Title: Creating *opportunities for coexistence* to overcome the food–biodiversity challenge

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Word count: 5765

Tables: 1

Figures: 1

References: 76

Acknowledgements

SJC was supported by the Vicerrectoría de Investigación, Innovación y Creación (USACH) through the Postdoctoral project grant 092475MA_Postdoc. DM-A was supported by Fondecyt ANID 1231261 and Grant ANID PIA/BASAL FB210006. The authors declare no conflict of interest.

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Abstract

Coexistence with biodiversity in agricultural landscapes is a global vision by 2050. However, the co-occurrence of wildlife and human food production often results in conflicts which require resolution. Therefore, agroecological landscapes that emerge when sharing land ultimately require achieving human-nature coexistence. We conceptualize human-nature coexistence as an n-dimensional space located in the intersection of multiple components of food security and biodiversity each acting as a dimensional axis and coalesce them into a single framework. Here, we expand upon the concept of coexistence parameters to introduce the concept of *opportunities for coexistence* to explain how different combinations of parameters can meet the needs of both food security and biodiversity conservation in different agroecological landscapes. Establishing this framework in an 'Agroecological Systems Model of Coexistence' provides further insight into understanding human-nature coexistence as a system state unique to every landscape and serves as a tool to conceptualize components as explanatory factors of such a state to inform policy and management when dealing with the food-biodiversity challenge at the local level.

Keywords: human–nature coexistence, conflict resolution, basin of coexistence, coexistence niche, social-ecological systems, coexistence parameters

Introduction

Ensuring coexistence with native biodiversity and achieving food security are both necessary for humanity to comply with the self-imposed agenda of reaching environmental sustainability in a post-2020 world (see 2050 Vision 'Living in harmony with nature', Convention on Biological Diversity 2020). The existence of a win-win scenario has been proposed for food security and biodiversity conservation, which focuses on landscapes with small-holder agroecology as a solution to meeting both food security and biodiversity goals (Fischer et al. 2017). In these landscapes, wildlife-friendly farming and land-sharing strategies may reduce agricultural yields per unit area with regards to fully exploited landscapes (but see Clough et al. 2011), however they also allow wildlife to survive within agricultural plots (Green et al. 2005; Fischer et al. 2008), expanding the amount of land available for wildlife conservation beyond the confines of natural areas. Crucial for nations with little remaining natural habitat, agroecological landscapes brought about by land-sharing strategies might be the only way to ensure sufficient habitat for species with large home ranges, barring the restoration of current farmland back into natural habitat (Crespin & Garcia-Villalta 2014). Herein lies the *food–biodiversity challenge* which reveals itself only once the scope is widened from aiming to accomplish only either food security or biodiversity conservation, towards a broader focus that includes meeting both goals in the same space.

Making efficient use of space to accomplish either food security or biodiversity conservation goals requires optimizing resources in such a way that land area is completely accounted for in a specific landscape (Fischer et al. 2014). Thus, in multiuse landscapes, resource optimization of distinct components of food security and biodiversity creates a trade-off that can be managed to allow for win-win scenarios (Fischer et al. 2017). However, optimizing one or the other results in the clashing of stakeholders vested in opposing interests, generating conflicts based around conservation and/or stock yielding issues (Young et al. 2010). Once these conflicts emerge, a landscape's potential to meet both food security and conservation goals is impaired. It has been previously established that for landscapes to be truly shared they require for native biodiversity and food production to not only co-occur, but to also coexist (Crespin & Simonetti 2019). Coexistence in a social context refers to a state in which groups of people live together, respect their differences, and resolve their conflicts without violence (Weiner 1998). Coexistence in ecology entails the ability of species to persist in time and space along with the continuation of species interactions, including competition and predation, the Lotka-Volterra model being a classical example. Thus, meeting the aims of biodiversity conservation and the production of human food and services on the same land by enabling the fulfillment of both interests, all the while avoiding the emergence of conflicts, requires approaching human-nature coexistence from a social-ecological perspective. This is done with the goal of reaching *social-ecological coexistence,* which has been defined first by Carter & Linnell (2016) and lastly by Pooley (2021) as "a sustainable though dynamic state, where humans and wildlife co-adapt to sharing landscapes and human interactions with wildlife are effectively governed to ensure wildlife populations persist in socially legitimate ways that ensure tolerable risk levels". Such a definition of coexistence does not consider the presence of conflicts to be incompatible with coexistence (Pooley 2021), but it does establish the existence of tolerable risk levels that can be regulated by means of social rules such as norms, beliefs, deals and laws. Interpretations of coexistence that feature dynamic states allow for both negative and positive human responses at the behavioral and attitudinal level to exist and manifest tolerance as a positive (stewardship) or negative (manifested intolerance) response to wildlife (Bhatia et al. 2020). This coexistence must also be achieved at different ecological and sociological levels, ranging from individual (or personal) to ecosystem (or societal) level interactions between humans and nature (Lischka et al. 2018).

When viewing production-oriented landscapes as systems, interpreting coexistence as a dynamic state means that time can change the parameters of the system, that is, the social-ecological factors that affect human response to wildlife impacts, and yet still be considered to be in a state of coexistence (Crespin & Simonetti 2021). Adding to this interpretation of coexistence as a system state, it is then natural to conclude that the property of being dynamic would then allow for the existence of alternative states in the system other than coexistence, particularly states of conflict. Let us elaborate.

