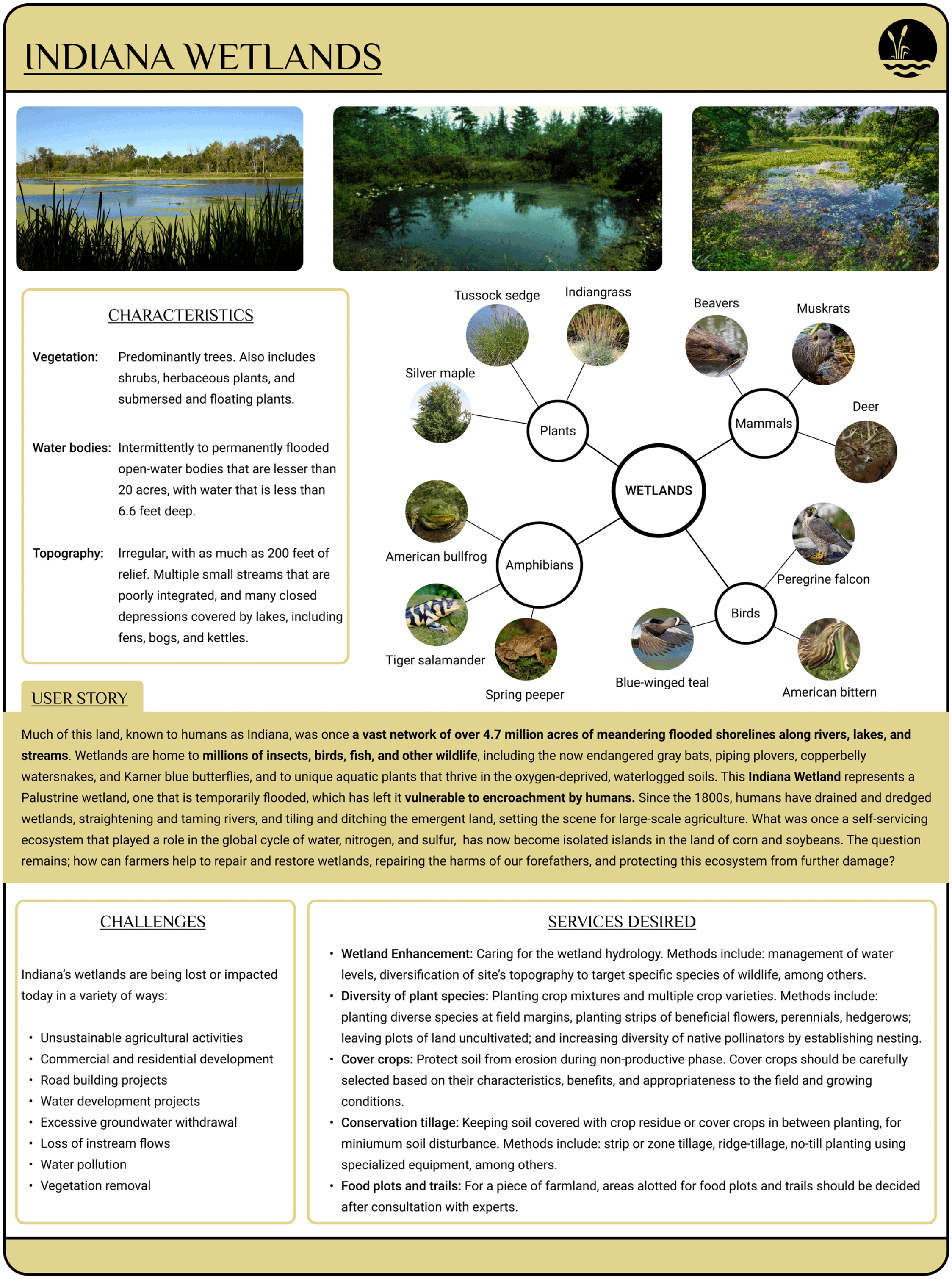
In the example of the design of CarbonMarket ESM, the use of ecosystemas by the design team may lead to various feature requests or perspectives being taken. For example, the ESM could provide ecosystem service recommendations for future conservation areas and selection of regenerative agricultural practices to further provision an ecosystem with protections. This functionality suggests new ecosystem services that a farm can provide given its proximity to different ecosystems, its current practices, and other considerations based on farm participation in the ESM. Design constructs such as ecosystemas could help ensure that agricultural technologies such as ESMs are designed with consideration for ecosystems, and take into account the realities of both agricultural and ecological systems.

