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Integrating Participatory Mapping and Stewardship Perspectives to Support Human–Wildlife Coexistence in Shared Landscapes

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ABSTRACT

Understanding the drivers of coexistence between humans and wildlife in shared landscapes is critical for biodiversity conservation. This inquiry challenges us to reflect on our relationships with nature and highlights the need to consider the complexity of social-ecological systems. Although useful approaches exist for mapping the distribution of species, habitats, or ecosystems using statistical methods, a purely bio-physical description of space cannot account for the diversity of relationships within the system and the complexity of coexistence issues.

In this study, we adopted a transdisciplinary approach to understand coexistence processes between humans and wildlife in the Garden Route region of South Africa. We estimate species' distributions using a combination of species distribution modelling informed by a participatory mapping approach, and summarising focus-group discussions which discussed the diversity of perspectives towards conservation action.

Our study highlights the importance of considering a diversity of relationships to address coexistence issues in shared landscapes and suggests that the collaboration of different knowledge systems, through research co-construction, local knowledge and biotic interactions integrated in species distribution modelling, provides an important baseline to describe a shared landscape. Focus-group discussions highlighting the different stewardship perspectives among local actors contributed to contextualise spatial analysis

showcasing the inherent political dimension of conservation needed to move from theory to practice.

Keywords: transdisciplinarity; human-wildlife coexistence; participatory mapping; habitat suitability; stewardship action; social-ecological systems

INTRODUCTION

Biodiversity loss and species extinction is happening at an unprecedented rate due to anthropogenic causes (e.g., land-use change, over-exploitation, climate change, pollution, and invasive species spread amongst others). The extent and the diversity of the human-driven impacts raise questions about our relationship with nature (Jaureguiberry et al., 2022). The entire surface of the Earth has been transformed by human populations for at least 12,000 years, suggesting that it is not so much a question of human occurrence as such, but of the intensity of activities resulting from very specific ways of relating to nature (Ellis et al., 2021).

Western-based, conservation science studies have explored the relationships between human populations and wildlife, but primarily from the perspective of conflict, i.e. by focusing on the entities involved in the interaction (e.g. conflict between baboons and humans focusing on human welfare on the one hand and baboon welfare on the other) as antagonists rather than on the nature of the relationships between them (Bhatia et al., 2019). This approach implies a separation between humans and nature, a very specific mode of relationship that Descola (2013) describes as a 'naturalist ontology', specific to Western worldviews.

Adopting a single worldview perspective is likely to result in a narrow set of values which has been shown to limit our ability to understand complex social-ecological processes (Pascual et al., 2021). The broadening of perspectives, particularly through the recognition of diverse worldviews and modes of relating to nature as explored in social-ecological systems (SES) studies (e.g. relational values; Berkes et al., 2001; Chan et al., 2018; Preiser et al., 2018), allows for a more inclusive understanding of the varied relationships between human populations and nature. As a result, the term *coexistence* (between human society and nature) is gradually gaining acceptance within conservation science and practice because it allows consideration of the relationships as the structuring elements of social-ecological systems (Bhatia et al., 2019; Pooley et al., 2021; Redpath et al., 2015). Here, we use the term 'coexistence issue' rather than conflict, to maintain the semantic coherence of relational continuity.

Coexistence relationships are structural elements of social-ecological systems, yet few studies have applied theoretical concepts and considerations in practice (de Vos et al., 2019). When investigating coexistence issues, transdisciplinarity is a fundamental epistemological approach to understand social-ecological systems from a relational perspective. Through the inclusion of non-scientists in the research process, transdisciplinarity brings to light relationships that were in the blind spot of disciplinary segmentation (Morin, 2008; Preiser et al., 2018; Tengö et al., 2017).

At a time when the scientific community and intergovernmental bodies (e.g. Convention for Biological Diversity) are calling ever more urgently for "transformative changes" in our relationships with "nature", the question of how to move from theory to practice in SES is no longer just a gap in the scientific literature, but a critical need (Bennett & Roth, 2019; Foggin et al., 2021; Wyborn et al., 2020). Although the importance of considering relationships in conservation is recognised and theoretically promoted as required to further our understanding of conservation issues (Bennett & Roth, 2019; Bennett et al., 2017; Holmes et al., 2022), it remains to be determined how to move from social-ecological theory to conservation practices.

Landscape ecology can be a useful discipline to understand SES and enact tangible management measures which better consider coexistence and conflict of human society and nature. However, although useful approaches exist for mapping the distribution of species, habitats or ecosystems using statistical methods (Franklin, 2023; Stephenson et al., 2023; Zimmermann et al., 2010), a purely bio-physical description of space cannot account for the diversity of relationships within the system (e.g. a landscape of coexistence cannot be described only by the distance between human settlements and protected areas but the product of a diversity of relationships between entities). We therefore use the term 'relational landscape' proposed by Mitchell (2017), which views the landscape as the product of a diversity of relationships and would allow the concepts of social-environmental justice as well as stewardship. Stewardship can be understood as the set of actions that arise from specific worldviews to engage with nature and ultimately to take care of it (Enqvist et al., 2018; Mathevet, Bousquet, Larrère, et al., 2018; Mathevet, Bousquet, & Raymond, 2018). It is often associated with long-term conservation strategies that are guided by a broader societal vision. It enables the integration of spatial analyses in one hand, and political dimensions of spatial organisation on the other (Mitchell, 2017; Setten & Brown, 2013; Stenseke, 2018). Participatory mapping enables the integration of complex human–nature relationships into habitat suitability modelling, allowing for the investigation of coexistence from a relational landscape perspective (Stern & Humphries, 2022).

In this study we aim to apply a relational approach of human-wildlife coexistence with the desire to support a more detailed SES understanding for conservation sciences and practices. Based on a research co-construction process realised with a diversity of research partners in the Garden Route, South Africa, our objectives were (1) to get a baseline description of the relational landscape by integrating local knowledge and biotic interactions in species distribution modelling through participatory mapping and (2) to characterise the embedded political dimension of coexistence, and thus conservation, by exploring the diversity of stewardship action perspectives among our research-partners, through group discussions. We discuss and identify practical leverage points that can inform and guide effective conservation strategies.