Understanding why human-nature coexistence is integral for food-biodiversity compatibility

When opposing interests manifest intolerance, they can create self-sustaining feedback loops resulting in states of conflict between social groups, such as people vying for food production versus those striving for biodiversity conservation (Crespin & Simonetti 2021). Some of these parameters, for instance, can be at the level of food demands or threats to biodiversity. *Conflict prevention* involves the progression of natural ecological dynamics (such as predator-prey interactions) and societal needs to be met without incurring damages to human wellbeing or native biodiversity, or at the very least make whatever damage is done become an acceptable loss at a tolerable risk level. In general, the realization of land-sharing strategies requires the implementation of conflict prevention and resolution mechanisms to be successful.

Before continuing, we would like to address two points regarding conflicts and coexistence. First, it is important to separate conceptually distinct terms in conservation, *i.e.* impacts and conflicts. The situations where either people adversely affect biodiversity or biodiversity negatively impacts people, should be recognized as *biodiversity impacts* (Young et al. 2010). Once an affected party decides to eliminate a biodiversity impact, societal and conservation goals enter into opposition, generating *conservation conflicts* (Redpath et al. 2013), and sometimes referred to as biodiversity conflicts (White et al. 2009). Prior to the 2010s, the literature interpreted biodiversity impacts as conflicts (Young et al. 2010). Second, though the term "conflict" has permeated the scientific vernacular to describe opposing social interests, we support a phasing out of the term in favor of more productive interpretations of human-biodiversity relationships (Peterson et al. 2010). Therefore, when possible, from hereon instead of referring to conflict we shall refer to its counterpart, *human-nature coexistence*, as it is these states of coexistence that we as conservationists wish to achieve.

Planning for people and nature in production-oriented landscapes implies interpreting and recognizing these landscapes as *social-ecological systems* (SES) (Ban et al. 2013). This highlights the complexity that emerges due to their components being shaped from different levels and facets of both people and nature, and the fact that they are interlinked across scales, with people and nature affecting each other in one place but also elsewhere (Fischer et al. 2015, Ostrom 2009). Interpreting productive landscapes as systems allows for alternative states of conflict and coexistence to exist for a particular landscape (Crespin & Simonetti 2021). As dynamic systems, landscapes can have different attractors in their phase space (*i.e.* the space that represents all possible states in a system) for both states of conflict and coexistence, meaning that the overall goal of conservationists would be to nudge a landscape into a basin of attraction belonging to what we may consider to be coexistence. Such that, although biodiversity impacts may occur, these should hold only a small sway over the state of a landscape, whose state is governed by a multitude of other social-ecological factors.

Working through the lens of system theory and viewing landscapes as social-ecological systems allows traversing the food-biodiversity nexus towards coexistence by treating social-ecological variables as system parameters. These can include ecological, economic, psychological, cultural and physiological aspects of people and nature in a given landscape. Subsequently, one can identify which variables explain the emergence, intensity and frequency of conflicts, *i.e.* which ones define states of conflict, thereby allowing one to manage them accordingly and nudge the system toward a state of coexistence. Proposals to manipulate these parameters should aim to shift the state of a landscape through its phase space away from its current basin of attraction towards a desired one (from conflict to coexistence). Thus, those parameters that determine system states devoid of major losses for both food security and biodiversity can be called *coexistence parameters* (Crespin & Simonetti 2021).

Here, we expand upon the concept of coexistence parameters to explain how different combinations of parameters can meet the needs of both food security and biodiversity conservation to create *opportunities for coexistence*. To explain how to generate these opportunities for coexistence we have developed a conceptual "Agroecological Systems Model of Coexistence" by modifying the original food-biodiversity nexus systems model proposed by Fisher et al. (2017) so as to include components of food security and biodiversity as coexistence parameters. Thus, we conceptualize human-nature coexistence as an n-dimensional subspace located in a phase space comprised of the intersection of multiple components of food security and biodiversity, each acting as a dimensional axis. We term the combinations of parameters inside the subspace of coexistence as 'opportunities' because they are conceptual in nature. Reaching any of these combinations is the challenge conservationists face when confronting conflicts. Coalescing food-biodiversity components into a single model may allow for easier detection of actions required to manipulate coexistence parameters and decrease biodiversity impacts or increase tolerance, thus identifying opportunities for reaching states of coexistence in a landscape.

As a corollary, a more precise analogy for coexistence and conflict would be to describe them as basins of attraction. This allows the landscape to remain a dynamic system, constantly shifting through phase space inside a basin according to different scenarios of biodiversity conservation and food security arrangements. Biodiversity impacts of sufficient intensity and frequency can push a system out of one basin and into another. As conservationists, to bring a landscape into a *basin of coexistence* and keep it there, we must be willing to identify all coexistence parameters present in a landscape and engage with them, especially if they belong to unfamiliar disciplines (e.g., Saunders 2003). We would like to reiterate that our use of the term "basin of coexistence" is social-ecological in nature: we are aiming for a system state of human-nature coexistence after all, which differs from previous uses of the term that referred to coexistence in the sense of ecological population dynamics (e.g. Ni et al. 2010, Shi et al. 2010) or hard geographic limits (e.g. Lamb et al. 2000). It follows then, that reaching beyond our element and collaborating with professionals from distinct fields will inevitably be a part of finding opportunities for coexistence.

