

Potential for wolf-based conflicts – A transdisciplinary mapping approach for hotspots using socio-economic and ecological factors

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Abstract

The return of the grey wolf has intensified wildlife-based conflicts in human-dominated landscapes. We developed a spatially explicit, mechanistic model of wolf-related conflict potential (*COPO*) that integrates socio-economic and ecological variables. A panel of governmental delegates evaluated input variables using a modified Delphi approach. *COPO* was derived and combined with wolf habitat potential to form a bivariate hotspot model that captures both the ecological and socio-economic perspectives of wolf occurrence. The *COPO* revealed areas of high potential conflict in the western Alpine regions. For the same areas, the hotspot model highlighted concurrent high habitat potential, in contrast to areas of high habitat but low potential for conflict in the North and East. Our approach demonstrates that potential conflict can be modelled in a transdisciplinary way with structured expert input. The resulting maps provide a basis for evidence-informed wolf management by identifying leverage points for adaptive coexistence strategies.

1. Introduction

1.1. Rebounding of European Wolves

Over the past few centuries, the grey wolf (*Canis lupus*) disappeared from most parts of Central Europe due to extensive persecution and habitat loss (Ciucci et al. 2024). In recent decades, wolves have re-established populations in nearly all European countries, recolonizing regions from which they had been absent for more than a century (Chapron et al. 2014; Boitani et al. 2022). This resurgence represents a major conservation success, yet it has also led to a growing frequency of human-wolf interactions (Di Bernardi et al. 2025).

1.2. Wolf-based conflicts in Europe

Wolf-based conflicts (WBC) in Europe primarily arise from the species' recolonization into human-dominated landscapes, where traditional livestock husbandry, hunting interests, and rural livelihoods intersect with conservation objectives (Boitani and Linnell 2015; Chapron et al. 2014). The most common basis of tension includes livestock depredation, competition with hunters for ungulate prey, and divergent social perceptions of wolf presence (Kaczensky et al. 2013; Marino et al. 2021). While the ecological recovery of the wolf is widely regarded as a conservation success, its expansion into human-dominated landscapes has rekindled longstanding cultural, socio-economic and political conflicts (Di Bernardi et al. 2025; Pettersson and von Essen 2025). These conflicts are embedded in broader societal debates over land use, rural identity, and wildlife governance (Dressel et al. 2018; Kaltenborn and Linnell 2022; Hatlauf and Fuchs 2024). A meaningful debate about wildlife management requires a science-based understanding of management approaches (Kuijper et al. 2019). Currently, this evidence is largely lacking or not taken into account, and decisions are rarely made with all relevant stakeholders included. The implementation of management approaches is, however, likely to be unsuccessful if they are not developed in a transdisciplinary way and do not consider the whole socio-ecological system (Redpath et al. 2017; Dressel et al. 2018).

1.3. Modelling wolf-based conflicts

Modelling potential impacts and the potential for conflict has been used to understand conflict drivers and to enable evidence-based decision-making (Broekhuis et al. 2017, Ditmer et al. 2022). Understanding the spatial and temporal distribution of incidents and the factors that contribute to their occurrence has become an essential part of conflict resolution (Pimenta et al. 2018). Spatial models are a commonly used source of information for wildlife management and are used to visualize possible areas of conflict when analysing socio-ecological systems (Dressel et al. 2018). To display potential conflicts about wolves, such models have been used to visualize wolf habitat suitability and distribution (Davoli et al. 2022; Kaim et al. 2025; Kunz et al. 2026), livestock depredation susceptibility (Kunz et al. 2026; Miller 2015) and the acceptance of wolves based on a combination of those factors (Behr et al. 2017, Ditmer et al. 2022). To our knowledge, no approach has yet combined a participatory, expert-based assessment of conflict potential (*COPO*) with spatial habitat modelling to identify wolf management-relevant hotspots. We present an Austrian case study developed through a transdisciplinary, participatory process with governmental delegates.