METHODS

I. Study site

The study area of George municipality (542.96 km^2) is located between the Indian Ocean and the Outeniqua mountains of the Western Cape Province in South Africa (Figure 1). The area called the “Garden Route”, part of the Cape Floristic Region, is renowned for its biodiversity and high level of endemism (Grobler & Cowling, 2021). The Garden Route National Park (1210 km^2) is characterised by a network of protected areas connected by multiple corridors in a mosaic of land uses making it an interesting case-study for social-ecological conservation in shared landscapes (Palomo et al., 2014). The area is home to several key species (hereafter referred to as the ‘study species’), namely the chacma baboon (*Papio ursinus ursinus)*, vervet monkey (*Chlorocebus pygerythrus)*, predators such as the honey badger (*Mellivora capensis*), common genet (*Genetta tigrina*), leopard (*Panthera pardus*) and caracal (*Caracal caracal*) and antelope species such as the bushbuck (*Tragelaphus scriptus*), blue duiker (*Philantomba monticola*) and bushpig (*Potamochoerus* larvatus). These species move freely within the mosaic of land-uses. This area is characterised by major social inequalities: landowners with large, often fenced-in estates next to townships and informal settlements. The Khoï community forms South Africa's Indigenous community along with the San (Khoisan community).

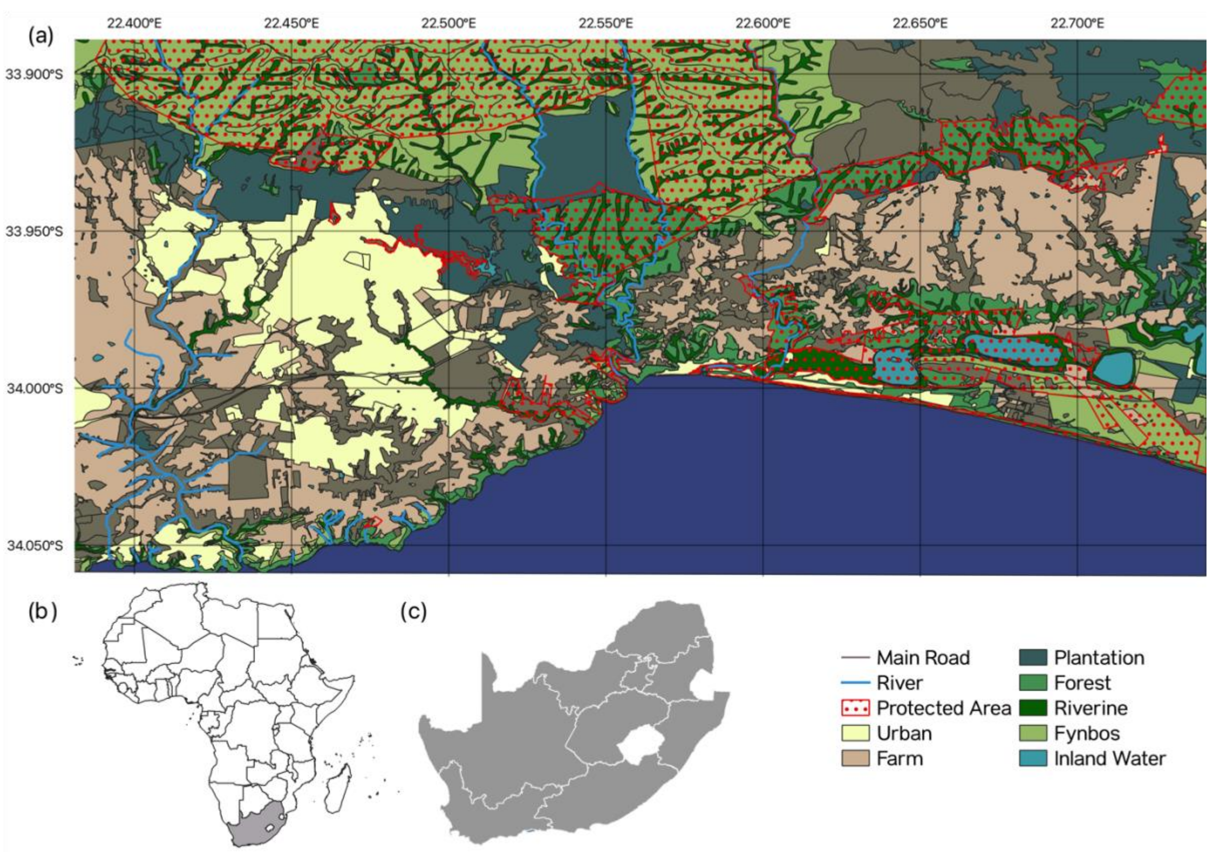


Figure 1. Map of the study area, Garden Route National Park (a) within Africa (b) and South Africa (c). Different land-use categories are shown (see legend). The extent of the Garden Route National Park (Protected area) is represented by red dots.

II. Research co-construction as a primer to define the set of transdisciplinary methodologies

This study was part of a collaborative research project which received ethical clearance from Nelson Mandela University (H20-SCI-SRU-003). To gather occurrence data from participatory mapping and to highlight the diversity of stewardship action perspectives we engaged with non-scientists research partners (Table 1) following a stratified purposeful sampling among four categories: governance, conservation organisations, residents, and Indigenous communities. The stratified sampling was adopted to target persons or groups of people knowledgeable about the area and interested in wildlife.

The research was co-constructed to adopt a transdisciplinary approach. Firstly, preliminary discussions through semi-structured interviews were undertaken with research partners to identify the potential coexistence issues in the study area, select the methodology and study species. We extended the stratified purpose sampling by snowballing (Goodman, 1961) to increase participants number for data collection. This first step of preliminary discussions had two objectives: (a) epistemological, by adopting a complex approach, we aim to go beyond the holism and reductionist approaches which can lead to a truncated perception of problematics at stake for conservation locally (Colloff et al., 2017; Morin, 2008) and (b) to create engagement, by involving local non-scientist research-partners in the research to give, according to Cash and Belloy (2020), "salience, credibility and legitimacy" to the project which is fundamental for conservation action. This co-construction process suggested the organisation of two workshops: a "data collection" workshop with participatory mapping and collaborative timeline methodologies. The Khoï community from Pacaltsdorp wanted to have carte blanche to perform a theatre show during the first workshop to showcase their struggles and relationships with the environment. A final “feedback” workshop was organised six months after to reflect on the products of the first workshop and discuss human-wildlife coexistence in the area.