Threats impeding human-nature coexistence

Human-nature coexistence may be impeded by direct or indirect drivers of conflict. *Direct* or *proximate* drivers of conflict consist of impacts on biodiversity (such as persecution, exclusion, and extraction) and human wellbeing (such as loss of economic solvency, increased risk of injury or danger of disease transmission). Persecution of wildlife occurs in retaliation for ongoing resource competition (carnivore-livestock production conflicts, elephant, or primate crop raiding) (Sillero-Zubiri et al. 2004, Fleming et al. 2006, Macdonald et al. 2010) or when perceived as dangerous to humans either by causing human death and injury (Baker et al. 2008) or transmitting diseases (Löe & Röskaft 2004). Spatial exclusion happens when critical resources are lost and coopted by human-dominated landscapes such as destruction of carnivore hunting grounds (or prey habitat) or herbivore feeding stock (Chapron & Lopez-Bao 2016). Extraction for use as resource with either commercial or cultural purposes refers to uses such as in the exotic pet trade industry and medicinal uses (Darimont et al. 2015, Chapron & Lopez-Bao 2016). It is thus unsurprising that focusing on direct or proximate drivers of conflict, which rise from human-wildlife interactions and require ecological approaches, have left indirect or distal drivers by the wayside in lieu of more noticeable quantitative solutions.

Indirect or *distal* drivers of conflict emerge from behavioural, cultural, and identity needs that involve interactions with wildlife, and thus, require underlying social (legal, cultural, psychological, et al.) approaches to resolve (Young et al. 2010). In such cases, relying on strategies that only employ quantitative trade-offs (ecologic or economic) are insufficient to deal with the underlying conflicts that are at the root of the seemingly unending observable disputes surrounding quantifiable or perceived losses. Even strategies that overcompensate losses may not be enough to signal the end of an underlying conflict (Bautista et al. 2019). This complexity and depth concerning the number of drivers that need to be addressed in conflicts is described by the Levels of Conflict model (Canadian Institute for Conflict Resolution 2000) that has served to better understand conservation conflicts (Madden & McQuinn 2014). In essence, disentangling conflicts often requires going beyond factors that enact quantitative effects and delving into the social sciences. Thus, we should look toward social-ecological interdisciplinary approaches when cultural and identity-based needs are affected by conservation targets or actions (Young et al 2010).

Complexity in managing human-nature conflicts: no silver bullet

Biodiversity conservation is complex in that it requires navigating myriad interactions between cultural and biophysical systems, leading to their conceptual integration in social-ecological systems models in an attempt to mirror aspects of reality. Multiple advances in analyses regarding social-ecological systems (see Binder et al. 2013) have given way to frameworks that specifically center on human-wildlife interactions, which tend to describe system wide drivers of these interactions and even offer integration at multiple levels of social-ecological organization (e.g., Morzillo et al. 2014, Carter et al. 2014, Lischka et al. 2018). However, for policy to acknowledge these different approaches, first academics must also acknowledge a lack of the transdisciplinary work needed to achieve coexistence (Hartel et al. 2019). The fact is that for a long time, approaches towards solutions have been sectorial in nature, limiting the integration of research and management needed to adequately address conflicts in human-dominated landscapes (Hartel et al. 2019).

Negative interactions between humans and wildlife have historically taken place throughout the formation of human society. The Holocene saw the magnitude of these interactions increase and tip in favor of humans to the point that in the present, human interests in wildlife and ecosystem wellbeing have matured into structured areas of science, clashing in turn with interests in human productivity and wellbeing, creating conservation conflicts. Among conservation conflicts, none are more conspicuous than those involving specific species such as livestock predation by carnivores (Baker et al. 2008) with crop raiding by large herbivores and primates following close behind (Redpath et al. 2013), commonly labeled *human-wildlife conflicts*. Predation of livestock or raiding of crops results in the subsequent persecution of the presumed culprits, and in some cases, includes the targeting of other predator/herbivore species in the hope of preventing further loss. Essentially, these interactions result in conflicts between stakeholders whose vested interests align with either conserving carnivores/herbivores or livestock production and human wellbeing. Therefore, human-wildlife conflicts are at the forefront of conservation conflicts, a pressing matter considering most species involved suffer from vulnerability to habitat loss and persecution due to usually low population densities (in the case of carnivores), long gestation and parental care periods (in the case of elephants or primates) and requiring large home ranges. However, we would like to remind the reader that human-wildlife conflicts are not limited to carnivore-livestock predation or large herbivore-crop raiding and can emerge in human-dominated landscapes from interactions involving multiple taxa, including small mammals, birds, insects, and other ruminants, both native and exotic (Anderson et al. 2021).