1.4 Aim of this study

The general aim of our research was to investigate *COPO* for wolves in Austria, thereby enabling an enhanced science-based management. Results were produced using a transdisciplinary research approach that integrates expert knowledge, especially for aspects lacking an existing database.

Our study was guided by the following more specific aims: (1) Evaluating the variables with the potentially strongest influence on the conflict with wolves in Austria based on expert assessment; (2) analysing and mapping the spatial distribution of conflicts – resulting in the *COPO* map; and (3) enabling a realistic and management-relevant application by displaying potential hotspot areas with high habitat potential and high conflict potential. To achieve these aims, we have constructed a mechanistic model that incorporates empirical data on various socio-economic and socio-ecological variables. The model setup aimed to encompass various land use sectors and, consequently, different stakeholder groups. The corresponding variables were weighted through a heterogeneous group of governmental representatives. By doing so, we aimed to identify variables relevant to wolf management and to investigate leverage points within adaptive management. In a final step, we combined a habitat potential model for wolves (Kunz et al. 2026) with the conflict potential model to present hotspots for wolves in Austria.

2. Theoretical backgrounds

2.1. Wildlife-based conflicts

Human-wildlife interactions encompass a wide range of dimensions, among which, despite the term's conceptual ambiguity, "human-wildlife conflicts" are particularly influential for both humans and wildlife, including perceived or actual impacts of wildlife on human interests (Zimmermann et al. 2020).

Regardless of definitional nuances, a general societal-level conflict between humans and wolves is evident. Such conflicts tend to intensify when public attitudes and values diverge (Manfredo et al. 2003; Vaske et al. 2006) or when underlying issues remain unresolved over extended periods (Redpath et al. 2015; Nyhus, 2016).

In this study, we use the term “wolf-based conflicts (WBC)” as a derivation of “wildlife-based conflicts” to encompass what is commonly referred to as “human-wildlife conflict” (IUCN 2023), “conflicts over wildlife” (Zimmermann et al. 2020), or, in specific contexts, “conservation conflicts” (Redpath et al. 2013). We adopt this terminology because such conflicts are typically catalysed by wildlife but often evolve to concern broader issues within the human dimension, including social identity, values, and governance (Dickman 2010). These conflicts generally have negative effects on at least some of the stakeholders involved, such that mutually acceptable trade-offs or solutions cannot be achieved without effective conflict management (Redpath et al. 2013). Without an effective conflict management, realized conflict levels remain persistently elevated, even when the underlying conflict potential is moderate.

2.2. Conflict potential

Following Carter and Linnell 2016, we define human-wildlife coexistence as a spatially and temporally dynamic condition that enables the sustained presence of both wolves and humans through the implementation of appropriate management measures. COPO can be understood as an impediment to coexistence: the higher the conflict potential, the greater the need for holistic adaptive management interventions, including approaches focusing on humans, e.g., conflict management and mediation. These interventions require an adaptation of current management (Carter and Linnell 2016).

In this context, COPO covers the impacts of wolves on humans, through different effects (direct effects on humans and their livelihoods, e.g., livestock depredation, and indirect effects, e.g., spatiotemporal changes of ungulates leading to potential browsing impacts in protective forests) or as a catalyst of human-human conflicts (e.g., lack of consensus about wolf management). A mismatch in the perception of effects and conflicts that are “perceived” and “actual” can subsequently catalyze conflict arising from human disagreements (Dickman 2010). The transdisciplinary participative approach, based on expert assessment, enables COPO to address direct and indirect, perceived and actual effects, as well as conflicts. The variables used in COPO describe the exposure and vulnerability of humans to wolves. Following this, we modelled COPO independent of wolf occurrence and abundance. COPO therefore represents a combined potential for WBCs, but neither the risk of WBCs nor their actual occurrence is visualised.