Table 1. Research-partners description and involvement in participatory mapping and discussions

Research-partner group	Potential landscape area conservation influence	Number of participants		Female/Male ratio		Most frequent age class
		Mapping	Discussion	Mapping	Discussion	
Pacaltsdorp residents	Pacaltsdorp township (Khoï community)	7	6	0.57	0.50	40-50
Municipality representatives	George	0	4	0.00	0.75	40-50
Property owner	Private properties	14	3	0.43	0.00	>50
Informal settlement residents	Wilderness camp	6	3	0.50	0.00	20-30
Commercial farmers	Commercial farms	1	0	1.00	0.00	>50
Conservancy members	Conservancies	3	4	0.33	0.50	40-50
Academics	Potential facilitators	2	1	1.00	1.00	20-30
Conservation institutions	Protected areas	2	4	1.00	0.50	30-40
Free access to mapping in the workshop venue	NA	14	NA	NA	NA	NA
Total identified		35	25	0.60	0.44	40-50

III. Social-ecological processes of coexistence: describing a relational landscape

i. Participatory mapping data collection

We adopted a participatory mapping methodology to allow knowledge co-production to better understand species' habitat use – the participatory mapping aimed at collecting and sharing informant's sightings in the area. We organised a data-collection participatory mapping workshop where researchers defined the overall extent of the study area, after which participants were asked to provide locations of where study species were observed on an A0 printed map of aerial imageries of the study area (1/45000) (resolution of a 300 x 300 m grid) (as in Pédarros et al., 2020). This resolution limits the spatial autocorrelation of the observations (Fourcade et al., 2014; Kramer-Schadt et al., 2016). Aerial images were provided by SANParks GIS services (Behrends, 20189), where main roads (Ahrends, 2018), rivers and inland water (SANLC, 2020; Behrends, 2018) were displayed to facilitate identification of specific locations.

Research-partner groups were mixed to maximise cross-interactions between participants from different backgrounds and knowledge bases. Each informant was first asked to identify sites which they visited at least twice a week (e.g., households, work, regular leisure activities using a flat pin) in order to define the overall area where they would be likely to observe species. Subsequently, informants were asked to identify locations where they observed the study species using pins (which were different colours for each of the species). Cards with species names (Scientific name, English, Afrikaans, isiXhosa), pictures and pin colour were provided to ensure all participants had the same information and understanding of the process. Using participatory mapping data to model habitat suitability in shared landscapes means recognising that the product of this modelling is the result of social-ecological processes involving human populations and the species under consideration, implying a diversity of relationships going beyond the purely geographical occupation of space. The analysis here is therefore not concerned with absolute habitat suitability, but rather with habitat suitability relative to human-wildlife interactions, which allows us to consider the landscape according to a relational perspective and to envisage coexistence.

Estimated species' observations from participant maps were transferred to analytical software Quantum GIS 3 (QGIS 3.10.0) and R (R 4.2.2) using the coordinate system WGS84 calibrated to the 23° East meridian.

ii. Occurrence records and pseudo-absences generation

For species distribution modelling, both occurrence and absence data are needed. Observations were aggregated to the study area grid cells (300 x 300 m grid) to represent a single occurrence record in these locations. Pseudo-absences were generated which is a common approach to represent likely absences (when true, observed, absences are not available. Here, pseudo absences were selected according to a weighting of detectability index (Stephenson et al., 2023). We assumed that areas with a high detectability index without any occurrence are robust potential pseudo-absences (see Appendix I for the detectability index map). Species detectability index was estimated for the whole study area as a function of different factors integrating the diversity of potential biases associated with participatory data (Pédarros et al., 2020; Skroblin et al., 2021; Stern & Humphries, 2022). That is, for a given pixel unit, detectability was defined as:

$$D_i = S_i V_i R_i$$

Where detectability (D) within pixel i was the product of spatial sampling intensity (S), visibility (V), and proximity to the closest main road of pixel i.

We created distance matrices using frequently visited sites by participants to define sampling intensity (600 m buffer; S_i) and tarred roads to define the likely bias associated with higher traffic and relative accessibility (R_i). A target (~one meter high) was randomly placed for each habitat's visibility. The distance at which the target disappeared from the observer was measured 20 times for each habitat (Valeix et al., 2011). The relative visibility for each habitat (V_i) is given by the average visibility distance of the open environment as the reference for the highest visibility. Each detectability matrix follows a standardised normal distribution rescaled between 1 and 20 (Elith et al., 2010). We considered the product of these standardised bias correctors as a proxy of species detectability within the landscape (Appendix I).

iii. Environmental data

The selection of a set of independent variables was selected based on a literature review (Table 2). To avoid poor model performance, when a set of variables were co-linear (with Pearson's correlation coefficient >0.85) we selected the most relevant one for our study and the other ones were removed (Elith et al., 2010; Appendix II).

Table 2. Abiotic variables used for species distribution modelling

	Variable	Description	Reference	Layer
Land cover (Categorical)	Urban	Urban area		Urban
	Pasture	Rural residential area Commercial agriculture		Farm
	Plantation	Plantation areas	Vlok et al. (2008) Vromans et al. (2010) DEA National Land Cover (2015)	Plantation
	Degraded	Degraded areas mainly dominated by invasive species		Degraded
	Forest	Afrotropical forest		Forest
	Fynbos	Fynbos (shrubland)		Fynbos/grassland
	Wetland	Hygrophilous vegetation		Drain
	Thicket	Dune and coastal vegetation		Thicket/marine
Landscape metrics (Quantitative)	Protected area	Distance to the closest Protected area (m)	CapeNature (2017)	Protected Area
	Critical Biodiversity Area	Distance to the closest CBA (m)	CapeNature (2017)	Critical Biodiversity Area
	Water	Distance to the closest freshwater body area (m)	DEA National Land Cover (2015) & Ahrends (2018)	River, Inland water, Dry Riverbeds

	Slope	Average slope for each pixel (°)	Danielson and Gesch (2011)	Relief 10m contours

iv. Statistical modelling of species' distributions

Random Forest (RF) models were used to model habitat suitability (Breiman, 2001). RF is considered a robust model to use for species with few occurrences (Breiman, 2001; Luan et al., 2020). RF models were bootstrapped 100 times for all species. That is, for each bootstrap iteration, a random sample of sightings was drawn with replacement with the same number of random samples of pseudo-absences (Barbet-Massin et al., 2012). Sampling of pseudo-absences was drawn without replacement (e.g. Stephenson et al., 2023). For each bootstrap, the occurrences which were not randomly selected (approximately 33% of data on average) during each bootstrap, and an equal number of pseudo-absences were used as evaluation data. We evaluated the robustness of the models using the True Skill Statistic metric (TSS= Sensitivity + Specificity – 1; Allouche et al., 2006). Model fits calculated using evaluation data are presented here because these are considered a more robust and conservative method of evaluation than model fits calculated using the training data (the randomly selected data used to train the model)(Friedman, 2009).

v. Spatial prediction and inclusion of biotic predictors

For each species, RF models for each bootstrap were predicted geographically. The mean prediction of probability of occurrence and the coefficient of variation were calculated for each 0.09 km^2 cell to produce habitat prediction maps and spatially explicit maps of uncertainty, respectively. We obtained spatial distribution maps for each species (6 in total) that we also used as biotic predictors in a second round of modelling (Appendix III) (e.g. Stephenson et al., 2022). According to the preliminary discussion orientations, we focused on baboon and caracal, common species with potential coexistence issues with humans (Drouilly et al., 2018). For each focus species (i.e. baboon and caracal), we followed the same modelling process as above but with the iterative inclusion of one of the species distributions as a biotic predictor (Appendix III).