As we discussed above, resolving conservation conflicts requires focusing on both the biological basis and meeting the underlying social identity needs unique to each landscape (Madden & McQuinn 2014). It is during these context-dependent processes of reconciliation that distinct combinations of biodiversity components can be managed to meet the needs of local landholders and conservationists (Redpath et al. 2013). Contextualizing the benefits of distinct ecological functions related to the conflicting biodiversity aspect to land holders and transforming the us-against-them mentality of the affected people into one of belonging and comradery with nature may open previously unnegotiable issues up for discussion. For example, once all measures available for mitigation and compensation of livestock predation by carnivores can be accounted for, success of carnivore conservation might also require for the local perception to shift toward perceiving carnivores as a benefit for local landholders. Specifically, determining how the removal of carnivores affects supporting ecosystem services in the long run may grant communities a sense of cooperation with carnivores on the same land (Ripple et al. 2014, Williams et al. 2018). The same conditions might also apply to large herbivores and crop raiding.

When thinking back to the Levels of Conflict model to describe the complexity underlying conservation conflicts, we can see that it functions as a pyramidal classification of conflicts and their solution processes, beginning with *disputes* solved through *settlements* at the top, followed by *underlying conflicts* requiring more complex *resolutions* in the middle, and ending with identity-based or *deep-rooted conflicts* that demand greater degrees of discipline integration to counter their complexity through *reconciliations* at the bottom (Canadian Institute for Conflict

Resolution 2000, Madden & McQuinn 2014). Unsettled disputes can linger and accumulate negative emotions, generating underlying conflicts which when left unresolved, fester and seep into prejudices or identity-based beliefs, becoming deep-rooted conflicts in need of reconciliation processes. A plurality of inter- and transdisciplinary sciences, or biocultural approaches (Hanspach et al 2020), are needed to reach sustainability levels required for resolution and reconciliation processes. Fundamentally, as levels of conflict and their respective solution processes increase in complexity and intensity, so too do the number of coexistence parameters and the level of integration between inter- and transdisciplinary sciences needed to shift a landscape toward coexistence (Crespin & Simonetti 2021).

Navigating the food security – biodiversity nexus

The food security – biodiversity nexus systems model describes four archetypes of social-ecological systems wherein agroecological landscapes are recognized as the win-win scenario for conservation and human society (Fischer et al. 2017). These four archetypes of social-ecological system states are based on favorable scenarios either for food security or biodiversity, essentially describing degraded landscapes as being necessary to avoid at all costs, intensive agriculture and fortress conservation as capable of meeting their respective food security and biodiversity goals if less regard is taken for the other, and agroecological landscapes as ideal scenarios where both food security and biodiversity conservation goals can be equally met. The outcomes of these archetypes can be viewed as wins or losses for each axis based on optimal usage of resources. *Degraded landscapes* are lose-lose outcomes for biodiversity and food security where levels of social, manufactured and natural capital are low, resulting in poverty and degraded ecosystems with low capacity to provide ecosystem services. *Intensive agricultural landscapes* are win-lose outcomes, with high levels of food production and quality and allowing access to local communities, but low levels of local biodiversity because resources such as space are coopted for human use and impacts on nature are intense. *Fortress conservation* comprises lose-win outcomes because native biodiversity suffers minimal impacts, but local communities' livelihoods and wellbeing are not prioritized and remain low, such as preventing food production on the same land where biodiversity is protected. Finally, small-holder *agroecological landscapes* are win-win outcomes where optimally using resources in a landscape for both biodiversity and food production allows positive outcomes for both axes in the same space.

Identifying coexistence parameters is important when transitioning between system archetypes and seeking to shift from a lose-lose outcome to a more favorable one (Crespin & Simonetti 2021). When aiming for agroecological landscapes (envisioned as win-win outcomes consisting of shared spaces), the processes involved in achieving coexistence between human society and the biological community may function as navigational mechanisms between archetypes. Ultimately, transitioning towards agroecological landscapes requires understanding which social-ecological factors allow coexistence, and at what spatial scale and ecological level these factors interact. This added dimensionality allows establishing the multi-dimensional subspace where both food production and biodiversity conservation needs are met, which we interpret as human-nature coexistence and term as *coexistence niche*. Thus, one might employ such a niche to formulate hypotheses aimed at explaining transitions from alternative archetypes towards agroecological landscapes by identifying which dimensional factors make up the foundation of a systems' phase space. It is inside this coexistence niche where opportunities for coexistence might reside. That is to say, the coexistence niche of a system is the combined total of all the combinations of food production and biodiversity conservation components that meet the needs of both.

Agro-productive human-dominated landscapes may transition to agroecological shared lands if coexistence is reached. However, each landscape is a unique combination of food security and biodiversity components unto itself, meaning a one size fits all approach will not suffice. Therefore, an expanded food-biodiversity nexus (sensu Fisher et al. 2017) with added dimensionality, along with a more complete knowledge of how interactions between components play out, might allow for more specific approaches and management practices when dealing with transitioning to agroecological landscapes. On these premises, this text aims to propose a modified social-ecological systems model of the food-biodiversity nexus comprised by distinct components of biodiversity and food security, as a central mechanism for transitioning from intensive agriculture or fortress conservation towards agroecological systems. We offer a short glossary of terminology as an aid (see Table 1).