ECOSYSTEMA USE CASES

Beyond the extended example above, we envision an array of different contexts in which ecosystemas could impact design processes. Here we provide three shorter examples that populate the space of contexts where ecosystemas could be productively brought to bear.

First, an ecosystema could help a designer guide a client toward an alternative direction for the system they were seeking to design. Rather than focusing on a reductionist solution to a known "pain point," the designer could use the broader view informed by the ecosystema to help the client envision restructurings of the broader technological ecosystem that the particular design activity was seeking to improve. For example, in redesigning an

Fig. 1. A prototypical example of the ecosystema tool representing an Indiana wetland. Material in this ecosystema, including images, were drawn from U.S. Geological Survey 1996, Indiana Department of Natural Resources 2002, Wszelaki and Broughton 2012, U.S. Department of Agriculture 2013, Cornell University 2019a, 2019b, 2019c, Larsen 2020, Bella Vista Property Owners Association 2021, VanTryon 2021, Gardenia 2022, Illinois Extension 2022, National Wildlife Federation 2022, North Carolina State Extension 2022, Outsidepride Seed Source 2022, Wawasee Area Conservancy Foundation 2022; Baxter 2019, https://panoramanow.com/events/pinhook-bog-guided-tour/; Culler 2020, https://visitindiana.com/blog/index.php/2020/10/09/wildlife-northwest-indiana/; Swinehart 2022, https://shamrockwildlifeservices.com/animal-removal-nw-indiana/muskrat-removal/.



online shopping site such as Amazon.com, rather than simply sprucing up the visualization of customer reviews, an ecosystema could help the design team think about whether product features, reviews, and price are the only features salient to a customer's decision process, or whether environmental impact information should be included as well.

Second, an ecosystema could help a designer make connections between different clients and industries. Cradle-to-cradle design (McDonough and Braungart 2002) is supported, in part, by one organization using the "waste" products from a different organization as the inputs to their own processes. An ecosystema (especially one shared across industries, as discussed below) could help designers make introductions between multiple clients who could transform an ecosystem-polluting waste from one domain into an input in a different domain. Or, for example, if two companies have both used the same ecosystema (e.g., the Indiana Wetlands from Figure 1), designers at one company could use the shared ecosystema to identify the other company as a potential partner with a similar environmental focus.

Finally, an ecosystema could provide a launching point for helping guide a client toward undesign (Pierce 2012), the "intentional negation of technology," or helping a designer articulate "the value of absence" (Baumer and Silberman 2011). For example, if a client were asking the designer to develop a new system to "fix" something that was being broken by a different existing system (i.e., "the cure is worse than the disease," or simply contributing to the inexorable accumulation of complexity [Tainter 2006]), the designer could use the impacts of the hypothetical new system on an ecosystema as a way to guide the client toward a less impactful approach. Baumer and Silberman provide an example of data-driven gardening, and suggest forgoing a technical solution (installing temperature sensors) in favor of a social solution (asking for advice from nearby gardeners). This proposed solution, with its lower reliance on digital technologies, would likely lead to lower carbon emissions and less electronic waste (Nardi et al. 2018). Baumer and Silberman's (2011:2272) question, "Does a technological intervention result in more trouble or harm than the situation it's meant to address?" is salient here; an ecosystema could help the designer explain these tradeoffs to the client. (It's worth noting that, even if this approach were to be a desirable practice for designers, many designers might not choose to pursue it because it could potentially lead to less billable hours of work for them.)