3. Methods

3.1 Study area

Austria exhibits a pronounced altitudinal gradient ranging from 114 m to 3,798 m above sea level, resulting in a high diversity of ecological and climatic conditions (Federal Ministry of Agriculture,

Forestry, Regions and Water Management 2024). Recent spatial modelling of wolf habitat suitability and potential distribution indicates that approximately 47% of the country provides suitable conditions for wolf presence (Kunz et al. 2026). As in other parts of Europe, livestock depredation represents one of the primary sources of WBC (Singer et al. 2023; Di Bernardi et al. 2025).

Two-thirds of the national territory lies within the Alpine region. Alpine pasture management, together with the maintenance of protective mountain forests, is a component of traditional land-use systems and contributes to rural livelihoods, cultural identity, and key ecosystem services, such as natural hazard protection. Because these land-use systems are closely tied to local identities and value orientations, they are influencing societal perceptions and acceptance of large carnivores, including wolves, and thus contribute to the formation and framing of related conflicts (Hovardas 2018). At the same time, the wolf has emerged as a powerful cultural and political symbol, representing both a success of nature conservation efforts and a dangerous threat (Almarcha et al. 2022). These contrasting interpretations exacerbate existing societal tensions, especially in a country with diverse dependencies on extensive alpine pastures and forests (Hackländer et al. 2019, Hatlauf and Fuchs 2024).

3.2. Conceptualizing variables via stakeholder identification and delegate engagement

To assess the potential for conflict over wolves, we identified key stakeholder groups and corresponding variables that can shape human-wolf relations. In conservation science, stakeholders are understood as organizations, groups, or individuals who have interests in, may be affected by, or can influence the outcomes of management processes (Salvatori et al. 2020; Hovardas 2018; Marino et al. 2021). Based on research on wolf governance (Ostermann-Miyashita et al. 2025) and informed by available variables relevant to the Austrian context, we identified the following sectoral stakeholder groups: (1) agriculture, specifically livestock owners; (2) hunters; (3) forestry; (4) tourism and (5) the general public. This categorisation was intended so that these groups capture the main axes of WBC while retaining the diversity of viewpoints necessary for management-oriented spatial modelling.

3.3. Stakeholder involvement

After identifying the relevant stakeholder groups, a consortium of administrative authorities was established to formally represent these groups within the modelling framework and enable transdisciplinary knowledge transfer and integration. The consortium consisted of 15 delegates nominated by their respective national or federal institutions. We specifically aimed for delegates from national or federal state authorities contrary to delegates from the private sector (NGOs, associations, societies, etc.), as they are regularly confronted with wildlife management and governance while being bound by oath to act in the public interest. Delegates from seven of Austria's nine federal states participated; the federal states of Vienna and Burgenland did not participate because wolves are not yet regularly present there. The consortium covered the thematic areas of agriculture, hunting, forestry, nature conservation, rural development, landscape management, and legal affairs. It acted as an expert panel to define the set of variables used in our model, guide the weighting of these variables, evaluate

the model's validity, and serve as a contact point to collect relevant data from the federal states (see Appendix S2).

3.4 Variable assessment

To conceptualize and spatially represent the COPO, we defined a set of variables for each stakeholder group (Table 1). The variables are based on literature and expert opinion of the consortium with the prerequisite that they are available on a countrywide explicit spatial scale.

We used a modified Delphi method (Brady 2015) with individual semi-structured questionnaires and follow-up face-to-face group discussions in a workshop setting to gather information from the panel of delegates for the variable assessment (Table 1). The Delphi method was adapted in that participants wrote down their assessments, did not need to reach consensus, and were allowed to revise their prior assessments after the round of discussions. Complementary semi-structured questionnaires were carried out via video calls to receive responses from delegates who were unable to participate in the in-person workshop. The representatives were asked to complete the survey based on their professional experience as government officials. Expert assessment was necessary to parametrize the mechanistic COPO, because no predictive model exists.

Table 1

Overview of all variables, measuring units, their sources and whether stakeholder delegates (cf. Chapter 3.3) assessed that variable as relevant for the model. Abbreviations: InVeKoS = Integrated management and control system; BMLUK = Federal Ministry of Agriculture and Forestry, Climate and Environmental Protection, Regions and Water Management; GeDaBa (Gemeindedatenbank) = community database.