Because all species have similar suitable habitats (Appendix IV, V), we retained the models with the highest average TSS values:

Baboon habitat suitability ~ Abiotic variables + Bushbuck habitat suitability

Caracal habitat suitability ~ Abiotic variables + Baboon habitat suitability

IV. Identifying the diversity of stewardship perspectives

To identify stewardship perspectives among research-partners, we used a nominal group technic (NGT) approach to elicit research-partners' judgement during the second workshop (Hugé & Mukherjee, 2018). The nominal group technic is a structured method for group discussion ensuring that all individual and groups participate equally (Hugé & Mukherjee, 2018). Participants were placed in groups of six or seven, following the stratified purposive sampling categories (Table 1). We first discussed the outputs of the participatory mapping exercise realised during the first workshop and the habitat suitability maps. Two questions were then asked: "What is conservation?" and "What could be human-wildlife coexistence?". Participants were asked to write down or think about their answers for 5 minutes before debating the solutions within each group for 20 minutes and presenting a common answer listened to by the other groups before a group discussion.

We used the stewardship action concept to analyse the results of these discussions. Following Enqvist et al. (2018), we considered stewardship as a broad concept describing the convergence between the social-environmental aspirations of people for a given system and the means employed to practically tend towards this. Mathevet, Bousquet and Raymond (2018) noted that stewardship is the practical emergence of environmental discourses. Based on the environmental discourses classification of Dryzek (2013), Mathevet et al. (2018) propose a stewardship action typology based on two dimensions:

- System dimension (vertical axis of Figure 2): the extent to which we want to change the current system. Those who want a system close to the current one, are considered reformist and those that want a different system, are considered radical.
- Action dimension (horizontal axis of Figure 2): the type of actions we think would result in greatest conservation benefit: either focussing on specific parameters of the system (symptomatic action: "prosaic") or on the system as a whole (systematic action: "imaginative")

Following Mathevet et al. (2018) these two dimensions can be combined, and their product defines stewardship perspectives: reformist-symptomatic (reformist, Figure 2); reformist-systematic (adaptive, Figure 2); radical-symptomatic (sustainability, Figure 2); radical-systematic (transformative, Figure 2). Recordings of the discussions during the NGT exercise were compiled and thematic coding using Atlas.ti were used to identify stewardship perspectives based on the typology presented by Mathevet et al., 2018 (Supporting information II).

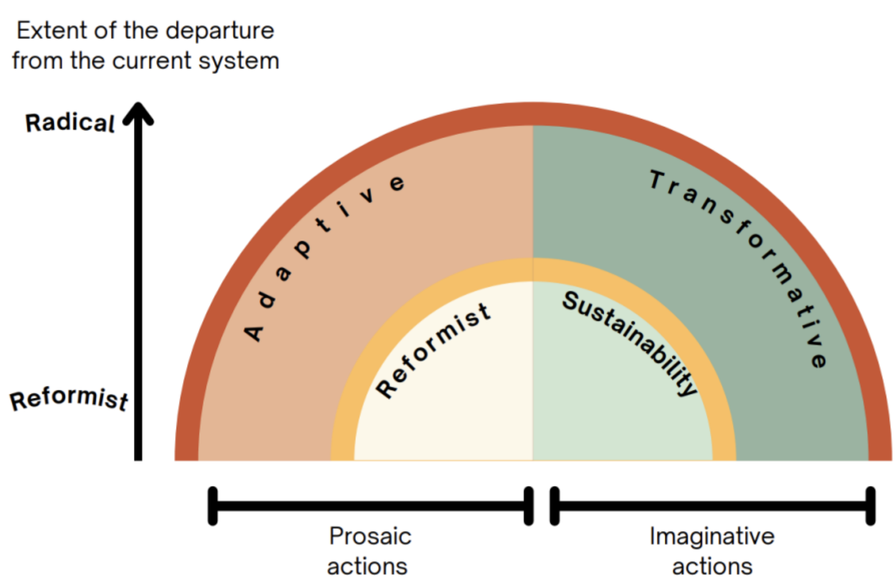


Figure 2. Stewardship categorisation according to Mathevet et al. (2018) based on Dryzek (2013). The combination of the two axes (extent of the departure from the current system and nature of actions to realise this departure) defines the related stewardship perspective.

RESULTS

1) Modelling habitat suitability using participatory mapping data

a) Random Forest modelling performance and effect of the inclusion of biotic predictors on modelling performance

Participatory mapping resulted in 119 baboons' occurrences, 64 caracal, 128 bushbuck, 110 vervets, 66 bushpig, 22 genet and 30 badger (Appendix VI). We did not obtain enough data to consider leopard (11 observations) and blue duiker distributions (12 observations).

Participatory mapping data in modelling habitat suitability resulted in a good performance of the models with TSS above 0.5 and sensitivity higher than the 0.70 'rule of thumb' that indicates a model can usefully predict actual occurrences correctly (Dang et al., 2020). Sensitivity (the proportion of actual occurrences that the model predicts correctly) was relatively homogenous among species whereas specificity (the proportion of pseudo-absences that the model predicts correctly) was more variable. Lower specificity values can be related to the random choice of pseudo-absences (Appendix V).

The inclusion of a biotic predictor increased the performance of baboon and caracal habitat suitability modelling (Table 3). Baboons and caracals being generalist and widespread species, the inclusion of generalist species habitat suitability as a predictor extended the range of potential suitable habitat increasing the performance of the modelling.

Baboon habitat suitability modelling had an increased performance when bushbuck and bushpig habitat suitability were used as biotic predictors whereas caracal habitat suitability modelling, had an increased performance when baboon, bushbuck, bushpig and vervet were used as biotic predictors (Table 3).