CREATING ECOSYSTEMAS

As ecosystemas are incorporated into design scenarios and decisions, a key challenge will be balancing the sometimes competing needs among humans, multiple other species, and long-term viability and resilience of the ecosystem. The design team as a whole, in conversation with other stakeholder groups, would need to arrive at a modicum of agreement about which design decisions constitute desired outcomes[8] in terms of balancing the needs of multiple species and the ecosystema they reside in. Is it possible to generate a generic set of guidelines or criteria that designers, and others involved in the process, could rely on or invoke as they work toward the goal of achieving the best overall outcomes for all stakeholder groups, non-human as well as human?

An interdisciplinary team of university faculty and students worked collaboratively on the design and content of two specific artifacts illustrating the ecosystema concept (see Fig. 1 and Fig. 2; Tomlinson et al. 2021). The team developed two different types of ecosystemas to explore the range of possible forms these design tools could take. The first type presents purely scientific content written in the third-person (Fig. 1). The second type anthropomorphizes the ecosystem in question, based on scientific content (Fig. 2).

In Figure 2, we present an anthropomorphized version of an ecosystema. This ecosystema is based on scientific data, but presented in a way that is similar to the personification commonly used in personas. We expect that there will be trade-offs between these two forms of ecosystemas, objective and anthropomorphized. Although a third-person, more objective style may be more scientifically rigorous, it is possible that an anthropomorphized version could help designers and other stakeholders develop empathy and consider the needs of ecosystems alongside the users represented by personas.