Deconstructing the food security – biodiversity nexus

Deconstructing food security and biodiversity into their respective components adds dimensionality to the archetypes of the social-ecological systems model. Food security is a multipart concept generally described as combining quantity, quality and access to food along with temporal stability (FAO 2002, Sunderland 2011), and it is with each of these components that biodiversity interacts and must coexist. In turn, biodiversity also exists as a multipart concept, yet multilayered, encompassing composition, structure, and function as its components at distinct hierarchical levels (Noss 1990). Both concepts are temporally dynamic. We may now ask which biodiversity components at which levels interact with the components dictating food security, and how can they be managed to coexist, ultimately transitioning towards agroecological landscapes. Viewing Fisher et al.'s (2007) conceptual model, both axes are composite variables whereby possible solutions to traversing the plane will require addressing questions by approaching two multidimensional concepts. In agroecological landscapes, compositional and structural biodiversity components are intuitively linked to both quantity and quality components of food security by easily understood quantitative relations (e.g. more carnivores/herbivores may result in less food yield), yet biodiversity function and access to food are not so easily connected to each other and other components. However, viewing the food security – biodiversity nexus as a Hutchinsonian n-dimensional space may allow more specific questions to be answered, including where in this space coexistence might be found. In essence, abstracting coexistence into a conceptual model as the resulting overlap between needs met for food security and biodiversity can grant managers a theoretical goal to work towards.

Constructing an Agroecological Systems Model of Coexistence

To construct a conceptual model of coexistence in agroecological landscapes we modified the social-ecological framework established by Fisher et al. (2017), *i.e.* the food-biodiversity nexus. This modification relies on increasing complexity to more accurately model real systems by adding dimensionality to the model while maintaining a semblance of simplicity, using the model advanced by Lischka et al. (2018) as a basis for how ecological and social systems interact. Lischka et al's (2018) 'social-ecological systems model of human-wildlife interaction' describes a bidirectional effect between social and ecological systems at all levels, and where individual interactions are affected by human and animal behavior in turn determined by extrinsic and intrinsic attributes.

An 'Agroecological Systems Model of Coexistence' should therefore first describe how distinct combinations of food security and biodiversity can allow meeting the needs of one without necessarily doing the same for the other (Figure 1a, b), while showing the multidimensionality of food security and biodiversity given by their respective components (Figure 1c, d). This enables us to envision the combinations that do meet the needs of both food security and biodiversity conservation as 'opportunities for coexistence' (Figure 1e), and which when taking into consideration the multiple components of each axis can be thought of as an n-dimensional space of combinations of the multiple components comprising food security (quantity, quality and access to food) and biodiversity (composition, structure and function) (Figure 1f). This n-dimensional space is what we call the coexistence niche from which opportunities for coexistence arise.

Using the proposed model

Decomposing food security and biodiversity allows finding opportunities for coexistence, at least by meeting food security and conservation needs. To formulate testable hypotheses regarding human-environment relations and the resolution of conservation conflicts, we mean for the model's increasing complexity to help visualize relations between biodiversity components and food security components in real agroecological systems. At first glance, when assessing a new landscape through the model, the main explanations for biodiversity impacts are the food security and biodiversity axes through their respective components, and more importantly how those components interact. Identifying the social-ecological factors that cause a biodiversity impact allows drawing a conceptual net or space around these combinations of factors and at which levels the impact can be alleviated or eliminated, thus identifying the coexistence niche. The different combinations of factors and their levels that can be managed are opportunities for coexistence that can be interpreted as any point confined to the n-dimensional space. Each of the factors taking part in an opportunity for coexistence is a coexistence parameter due to being capable of shifting the system away from conflict and towards coexistence. Operationality can be achieved by engaging with the social-ecological factors identified as coexistence parameters by either scholars or practitioners in the field, as we show in the following two case studies.

Case study 1: Carnivore sentiment in El Salvador: preparing for coexistence with the puma

Most wildlife is not well received in El Salvador, carnivores even less so. Evidence of the puma (*Puma concolor*) in El Salvador had not been found since 1942 (Burt and Stirton 1961) until two independent monitoring projects using camera traps in 2018 presented the first photographic evidence of puma in El Salvador (Morales-Rivas et al. 2020). This makes the killing of a puma in

2020 (MARN 2020) even more tragic as its front paws were taken in a presumed act of trophy collection (Amaya 2020).

Land in El Salvador is primarily used for agriculture (84% in 2011 *sensu* Crespin & Simonetti 2016), so if the puma is to make a comeback, an expansion of its distribution and increase in abundance might lead to biodiversity impacts. Recently, camera trapping has even revealed pairs in courtship, pregnant females, females with cubs and juveniles making use of northeastern areas of the country throughout the year, indicating that reproduction might be taking place (Pineda et al. 2024). Sharing that land might result in more biodiversity impacts either on humans or pumas. Humans may be impacted in the form of livestock predation, as of yet unknown issues with food security, economic solvency or even direct attacks on humans, leading to cessation of daily activities. Pumas may suffer retaliation, and even their mere presence may lead to pre-emptive hunting or increased support of trophy hunting. These potential impacts can turn into conflicts between carnivore conservation and human interests, stemming from issues with food security or more general worries. Thus, successfully transitioning to agroecological landscapes in northeastern El Salvador presents a food-biodiversity challenge specifically when trying to meet the needs for both puma conservation and food security, along with background factors driving attitudes that steer toward unnecessary killing for trophy purposes.