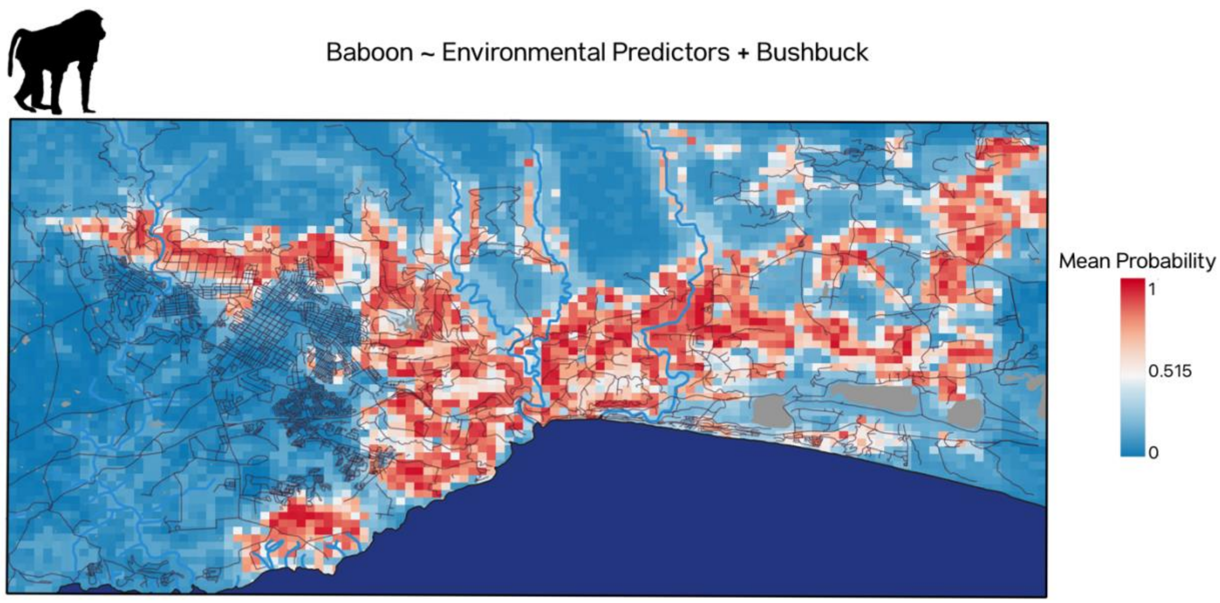
Table 3. Mean ± standard deviation cross-validated estimates of model performance (TSS: True Skill Statistic, Specificity and Sensitivity) using evaluation (withheld independent) data for bootstrapped Random Forest models fitted with occurrence/pseudo absence

Model	**Testing TSS**	**Specificity**	**Sensitivity**
Baboon ~ Environmental predictors + Bushbuck **	**0.512±0.098**	**0.745±0.056**	**0.795±0.046**
Baboon ~ Environmental predictors + Caracal	0.466±0.091	0.729±0.053	0.797±0.047
Baboon ~ Environmental predictors + Bushpig *	0.463±0.098	0.741±0.050	0.788±0.049
Baboon ~ Environmental predictors + Genet	0.470±0.092	0.735±0.053	0.771±0.054
Baboon ~ Environmental predictors + Badger	0.447±0.119	0.725±0.051	0.779±0.058
Baboon ~ Environmental predictors + Vervet	0.468±0.087	0.727±0.056	0.789±0.053
Caracal ~ Environmental predictors + Baboon **	**0.543±0.122**	**0.727±0.072**	**0.826±0.075**
Caracal ~ Environmental predictors + Bushbuck	0.537±0.102	0.741±0.084	0.780±0.077
Caracal ~ Environmental predictors + Bushpig *	0.460±0.116	0.695±0.088	0.773±0.090
Caracal ~ Environmental predictors + Genet	0.445±0.113	0.675±0.078	0.762±0.090
Caracal ~ Environmental predictors + Badger	0.380±0.111	0.680±0.082	0.756±0.079
Caracal ~ Environmental predictors + Vervet **	0.513±0.112	0.753±0.094	0.745±0.079

b) Describing a relational landscape based on multispecies modelling and participatory data

The analysis of baboons and caracal habitat suitability predictions (Figure 3) presents similar ranges enabling the identification of critical habitats for coexistence. Baboons have an occurrence ratio of 25.02% across the study area for the first model (Appendix III) and 26.37% when bushbuck distribution is included (Figure 3). It suggests that the inclusion of a biotic predictor implies an extension of the range of the predictors related to baboon occurrence. Bushbuck distribution maximises the potential range of habitats suitable for baboons. Interestingly, caracals have an occurrence ratio of 45.98% for the first model and 29.77% when baboon distribution is included as a predictor.

In addition, caracals and baboons are recognised as common species in these landscapes but caracals are much more elusive than baboons, making them difficult to observe. This is highlighted by the mean index detectability (Appendix I) of occurrence sites that is similar for baboons and caracals (10.17 and 10.25 index values respectively) while we have 119 occurrences for baboons and 64 for caracals.



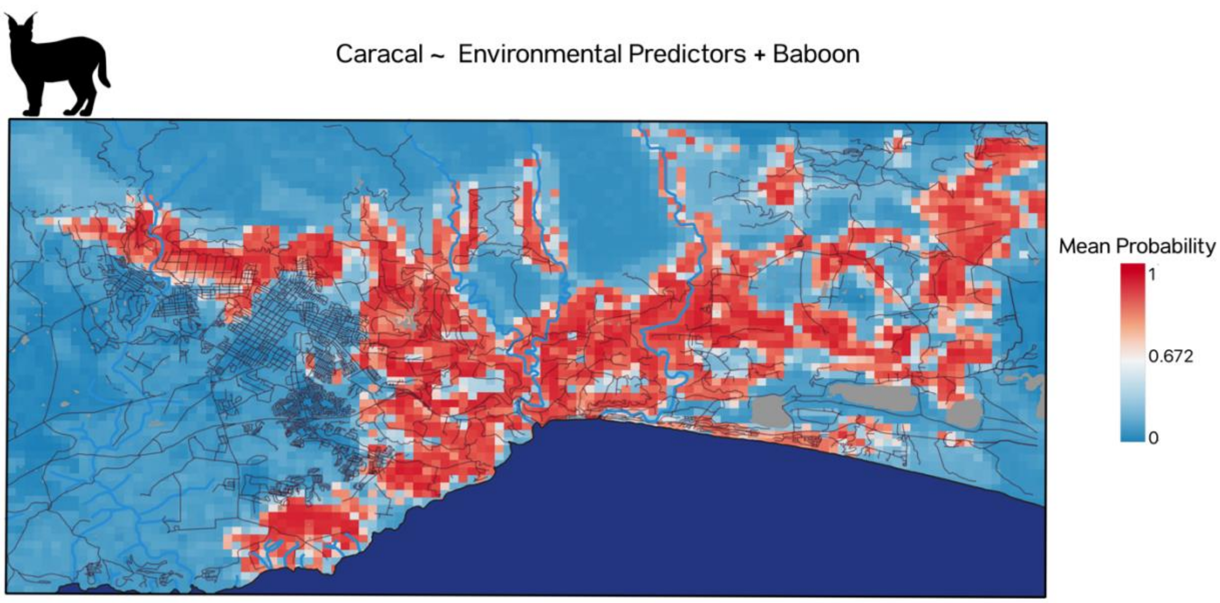


Figure 3. Predicted mean Habitat Suitability Probability for baboons and caracals. The mid-value on each mean probability legend represents the threshold above which the probability is considered as an occurrence.