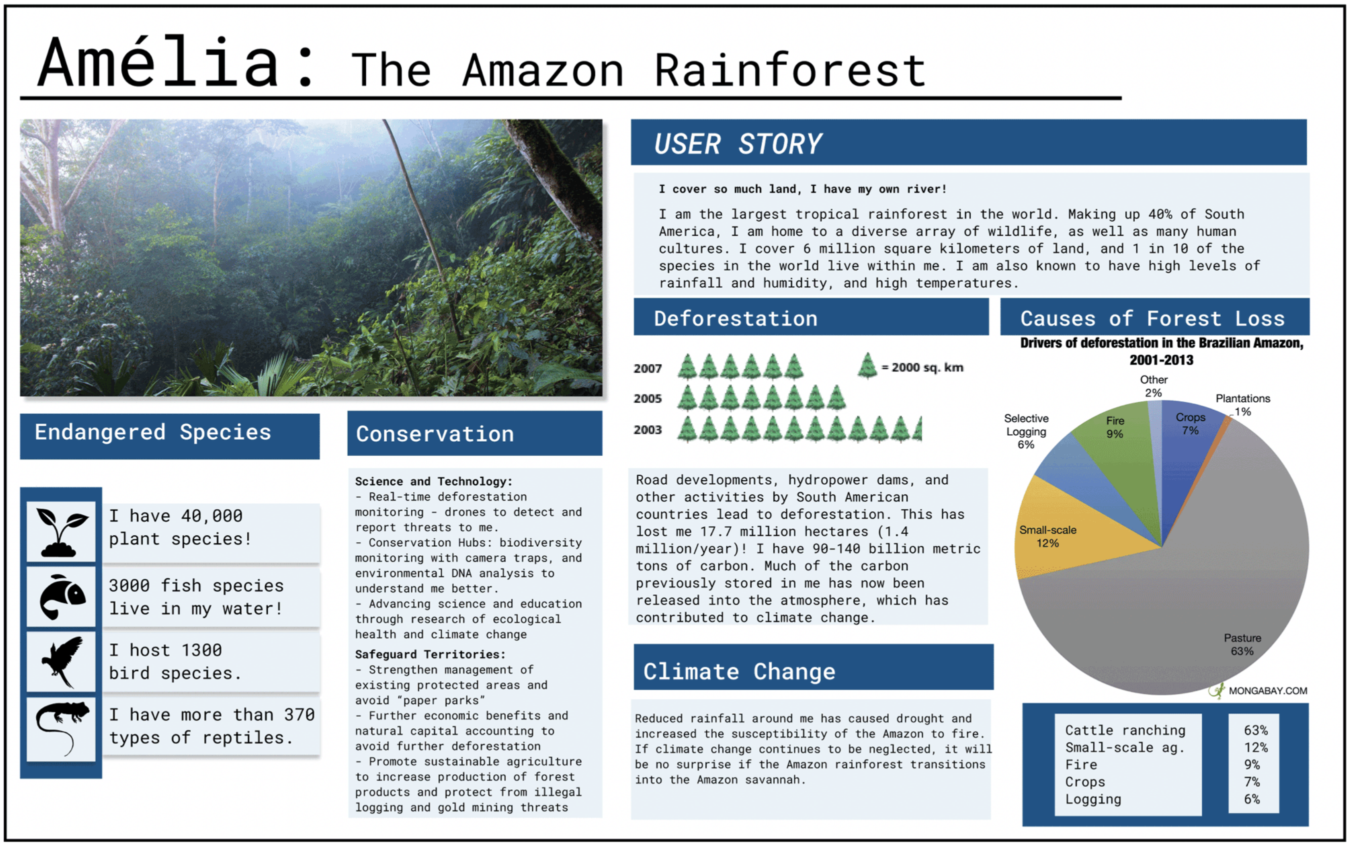
Another factor the team explored was whether a particular ecosystema should be based on one real-world ecosystem (which the team called a "simple" ecosystema) or on a hybrid of multiple ecosystems (which the team called a "composite" ecosystema). A simple ecosystema would have all of its information drawn from a single real, spatially delimited ecosystem. A composite ecosystema would be based on a single real ecosystem but potentially augmented by elements from other ecosystems (similar to how a persona may include aspects of multiple real people layered together into a composite representation). Both types would be tailored to the task of enabling human designers to consider the impact of their design on a range of ecosystems.

Figure 1, representing an Indiana wetland, is an example of a composite ecosystema based on the Pinhook Bog and surrounding agricultural lands in northern Indiana. The team augmented this ecosystema with data and characteristics of other wetlands taken from public resources and publications on wetlands and agricultural best management practices. For instance, the team obtained wetland characteristics from the U.S. Wetland Inventory curated by the Department of Fish and Wildlife (U.S. Fish and Wildlife Service 2020), species data from the Indiana Department of Natural Resources (2002), and information on agricultural practices to improve biodiversity and water quality from university agricultural extension resources (e.g., MacGowan and Miller 2002).

The Amazon ecosystema presented in Figure 2 is a mockup of a simple ecosystema, based on information drawn from a single ecosystem source. Different design contexts may lend themselves to simple vs. composite ecosystemas.

To ground efforts in real world parameters, ecosystemas should be developed collaboratively by designers working with biologists or ecologists, and potentially many others with relevant expertise in engineering, business, and other fields. Designers may work with members of a population unfamiliar to them to develop a viable persona for the population. This process could help designers keep unfamiliar aspects of the population in mind. Similarly, a designer could work with ecological experts on the constituents,

Fig. 2. An anthropomorphized ecosystema based on the Amazon Rainforest. The rainforest is given a name, the user story and other elements are written from a first person point of view, with more personal content. Material in this ecosystema, including images, were drawn from Figueiredo 2007, WWF 2014, 2020, 2022, Global Environment Facility 2021, Sengupta et al. 2021, Amazon Conservation Association 2022, Climate Institute 2022, Conservation International 2022; Jay 2015, https://commons.wikimedia.org/wiki/File:Amazon_Rainforest_in_Tena,_Ecuador.jpg; Butler 2021, https://rainforests.mongabay.com/amazon/amazon_destruction.html.



interactions, and temporal patterns of particular ecosystems to develop an ecosystema, as well as with other experts regarding which aspects of an ecosystema would enable it to be more accepted and effectively deployed.