Future impacts of the puma on Salvadoran food security might generate disputes and may be dealt through settlement processes such as monetary compensations or subsidization of strategies to protect against losses. However, unwarranted trophy hunting may be a deep-rooted conflict that will require a multigenerational strategy targeting cultural beliefs regarding value orientations all while respecting cultural history. From a systems perspective, social-ecological coexistence would be achieved by avoiding intolerable losses incurred through puma impacts and eliminating further unwarranted trophy hunting. Protection against losses of human lives and food security dimensions along with the elimination of cultural beliefs that lead to hunting might be the parameters that can lead this nascent agroecological landscape to a course of action. Coexistence parameters would be the direct and indirect drivers of beliefs implicating the puma as unwanted or overly dangerous. In such a case, opportunities for coexistence can be generated by instilling a sense of cultural pride and stake in puma conservation. Such positive beliefs can even form the basis of a basin of coexistence, leading communities themselves to seek conflict prevention. Multiple pathways to such a reconciliation can exist, interlinked at various levels of societal and ecological systems, creating a coexistence niche.

Case study 2: Wine production in central Chile: turning high-yield production lands into wildlife-friendly landscapes

The burgeoning wine industry in central Chile, a Mediterranean-climate biodiversity hotspot, presents a compelling case study for understanding the dynamics between agricultural expansion and nature conservation. Driven by global demand for high-quality wine, vineyard coverage has dramatically increased, in some periods by as much as 10% annually (Viers et al. 2013), reaching approximately 124,000 hectares by 2023 (SAG 2023). While some of this expansion reflects crop switching, a significant portion has resulted from the loss of vital natural and semi-natural ecosystems (Armesto et al. 2010; Schulz et al. 2010), including stream floodplains and sensitive hillsides. This conversion, coupled with intensive conventional vineyard management, poses a direct threat to local wildlife by fragmenting habitats and simplifying ecological communities, leading to declines in insect abundance, bat diversity and activity (Rodriguez-San Pedro et al. 2018), and bird richness (Muñoz-Saez 2024). Even meso-carnivores, particularly habitat specialists, are negatively impacted by the loss of native sclerophyllous forest-shrublands within these wine landscapes (Garcia et al. 2021).

However, multiple coexistence parameters can be found in vineyards throughout Chile that can lead to opportunities for coexistence. From a systems perspective, achieving socio-ecological coexistence between viticulture and local biodiversity will require a two-pronged approach regarding coexistence parameters. Firstly, the increasing environmental awareness within the Chilean wine industry, exemplified by initiatives like the voluntary program Wine, Climate Change and Biodiversity Programme (WCB), signals a shift towards more sustainable practices by encouraging wineries to adopt wildlife-friendly practices and engage in private land conservation (Marquez-Garcia et al. 2019). Thus, the robust monitoring and evaluation of management practices, supported by research and accessible to practitioners through ecological indicators and field observations (Diaz-Forester et al. 2021) allows for the identification of practices that minimize negative impacts and potentially enhance biodiversity, emerging as a first order of potential coexistence parameters.

Secondly, there is a growing realization of the positive outcomes associated with adopting conservation practices, which are crucial for generating opportunities for coexistence due to their synergistic effects. These benefits extend beyond mere altruism, encompassing financial advantages, strategic gains, and the tangible benefits of ecosystem services for wine production itself (Duran et al. 2022). For instance, the preservation of native vegetation can support beneficial insects that aid in pest control, reducing the need for chemical interventions. Soil microbial communities present in the native surrounding vegetation may enhance soil properties and ecosystem functions in vineyards (Castañeda & Barbosa 2017). Furthermore, a positive corporate image, often linked to environmental stewardship and the protection of the unique 'terroir' that defines wine identity and quality, acts as a significant strategic social driver for WCB members. This understanding that protecting nature maintains a terroir, which gives identity to the wine and an image to sell, can be a powerful catalyst for change and thus emerge a second order of coexistence parameters.

Building upon these opportunities for coexistence, basins of coexistence can emerge. When wineries and surrounding communities recognize the intrinsic link between a healthy environment and the long-term sustainability and marketability of their wine, a shared value system begins to form. This shared value can drive collective action towards landscape-level conservation efforts, where vineyards are managed in a way that integrates with and supports native ecosystems. For example, maintaining or restoring native vegetation corridors between vineyards can facilitate wildlife movement, enhancing biodiversity and potentially reducing the need for intensive pest control. The positive feedback loop created by enhanced biodiversity (e.g., natural pest control, pollination) contributing to wine quality and brand image, which in turn incentivizes further conservation efforts, can solidify these basins of coexistence. Multiple pathways to this harmonious relationship can exist in what we interpret as a coexistence niche, one of which is the development of eco-tourism initiatives centered around the unique biodiversity of the wine region, further strengthening the economic and cultural value placed on conservation. By focusing on the mutual benefits of biodiversity conservation and high-quality wine production, the Chilean wine industry can transition from a potential driver of conflict to a key player in fostering human-nature coexistence within this vital biodiversity hotspot.