Stakeholder group	Variable	Unit	Source / Calculation	Relevance
General public	<i>Human population density</i>	People per km ²	Statistics Austria / district average	Yes
	<i>Human demography (age)</i>	Average age per district	Statistics Austria / Excluded	No
	<i>Dogs</i>	Dogs per km ²	Austrian pet database / district average	Yes
Agriculture	<i>Livestock predation compensation payments</i>	Categorical classification per federal state	Review of federal state information / Classification into 5 classes	Yes
	<i>Livestock protectability</i>	--	Not available	Yes
	<i>Funding for livestock protection measures</i>	Categorical classification per federal state	Review of federal state information / Classification into 5 classes	Yes
	<i>Livestock depredation susceptibility</i>	Livestock depredation susceptibility index	Kunz et al. 2026	Yes
	<i>Livestock presence</i>	Binary presence (yes / no)	InVeKoS / Classification into 2 classes	Yes
	<i>Threatened livestock breeds</i>	Binary presence in the municipality (yes / no)	GeDaBa / Classification into 2 classes	Yes
Hunting	<i>Farmed game</i>	Binary presence (yes / no)	InVeKoS / Classification into 2 classes	Yes
	<i>Hunting dogs</i>	Categorical classification per federal state	Review of federal state information / Classification into 5 classes	Yes
	<i>Ungulate hunting bags</i>	Number per km ²	Statistics Austria / district average	Yes
	<i>Ungulate species diversity</i>	Number per km ²	Statistics Austria / district average	Yes

Stakeholder group	Variable	Unit	Source / Calculation	Relevance
Hunting, Forestry	<i>Wildlife protection areas</i>	Spatially explicit binary presence (yes / no)	Provided by federal state agencies / Classification into 2 classes	Yes
	<i>Red deer feeding sites</i>	Spatially explicit binary presence (yes / no)	Provided by federal state agencies / Classification into 2 classes	Yes
Forestry, General public	<i>Protective forests</i>	Spatially explicit binary presence (yes / no)	BMLUK / Classification into 2 classes	Yes
Agriculture, Hunting, Forestry, Tourism	<i>Wildlife ecological spatial planning (WESP)</i>	Spatially explicit binary presence (yes / no)	Provided by federal state agencies / Classification into 2 classes	Yes
Tourism	<i>Number of overnight stays (summer & winter)</i>	Stays per km ² (summer & winter)	Statistics Austria / district average	Yes

In the following, we use three terms describing the components of the variable assessment process. In a first step, the *variable weighting* was assessed, denoting the relevance of a variable for the conflict (the perceived importance for the COPO in relation to all other variables). In the second step, for each category per variable, the *category intensity* was assessed, representing the differences in perceived importance between categories of the given variable, ranging from 0-100. In a third step, the *conflict contribution* was calculated for each category per variable as the product of a variable's weighting and the *category intensity*. Through the expert assessment collected 1) the *variable weighting* and 2) the variables' *category intensities*. In the final computation these were then used to calculate the conflict score for each raster cell.

The questionnaire consisted of an explanatory part (on how to fill out the responses) and of four different sections (Appendix S3). The first section of the questionnaire assessed the relevance of potential conflict variables (inclusion: yes/no), and *variable weighting* was evaluated using a bipolar scale ranging from 0.2 ("very low") to 1 ("very high") in increments of 0.2 (Dillman et al., 2014). The second and third sections were used to gather information about potentially relevant missing variables. In the fourth section, the *category intensity* of each variable was assessed for each variable level on a scale of 0–100. The participants were not asked to report a degree of confidence in the predictions and only evaluated the variables they themselves assessed as relevant. To reduce confusion between the gradings during variable evaluation and subsequent discussions, we used different scales for the single components. All

individual values were averaged to obtain a mean value for each variable and category. To separate the effect of the variable itself from the influence of its levels, we calculated the contribution for each variable, defined as the product of its mean weight and *category intensity* (Fig. 1).