Baboon and caracal habitat suitability modelling highlights the importance of refuge areas in shared landscapes (distance to protected areas and critical biodiversity areas predictors, Figure 4). For all the models (baboons with and without bushbuck distribution and caracal with and without baboon distribution), the maximal distance from protected areas to predict occurrence is between 0 and 1500 meters. Above this threshold, models do not predict any baboon or caracal occurrence. Additionally, water, slope, and land cover are more important for baboons than for caracals (Figure 4). When included, the biotic predictor was the most important variable for the two species modelling. The inclusion of a biotic predictor in the modelling process diminishes the importance of environmental predictors for the two species without changing the order of importance.

In terms of space occupation, another important result is the low importance of land-use for both species, which could be expected given the common and generalist character of the two investigated species. Land-cover modalities analysis suggests that both for caracals and baboons, the criteria of “natural indigenous” or “anthropogenic degraded” landscape is not pertinent, as pine plantations, commercial pastures, or plots degraded by invasive species appear as the most suitable for baboons and caracals together with Afromontane Forest.

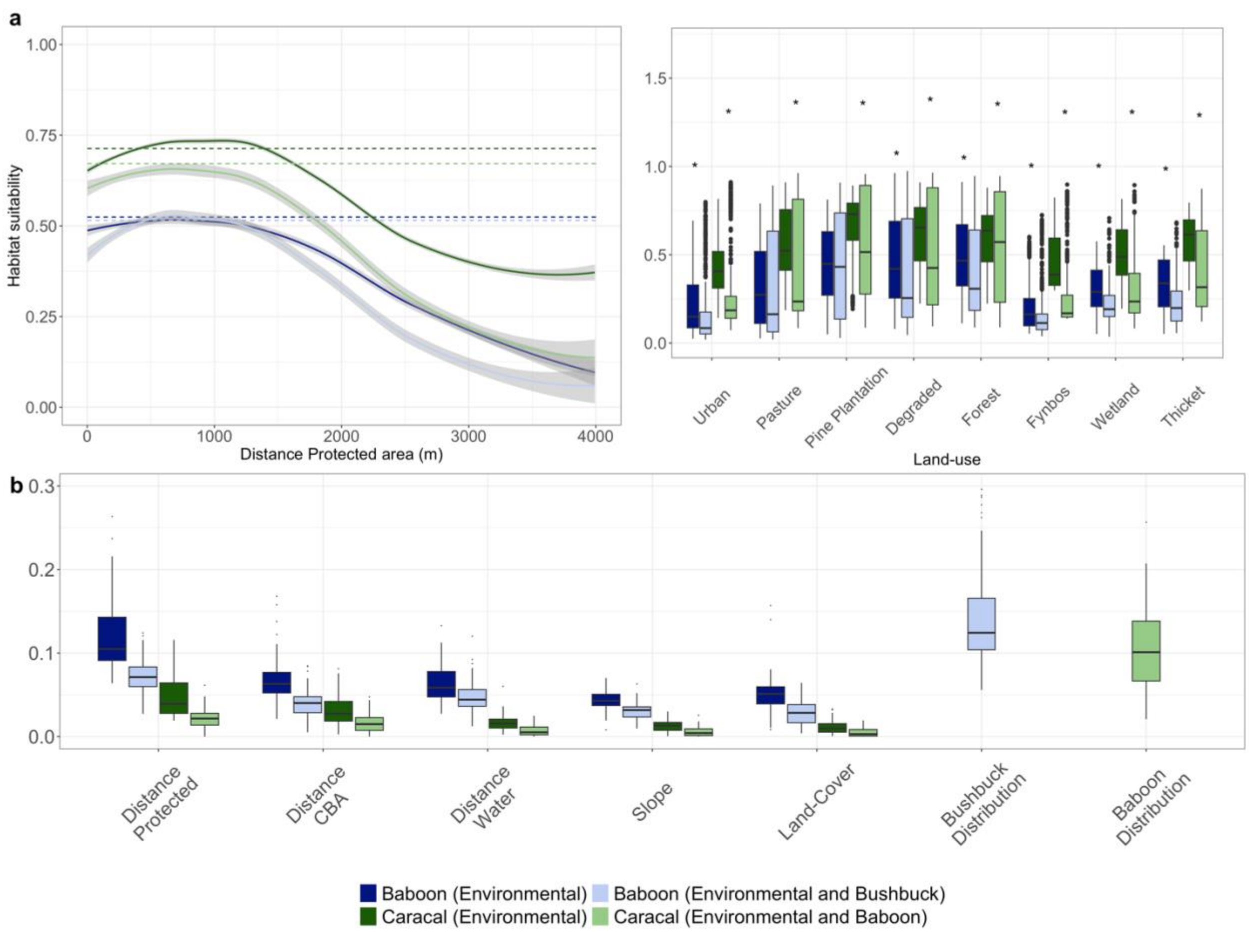


Figure 4. Response curves for the Distance to the closest protected area and land use (a and (b) variable importance (*: pvalue<0.05).

2) A diversity of stewardship perspectives leading to various potential conservation strategies

Species distributions maps were presented and discussed before the group discussion (nominal group technic). The co-construction of discourses during the nominal-group technic around the issue of coexistence allows the identification of local issues related to landscape occupation by human populations. The main discussion was related to mobility allowance for humans and wildlife species. Specifically, fencing and access to some parts of the park or critical biodiversity areas for human populations. There was no formulated disagreement among research-partners except Pacaltsdorp residents towards the

Municipality about the growing development of George municipality threatening Pacaltsdorp area potentially forcing inhabitants to be relocated by the municipality.