Future design efforts to minimize environmental harm could be built on shared, evolving representations of ecosystemas. These representations would require collaboration across fields and industries. For example, the process of designing a food production system would need to engage with an ecosystema that reflects likely ecosystems where that food production system may be deployed. It might produce design knowledge that would be relevant to an adjacent food distribution system, or to some non-food related system (e.g., a park, an energy infrastructure effort) that would engage with similar ecosystems.

A key challenge facing interspecies wealth transfer is the friction between the need for information openness in promoting environmental concerns and corporations' needs to protect trade secrets and other intellectual property. Nevertheless, various alternate legal frameworks, such as the benefit corporation (Clark and Vranka 2013) or the Accountable Capitalism Act put forward in the U.S. Congress by Senator Elizabeth Warren (Warren 2018, Tomlinson et al. 2020), could potentially help lay the groundwork necessary for industries to create shared representations of ecosystemas as discussed above, and more broadly, to confront the difficult anthropogenic problems facing life on Earth that underlie the need for such constructs. Common efforts surrounding the development of ecosystemas would hopefully enable these constructs to become more fully developed, and more useful in design.

For those common efforts to include the good of non-human species and ecosystems in a nontrivial way, there would need to be substantial shifts in priorities for most corporations. Current models of capitalism focus on benefits to shareholders, i.e., shareholder primacy (Rhee 2018). However, voluntary frameworks such as corporate social responsibility (Chaffee 2017) and triple bottom line accounting (Elkington 1997) provide some hope that capitalism may be able to shift its focus, though company proclamations of their CSR sometimes amount to "greenwashing" marketing ploys that serve the company's financial bottom line rather than social and ecological accounting criteria. It is unclear if capitalism as a system is up to the challenge of substantial shifts; recent proposals around post-growth and degrowth economics (Kallis 2011) provide intellectual framings for transitioning to new economic systems, directly challenging key tenets of neoliberal capitalism.

Currently, designers, clients, users, and other stakeholders often ignore many of the ecological costs to other species implicated in nearly all human design activities. By foregrounding these costs, and highlighting the realization that a great deal of humanity's material flourishing comes at the direct and indirect expense of non-human species, future design activities can help promote system transformations that take into account the impacts on other species (Tomisch et al. 2021c). Just as software designers have an obligation to talk to clients about non-functional requirements such as safety and security (and now sustainability is beginning to be seen in a similar light [Penzenstadler et al. 2014]), so too should designers have an obligation to raise the issue of the ecological costs to other species of a particular design. Just as clients can overrule a software designer who suggests adding a password, clients can overrule designers with regard to environmental impacts as well. However, the requirement to raise sustainability considerations through explicit analyses of ecosystemas, we believe, is a potentially valuable contribution toward enacting broad-scale system transformation, especially by confronting thousands of clients with ecologically supportive design options and pervasively raising awareness of them.

Ecosystemas are not a panacea for all sustainable design concerns. However, we contend that they usefully complement existing sustainable design strategies (cf. Ceschin and Gaziulusoy 2019). They will necessarily operate alongside non-sustainability related design tools and techniques in the broader design ecosystem. As with many human processes, adding "just one more thing" risks overwhelming the people and systems engaged in that process. We acknowledge the challenge that ecosystemas will face in finding a place among existing design approaches; what persona will be removed to make space for an ecosystema? What user's needs will be compromised to address the needs of an ecosystem? Although there may often be opportunities for "win-win" solutions, they are not always possible. Nevertheless, we believe ecosystemas are well-positioned to participate in design processes in the same way personas do by having a place "at the table" as design takes place.