scientists; marked in black) and transdisciplinary steps (conducted together with the delegates; marked in orange) for the variable identification and assessment process

3.5 Modelling COPO

The conflict variables were collected from different public sources: the agricultural database (InVeKoS), the national statistical database (Statistics Austria), the municipality database (GeDaBa) and the pet database (Federal Ministry of Health and Social Affairs 2024). All variables that could not be assessed openly were requested from the national and federal sources. Data for the variables *red deer feeding sites* and *wildlife protection areas* were not provided by all federal states, and therefore the variables had to be excluded from the modelling as they did not meet the prerequisite of being available all over Austria. The raw conflict variables were either available in binary classes (yes/no) or in a continuous numeric scale. The highest spatial resolution of input data was 10 x 10 m, while the lowest was the level of the whole federal state. The four variables: *livestock predation compensation payments*, *funding for livestock protection measures*, *threatened livestock breeds* and *hunting dogs* could not be included in the final model, due to missing spatially explicit datasets or changing policies.

All variables were converted to the coordinate system ETRS89 (EPSG:3416) and aggregated to a spatial resolution of 100m x 100m. The processing of the spatial variables was implemented in ArcGis Pro and in R v. 4.4 (R Core Team 2024). The continuous scale variables were reclassified into five classes (very low, low, medium, high, very high) using natural breaks with the R-packages BAMMtools (Rabosky et al. 2014) and classInt (Bivand et al. 2025) using R v. 4.4 (R Core Team 2024). The natural breaks for the variable *depredation susceptibility* were adjusted manually, due to a high skewness and overrepresentation of very low values. After reclassification into classes, “monotone hermite splines” from the R-package stats (R Core Team 2024) were used to achieve continuous weighted values for each variable.

We modelled COPO following an expert-based mechanistic modelling approach, similar to habitat suitability index models (Drew and Perera 2010; Evans et al. 2015; Di Febbraro et al. 2018; Nopp-Mayr et al. 2022). Hence, the model predicts the potential for conflict, independent of the intensity of the currently perceived or actual conflict for each raster cell. As such, we defined the COPO model formula as follows:

$$COPO = \frac{CatInt_1 * WeightVar_1 + \dots + CatInt_n * WeightVar_n}{Max. CatInt_1 * WeightVar_1 + \dots + Max. CatInt_n * WeightVar_n}$$

COPO for each cell is composed of the sum of the *conflict contributions* of all the variables for this cell, which is computed as the *category intensity* (CatInt) multiplied by the *variable weighting* (WeightVar). To

obtain a scaled value, this was divided by the sum of the maximum *category intensity* of each variable across all levels, multiplied by their weighting. The score was afterwards reclassified into five conflict classes (very low - very high) for visualization.

3.6 Creation of a combined habitat and conflict model

To enable an integrative assessment of potential wolf habitat in combination with areas of increased COPO, a bivariate combination model (hereafter: hotspot model) was computed (Fig. 2). This was achieved by using the wolf habitat potential model (SDM) from Kunz et al. (2026) and intersecting it with the COPO model by overlaying and attaching the classes. The hotspot model consists of a matrix with 25 classes, composed of five habitat and five conflict classes (0–4; Ditmer et al. 2022), leading to values of pixels between 0 and 44 for each raster cell. As such, we defined the hotspot model formula as follows:

$$hotspot\ model = COPO + SDM * 10$$

This intersection enables a spatially explicit representation and facilitates the interpretation of ecologically suitable areas with land use conflicts and an evidence-based identification of hotspots for wolf management based on spatial priorities and risk by decision makers. The models were created with the same reference raster and using a spatial resolution of 100m x 100m. All models were visualized in maps and visually evaluated by experts (scientists, practitioners and governmental representatives) in the framework of a follow-up workshop (Krausman 2020). Updating the model predictions by including new monitoring data or variable evaluations is ensured by using an expandable model formulation and repeatable participatory approaches (Fig. 2).