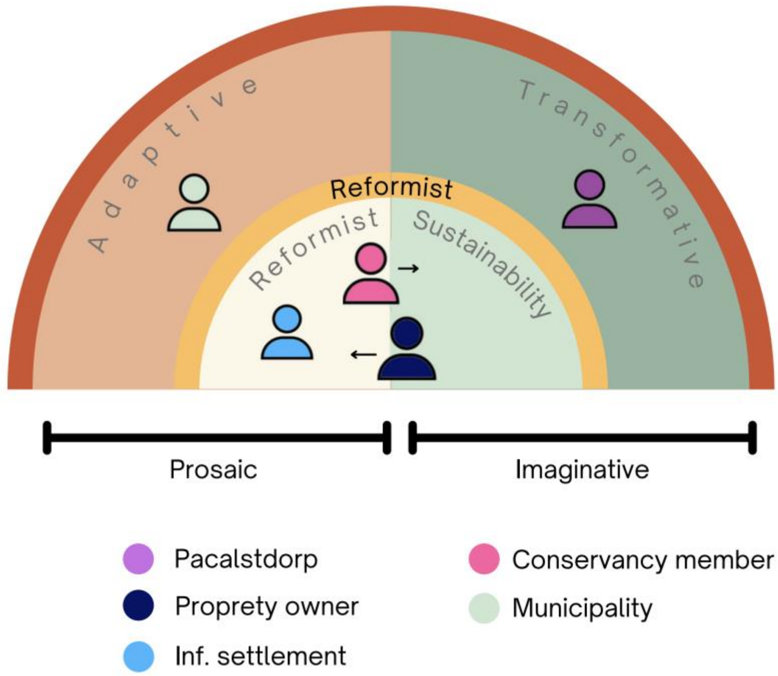


Figure 5. Representation of stewardship types according to environmental discourses dimensions formulated by each research-partner group. Arrows represent a research-partner's tendency to develop arguments toward another stewardship type.

The stewardship analysis shows an important heterogeneity within and among research-partners groups (Figure 5). The municipality sees nature to be managed by social sphere with scientists as facilitators with policymakers defining public interest, the dominant knowledge is scientific and the governance is made with consultation of key stakeholders (Mathevet et al., 2018). According to Mathevet et al. (2018), this is characteristic of an adaptive stewardship perspective. The aim is to tend towards a radical new system by mobilising symptomatic actions (acting upon specific parameters without redefining the relationships of the system). Pacaltsdorp participants see coexistence issues related to questions of governance and values plurality, the dominant knowledge is thus made of a diversity of knowledge systems, facilitators are scientists, citizen and managers, the governance is orientated towards community-based management with many actors presenting a diversity of motivations (Mathevet et al., 2018). Pacaltsdorp participants are thus adopting a transformative stewardship perspective according to the categorisation of Mathevet et al. (2018). Informal settlement participants can be situated into the economic rationalism of the reformist stewardship with guiding principles related to property and economic issues, nature being considered as “a force to be regulated by social sphere” (Mathevet et al., 2018). Conservancies participants are also reformist but from a democratic rationalism perspective: they consider citizens as central with motivations mixing “self-interest” and “multiple conceptions of public interest” (Mathevet et al., 2018). However, some conservancies statements could be related to the sustainability stewardship, especially concerning the need for multiple actors at different scales for the public good (Mathevet et al., 2018). Property owners are in-between sustainability and reformist stewardships. The difference is then related to the nature of the actions to stick to the current system. The sustainability stewardship proposes to mobilise knowledge coming from “a mix of experts, science” and local knowledge with governance orientated by a “mix of adaptive co-management and public policy” (Mathevet et al., 2018). Sustainability stewardship consider the environmental problem as related to governance issues (Mathevet et al., 2018).

There are individual discrepancies within research-partner groups: property owners, for instance, vary along all the dimensions of environmental discourses identified by Dryzek (2013), from adaptive to reformist and sustainability stewardship (Mathevet et al., 2018).

DISCUSSION

1. Relational approach of coexistence issues: ontological, epistemological, and methodological redefinition in practice

Adopting a relational approach of social-ecological processes driving coexistence in shared landscapes has important implications for conservation. It enables us to reconsider social and ecological processes as intertwined, with complex dynamics going beyond purely causal ones (Preiser et al., 2018). The output of the modelling thus acknowledges specific relationships giving insights concerning the relational landscape. The relational description of the landscape integrates potential interactions between species and the landscape perception of research partners. Habitat suitability modelling using participatory mapping data is thus the product of interactions between modelled species distribution and interactions with research-partners.

The co-construction and co-design of the research through preliminary discussions is an efficient approach to engage with a transdisciplinary approach, it contributes to adjust our approach to better integrate groups not often engaged in current debates about conservation and coexistence. Maintaining a unique two-way relationship between the researcher and participants enabled the establishment of trust and ease of discussion between research partners. For instance, the Khoï theatre forum from the preliminary discussion provided the opportunity for the community to express their issues and discuss it with other research-partners in the form that they felt was most appropriate. Preliminary discussions contributed to identifying social-ecological processes and co-designing suitable methodologies. The discussion on potential studied species contributed to select important species for research-partners. Kronenberg et al. (2017) note that conservationists select species and formulate conservation objectives based on *a priori* assumptions, which can bias conservation purposes towards maladapted actions (Clucas et al., 2008; Tisdell & Nantha, 2007). Species mentioned during the preliminary discussion allowed us to align with participants' interests and extend the research on under-studied species in human-dominated landscapes.

This transdisciplinary process applies a methodological redefinition to understand the system. It was done by combining social-ecological analyses and participatory methodologies. As expected, it led to a reflection on the nature of the data collected and its potential use in the scientific knowledge system (Tengö et al., 2017). Participatory mapping methodologies to gather data for species distribution modelling are increasingly mobilised to understand specific species' ecological requirements (Bernard, Fritz, et al., 2024; Stern & Humphries, 2022). These methodologies are also means of public participation and the expression of a relational landscape transferred into mathematical conceptions of space (from a given knowledge system to the scientific knowledge system) that could lead to the decontextualisation and the denaturation of original data. Species observations are thus not only of particular ecological interest (Pédarros et al., 2020) but translate a network of relations. The variability in species occurrence number during the participatory mapping process is related to specific relationships. Extending the ecological keystone species concept to one of the social-ecological keystone species appears particularly relevant to understanding the nature of participatory mapping products (Winter et al., 2018). Species mentioned during the participatory mapping methodologies, emerging from participants' practice of the landscape, are eminently social-ecological keystone species as they embody the object of social and ecological dynamics (e.g. baboons, caracals, vervet monkeys or bushpigs are structuring wildlife policies and conversations between landscape inhabitants).

Adopting a relational approach to coexistence issues in conservation science enables the establishment of a link between conservation science and practices by recognising the organisation of the territory (i.e. political dimension) as an integral part of social-ecological processes. This marks a major difference with the usual approach in conservation that consider the results of a study of ecological or social-ecological processes as the independent substrate on which conservation policies are formulated. The confrontation of species distribution modelling and stewardship analysis gives essential perspectives on conservation strategies and thus to move from theory to practice in integrating political dimension (organisation of the territory).