Concluding Remarks

Throughout this text we endeavored to plainly state why adding dimensionality into the food-biodiversity challenge is necessary. The inherent complexity in social-ecological systems, which makes each system unique, does not allow aggregate concepts to offer blanket solutions to multiple agroecological landscapes simultaneously at the local level. Increasing dimensionality offers more specific concepts for opportunities for coexistence to flourish by offering solution-finding operationality. More specifically, general concepts, such as biodiversity and food security can ease understanding of issues and relations between variables in academic environments and at global or regional scales, but it is practicality and utility that are required to solve problems for practitioners and managers at the local level. Conceptual disaggregation is needed because more specific variables that can actually be measured and managed will allow for increased operationality.

Our "Agroecological Systems Model of Coexistence" framework can be viewed as a method to identify system-level leverage points (Meadows 1999) in an agroecological system. Leverage points are places to intervene in a system and range from easiest (but less effective) to hardest (but state defining) to manipulate. Fischer and Riechers (2019) illustrate how the leverage points perspective can initiate causal cascades in different landscapes and establish their advantages as tools for sustainability science, key among them their value as methodological boundary objects due to their potential use by multiple groups of scholars and practitioners from diverse disciplinary backgrounds. Concepts used in this framework such as 'coexistence parameters' and now 'opportunities for coexistence' only build upon the need for boundary objects in sustainability science and aim towards identifying the most cost-effective leverage points in an agroecological landscape.

We have added dimensionality to a specific challenge society faces, but we believe this can be extrapolated and repurposed to multiple challenges across the human-nature coexistence narrative. We hope to continue using, improving and coalescing our own framework with others in the near future and most importantly to aid conservation practitioners when engaging with the food-biodiversity challenge.

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Table 1. Glossary of concepts used to construct the proposed 'Agroecological Systems Model of Coexistence' framework.

Term	*Definition*
Food–biodiversity challenge	The trade-off between food production and biodiversity conservation (Green et al. 2005).
Social-ecological coexistence	"A sustainable though dynamic state, where humans and wildlife coadapt to sharing landscapes and human interactions with wildlife are effectively governed to ensure wildlife populations persist in socially legitimate ways that ensure tolerable risk levels" (Pooley et al. 2021).
Conflict prevention	The development of policy and management that allows the progression of natural ecological dynamics and societal needs to be met without incurring damages to human wellbeing or native biodiversity, or at the very least make whatever damage is done become an acceptable loss at a tolerable risk level.
Biodiversity impacts	The situations where either people adversely affect biodiversity or biodiversity negatively impacts people (Young et al. 2010).
Conservation conflicts	"Situations that occur when two or more parties with strongly held opinions clash over conservation objectives and when one party is perceived to assert its interests at the expense of another" (Redpath et al. 2013)
Human-nature coexistence	Synonymous with social-ecological coexistence.
Social-ecological systems	"Systems of biophysical and social factors that interact at multiple spatial, temporal, and organizational scales and whose flow is regulated in dynamic and complex ways" (Lischka et al. 2018, adapted from Redman et al. 2004).
Coexistence parameters	"The tangible and perceived variables that dictate coexistence in a system and thus are subject to management." (Crespin & Simonetti 2021)
Opportunities for coexistence	Combinations of parameters that can meet the needs of both food security and biodiversity conservation in a landscape.
Basin of coexistence	All system states whose trajectories in phase space converge into the same attractor, *i.e.* a stable state representing human-nature coexistence.
Direct or proximate driver of conflicts	Social and ecological pressures that directly or proximally influence the emergence and continuity of conflicts.
Indirect or distal driver of conflicts	Social and ecological pressures that indirectly or distally influence the emergence and continuity of conflicts.
Human-wildlife conflicts	Situations that arise because of biodiversity impacts, particularly from ecological and economic impacts: "the most widespread and serious conflicts involving people and threatened wildlife: crop raiding, livestock depredation, predation on managed wildlife (such as farmed or otherwise managed game species) and, least common but most emotive, killing of people" (Woodroffe et al. 2005).
Dispute	"The first level of conflict—the dispute—is the obvious, tangible manifestation of a conflict" (Madden & McQuinn 2014).
Underlying conflict	"The second level of conflict that may exist in a specific conflict context is underlying conflict. Underlying conflict is a history of unresolved disputes." (Madden & McQuinn 2014).

Deep-rooted conflict	“The third level …—identity conflict—involves values, beliefs, or social-psychological needs that are central to the identity of at least one of the parties involved in the conflict.” (Madden & McQuinn 2014).
Settlement	Approaches to disputes, or conflicts that can be addressed through practical solutions, such as management of ecological or economic factors leading to negotiation or compromise acceptable to all interests (Zimmerman et al. 2020).
Resolution	Approaches to underlying conflicts that require relationship building “to address the history of disputes and search for common ground among the parties” (Zimmerman et al. 2020).
Reconciliation	Approaches to deep-rooted conflicts that require reconciling conflicting identities “as the parties perceive its outcome to impinge on their values, identities, or way of life. This level requires reconciliation dialogues and conflict transformation approaches” (Zimmerman et al., 2020).
Degraded landscape	Landscape archetype where “Both biodiversity and food security outcomes are poor.” “…characterized by low levels of human, technological, physical, natural, and sometimes even social capital.” (Fischer et al. 2017).
Intensive agricultural landscape	Landscape archetype where food security “‘wins’ as long as the benefits of agriculture flow to local people, but biodiversity ‘loses’ because intensive agriculture has negative on-site and offsite effects” (Fischer et al. 2017).
Fortress conservation landscape	Landscape archetype that “…provides benefits for biodiversity, but not food security.” “…less common, but can arise when the pursuit of narrowly defined green agendas (for example, through the top-down establishment of protected areas) impinges upon local people's livelihoods or human rights.” (Fischer et al. 2017).
Agroecological landscape	Landscape archetype that “…serves both conservation and food security goals.” (Fisher et al. 2017). Such land-sharing “requires abdicating complete human domination of a landscape and establishing a degree of syntopy between wildlife and domesticated plants or animals meant to be reared as food for human society. This scenario is primed for the emergence of conflicts.” (Crespin & Simonetti 2021).
Coexistence niche	A multi-dimensional subspace where both food production and biodiversity conservation needs are met. Opportunities for coexistence can be found inside such subspaces.