The human world is in a moment of global social ferment because of COVID-19, planetary warming, and other phenomena. Whereas proposing ideas such as interspecies wealth transfer might have seemed unrealistic even a very short time ago, humanity is now grappling with the agency of powerful environmental forces, e.g., viruses and climate change, that may usher in new ways of thinking and living.

Designs that reverse interspecies wealth transfer may sometimes (perhaps even frequently) come at the cost of decreased resources for humans in the short term, as ecological wealth is returned to other species in the form of land, lowered emissions, and other assets. As such, they may require a shift in societal mindset to see them as desirable outcomes of design activities. For example, Irwin et al. (2015:3) have discussed the need for "design-led societal change," in which "design [does] more than cater to capitalist retail economies." Nevertheless, because humans ultimately rely on the ecosystems for our own survival, these shifts may well be in the long-term best interests of humanity as well as of other species.

FUTURE WORK

There are a number of elements of the approach described in this article that point to future work. With regard to ecosystemas specifically, there is a need to deploy and evaluate these design tools in real-world contexts. For example, what processes are necessary to cause a design team to use an ecosystema at all? If they use it, will they use it in ways similar to how they use personas? Does the presence of an ecosystema change how they engage with other design tools? Does the ecosystema lead to identifiable changes in the outcomes of design processes? What considerations might motivate designers to use the ecosystema in their future design projects?

The perspectives represented by various personas, ecosystemas, and related design tools are sometimes interconnected. A member of a particular user group (represented by a persona) may live within an ecosystem represented by an ecosystema. As such, there may be overlap between aspects of the two design tools. Similarly, a non-human species may inhabit two different ecosystems represented by two ecosystemas. Therefore, an important question becomes: how best to align the needs of multiple, diverse organisms situated in an ecosystema, and harmonize those with other ecosystema considerations/requirements that are separate from the specific needs of its resident groups? This is an open question for future research.

Looking beyond ecosystemas to the future of design more broadly, we envision a future in which humans treat members of other species as having inherent worth beyond their value to humans, as well as having value to humans via their role in the ecosystems on which human civilizations rely. This inherent value is a keystone of animal rights law, as well as of the deep ecology movement, mentioned earlier, which arose in the 1970s through the work of Norwegian philosopher Arne Næss (Næss and Sessions 1984) who was inspired by Rachel Carson's seminal work (Carson 1962). There is a pressing need for design to engage with these ideas and concepts.

Looking beyond the realm of design, the use of ecosystemas could potentially inspire new directions for science, engineering, and potentially other fields. What scientific knowledge may need to be discovered to inform future ecosystemas? What new ecosystema-inspired tools and techniques could be adapted from design processes to scientific investigations? Similarly, with engineering, how may the broad purview of ecosystemas help engineering researchers and practitioners think differently about their activities as ecosystem impacts become centered in human processes?

Humans have exploited other species for their own gain for millennia. This exploitation has been facilitated by many new technologies since the Industrial Revolution. It has been pursued with even greater power since the rise of rapid wealth accumulation that accompanies capitalism (Harvey 2005, Stutz 2010, Piketty 2014) and the massive environmental damage associated with generating economic growth in non-capitalist regimes (Dominick 1998). The future we envision is one in which exploitation of animals, human and non-human alike, is considered problematic and deliberately addressed through science, technology, politics, and economics. It is a future in which mutual respect and empathy beget equity and justice. In this vision, humans have sole power among species to enact directed, intentional, system-level change, and are the only species that can, and should, accept responsibility for both problems and progress.

Within this vision, designers would engage with many different stakeholders (Reed et al. 2009) to consider human environmental impacts as a critical theme in all design activities. Such a reformulation would be driven by a variety of motivations, including justice for other species, as well as pragmatics for humans themselves.