Although the open-access of the Garden Route National Park is a significant step in the coexistence process, the values associated with the park, its wildlife, and the social-ecological system still need to be clarified to formulate conservation strategies considering the complexity of the social-ecological system. How human–wildlife relationships are framed affects how these are interpreted and managed (Bhatia et al., 2020). Integrating the diversity of environmental discourses and associated stewardship action perspectives is thus needed to inform conservation strategies. Acknowledging the need for a diversity of human-nature visions does not mean replacing one idea with another; the critical point is the collaboration between these diverse visions around common objective. As previously mentioned, reformist discourses constitute most environmental discourses, but Pacaltsdorp people (in their diversity and complexity) were the only ones to defend their preference for transformative stewardship. The challenge of transformative stewardship is related to the relationships between knowledge and social-ecological systems (Mathevet, Bousquet, & Raymond, 2018). Although all stewardship perspectives except transformative ones have excluding edges in acknowledging a diversity of human-nature visions, moving towards transformative stewardship could be an integrative way of bridging different perspectives. Extending (and not restricting) the worldviews regarding landscape planning strategies could bring reformist, adaptive and sustainability stewardship objectives together, through dialogue, with transformative ones without reducing their specificities.

2. Complex spatial coexistence dynamics in shared landscapes

Social-ecological analysis of coexistence processes under this approach stresses the complexity of spatial coexistence dynamics in shared landscapes. Including other species in modelling processes improves the ability to predict habitat suitability (De Araújo et al., 2014; Leach et al., 2016). The Eltonian noise hypothesis advocates that biotic interactions influence species distributions at local geographical scales but it is still difficult to clearly identify interspecific interactions because the inclusion of a biotic variable in the modelling process conveys information about environmental variables that can be absent from the modelling process (Dormann et al., 2018; Zurell et al., 2018). For baboons and caracals, the respective inclusion of bushbuck and baboon distributions, informed the potential suitability of the landscape for those species by refining and maximising suitability range. Moreover, baboons and bushbucks are known to be common species (Pebsworth, 2020; Wronski, 2005). Bushbuck distribution could explain baboons' observations linked to foraging behaviour thus extending the understanding of baboons' habitat suitability. As bushbuck are the widest distributed large mammal in this landscape (Bernard, Guerbois, et al., 2024). Mostly solitary or in small groups, they use very discrete refuge areas in the middle of human settlement, they may translate the presence of movement corridors and micro-refugia that are difficult to perceive with baboons. Although no specific interaction has been found in the literature, our results could suggest similar interactions with humans' populations as the two species are easily visible in shared landscapes. Cooperation between the two species against predation could be an hypothesis as it has already been observed between primates and antelopes in India (Vasava et al., 2013). Baboons and caracals are attracted by food resources related to human occurrence: baboons practice crop, bin and house-raiding (Fehlmann et al., 2017; Mazué et al., 2023) and caracals are important predators of domestic cats (Nattrass & O'Riain, 2020) as well as poultry or small stock. Baboons could then explain specific occurrences of caracal related to anthropogenic forage resources spatial distribution.

Testing *a priori* interactions when including a biotic factor can be limited in multispecies distribution modelling, as we showed that including biotic factors could strongly inform unconsidered abiotic factors. For instance, the improved modelling performance suggests a finer prediction of baboons' landscape requirement and the paramount role of protected areas as a refuge, as shown in other studies (Guerbois et al., 2012; Pédarros et al., 2020). Protected areas appear as a structuring factor rather than limiting for baboons and caracals given the associated low importance of the land- cover to predict habitat suitability. It implies considering protected areas as integrated features of a complex habitat matrix, a landscape continuity embedded in the relationships structuring social-ecological systems. Despite the importance of protected and critical biodiversity areas, our results suggest that conservation strategies should not be limited to protected areas. This observation aligns with the reconciliation ecology idea advocating the importance of protected areas and anthropised landscapes suitable for wildlife (Rosenzweig, 2003a). It questions the efficiency and relevance of fenced protected areas compared to unfenced ones. It corroborates the essential idea of reconciliation ecology which is to deconstruct the dichotomy between artificial and natural infrastructures in the way they promote wildlife persistence. The diverse use of the landscape suggests the possibility of human-wildlife coexistence under the condition of the acknowledging of other species as part of the social sphere from which policymaking are formulated in integrating wildlife in the organisation and planning of the territory. Our study suggests that wildlife can thrive in different land uses where "*people live, work and play*" (Rosenzweig, 2003b).

The question is thus not to understand how human social spheres can persist next to other species (usually described as the "natural world", core objective of many coexistence or conflict studies) but more precisely how social spheres can integrate other species within them (Latour, 2004). This set of relations is paramount to understanding how wildlife species thrive in human-dominated landscapes, and the inclusion of biotic factors in the species distribution modelling highlighted this importance. While integrating species distribution as a biotic factor in modelling a specific species increases models' performance, it also gives another reading of social-ecological processes behind species distribution.

According to Abson et al. (2017) based on Meadows (1999), the leverage point to focus on here would then be the "intent" of the system defined as "the underpinning values goals, and world views of actors that shape the emergent direction to which a system is oriented". Based on the dialogue between multispecies habitat suitability modelling and stewardship action perspectives analysis, we suggest promoting dialogue across a wide range of parties to share knowledge and to allow a common understanding of what it means for everyone to live with, next to, or separated from wildlife in this relational landscape. Integrating more thoroughly Khoï people in decision-making processes and the expression of the values underpinning transformative stewardship action (e.g. through the performance of the theatre show) could be the first step "to make society" and create sustainable dialogue. It would allow to envisage relationships in George municipality structuring a broader society also recognising wildlife, already part of the network of interactions in the area. The diversity of these perspectives leads us to emphasise the importance of contextualising conservation measures and more broadly to politicise social-ecological studies to enable to move from theory to practice.

CONCLUSION

Transdisciplinary approaches to conservation are crucial to investigate coexistence issues from a complex perspective. The mobilisation of participatory mapping data to modelling habitat suitability enabled to consider the relational landscape where coexistence issues occur. Integrating biotic factors in habitat suitability modelling is a step further in considering the diversity of relationships and increased the modelling performance, giving key insights concerning the role of protected areas as structuring features rather than limiting wildlife occurrence in shared landscapes. However, this important baseline description of a shared landscape cannot lead alone to the formulation of conservation strategies. The stewardship analysis with different research-partners led to a diversity of perspectives concerning the type of actions to implement and the system in which they want to live. A shared issue leads to competing views in the ways it would be addressed, and these different perspectives must be equally considered to ensure the legitimacy and efficiency of conservation strategies. Transformative stewardship is however the only perspective that could accommodate this diversity of perspective because it recognises a diversity of motivations, relationships, and knowledges. Considering transformative stewardship in the formulation of conservation strategies could be a way to bridge together different actors towards a common society project. As highlighted by our study, the "intent" of the system should be commonly discussed among parties to promote the needed collaboration for human-wildlife coexistence.

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