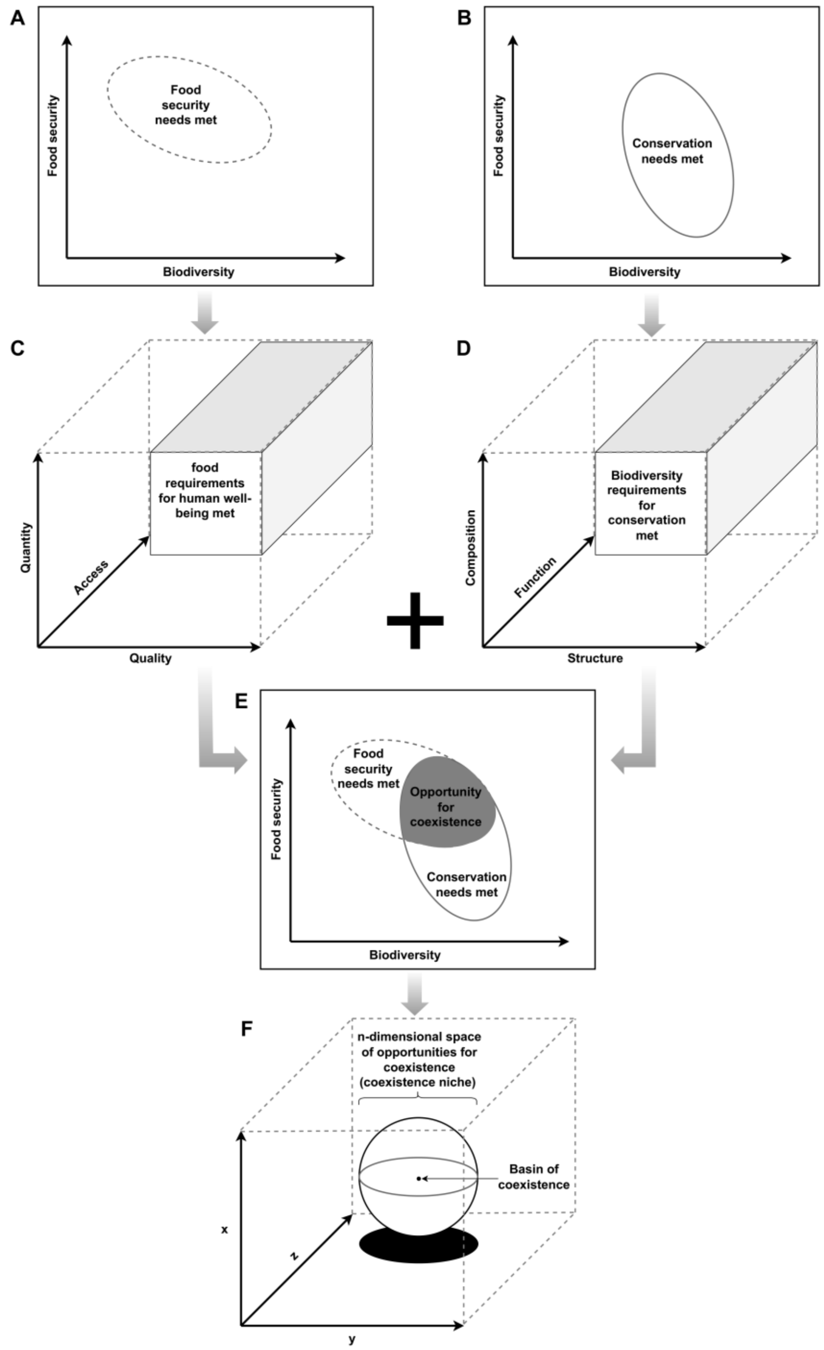

Fig 1. Agroecological Systems Model of Coexistence. For any particular agroecological landscape, when interpreted as a system relying on parameters of food security and biodiversity, we will find combinations of food security and biodiversity parameters that allow meeting respective food and conservation needs (A & B). Both food security and biodiversity are both multidimensional concepts which can be decomposed into elemental components that can each act as parameters (C

& D). The overlap of the different combinations of food security and biodiversity that meet both needs offers *opportunities for coexistence* (E) which when accounting for multidimensionality can be assessed in an n-dimensional space, or *coexistence niche* for a given social-ecological system, leading to basins of coexistence and thus stable states of coexistence (F).