In his 1916 book, *A Thousand-Mile Walk to the Gulf*, John Muir wrote, "Why should [humans value themselves] as more than a small part of the one great unit of creation? ... The universe would be incomplete without [humans]; but it would also be incomplete without the smallest transmicroscopic creature that dwells beyond our conceitful eyes and knowledge ... They are earth-born companions and our fellow mortals." (Muir 1916). The prevailing paradigm of interspecies wealth transfer threatens both our "fellow mortals" and our human selves. The ecosystema framework we propose holds promise for equitable sharing of the Earth with the rest of biodiversity for our mutual benefit and survival.

CONCLUSIONS

We have outlined an approach to design and design knowledge that could help to reduce and reverse anthropogenic environmental harm, specifically through the use of ecosystemas. Design processes lie at the heart of much human activity; intervening in these processes has the potential for impact across a wide range of domains. The ecosystema concept, through which the concerns of various ecosystems and the species within them are kept at the fore in design processes, could influence design and the real-world systems that design brings into existence. In this article, we have described elements we believe are important to the creation and use of ecosystemas, and presented conceptual prototypes of particular ecosystemas. Ecosystemas will not enact change in design processes where there is not a will, at some level, to serve the needs of ecosystems. However, we believe there is substantial environmental goodwill present in many design processes, and that as awareness of climate change spreads the will to enact environmental change will grow. As the willingness to allow these concerns to influence human processes at all levels becomes more widespread, we hope that ecosystemas can help operationalize this willingness across many human activities.

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[1] Portions of this article have been adapted and expanded from an earlier conference paper (Tomlinson et al. 2021).

[2] The authors recognize that there is no fundamental biological distinction between humans and non-humans. This distinction is used for pragmatic purposes, given that humans have caused a disproportionate amount of ecological disturbance, change, and damage. Social ecologist Murray Bookchin also argued that humans' capacity for rational decision making and moral thought places a special onus on them to become ethical stewards of multi-species ecosystems (e.g., Bookchin 2005), though the authors admit the possibility such capacity may one day be revealed in some non-human organisms. Bookchin's perspective on "thinking nature" remains an aspirational vision of human enlightenment, given the devastation to ecosystems unleashed by "enlightened" humans over recent centuries.

[3] Merriam-Webster's dictionary defines "wealth" as "abundance of valuable material possessions or resources" (https://www.merriam-webster.com/dictionary/wealth). We use the term "wealth" here to draw a parallel between human and non-human species (i.e., that non-humans may make use of valuable resources), a parallelism that is reflected in the ecosystema design construct proposed later in this article.

[4] We note that despite the broad trend identified here, many taxa, dogs, cows, rats, wheat, rice, various pathogens, etc., have benefitted, in terms of species abundance, from their association with humans.

[5] We note that other economic systems, such as totalitarian communism, have caused even more damage to biodiversity (Dominick 1998).

[6] Interestingly, results from a meta-analysis of 133 restoration efforts suggest that laissez-faire regeneration, in which regions are simply left unsupervised to recover on their own, tends to outperform active restoration, in which humans take steps to foster the regeneration process (Crouzeilles et al. 2017).

[7] We considered calling these "ecosystem personas," but the term "persona" itself is typically anthropomorphic, so we opted for a neologism. Although the personhood of non-human entities is part of various countries' legal frameworks, as discussed later in this article, the common usage of the related term "person" typically refers to a human individual. We recognize that the term "ecosystema" is similar to the Spanish term for ecosystem: "ecosistema"; the distinction in spelling should allow for this concept to be usable in Spanish-speaking contexts as well.

[8] We recognize that forming a consensus around such concerns is important yet nontrivial; various methodologies (e.g., participatory decision making [Smith 2015]) have been developed to help groups converge on shared understandings of desirable outcomes.

Responses to this article can be read online at:
https://www.ecologyandsociety.org/issues/responses.php/13324

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Data/code sharing is not applicable to this article because no data/code were analyzed in this study.

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