To simplify the model interpretation, the coloration of the hotspot model is directly derived from the sub-models (Appendix S1). White areas in the hotspot model represent low habitat and low COPO and therefore little relevance for management. Green areas correspond to high habitat potential but low COPO. Purple areas, on the other hand, have a high COPO but a low habitat potential. Dark blue areas are those which have both a high habitat and high COPO. Those are assumed to be the core conflict zones.

4. Results

4.1. Relevance of conflict variables

The COPO model combines socio-economic and socio-ecological variables to describe the potential intensity of WBC based on available data. As a first step, the relevance of variables was evaluated by an expert assessment. This resulted in the exclusion of the variable *human demography (age)*. *Livestock depredation susceptibility* was assessed as the variable with the highest importance for the COPO (*weighting*: 0.90; Table 2), followed by the variables *protectability* and *human population density* (*weightings* 0.84 and 0.70, respectively). The lowest importance was assigned to *ungulate species diversity* (*weighting*: 0.34). The maximum *category intensity* was reported for *livestock depredation*

susceptibility with a maximum value of 87.33, followed by *protectability* with a maximum 72.00 and *red deer feeding sites* with a maximum value of 67.66 (Table 2). The maximum *conflict contributions* (*category intensity* multiplied by weighting) ranged from 11.67 for the *ungulate species diversity* to 78.60 for the *livestock depredation susceptibility* (Table 2).

Table 2

Results of the variable assessment by the delegates, sorted by their maximum contribution. The *variable weighting* was assessed for each variable, regardless of their variable level, while the *min./max category intensity* corresponds to the min./max. values of any variable level of those variables. The *min./max. conflict contribution* is calculated as the *min./max. category intensity* multiplied by the *weighting*.

Variable	Variable weighting (0–1)	Min. category intensity (0–100)	Max. category intensity (0–100)	Min contribution (0–100)	Max. contribution (0–100)	Used in the final model (Yes / No)
<i>Livestock depredation susceptibility</i>	0.90	28.00	87.33	25.20	78.60	Yes
<i>Livestock protectability</i>	0.84	62.66	72.00	52.63	60.48	No
<i>Red deer feeding sites</i>	0.69	15.33	67.66	10.58	46.69	No
<i>Protective forests</i>	0.69	36.00	63.33	24.84	43.70	Yes
<i>Human population density</i>	0.70	23.00	57.00	16.10	39.90	Yes
<i>Livestock presence</i>	0.64	36.33	54.66	23.25	34.98	Yes
<i>Funding for livestock protection measures</i>	0.58	24.66	60.00	14.30	34.80	No
<i>Wildlife protection areas</i>	0.54	22.33	52.33	12.06	28.26	No
<i>Hunting dogs</i>	0.51	16.33	52.66	8.33	26.86	No
<i>Ungulate hunting bags</i>	0.53	46.66	50.00	24.73	26.50	Yes
<i>Wildlife ecological spatial planning (WESP)</i>	0.52	25.66	50.33	13.34	26.17	Yes
<i>Number of overnight stays (summer & winter)</i>	0.50	16.00	49.30	8.00	24.65	Yes
<i>Livestock predation</i>	0.44	21.66	54.00	9.53	23.76	No

Variable	Variable weighting (0–1)	Min. category intensity (0–100)	Max. category intensity (0–100)	Min contribution (0–100)	Max. contribution (0–100)	Used in the final model (Yes / No)
<i>compensation payments</i>						
<i>Dogs</i>	0.45	16.00	52.33	7.20	23.55	Yes
<i>Threatened livestock breeds</i>	0.40	10.00	36.00	4.00	14.40	No
<i>Farmed game</i>	0.38	20.00	37.66	7.60	14.31	Yes
<i>Ungulate species diversity</i>	0.34	28.50	34.33	9.69	11.67	Yes

4.2. COPO model

The cartographical prediction of the COPO (Fig. 3) shows a west-east gradient of conflict intensity. Especially the alpine areas in the federal states Vorarlberg, Tyrol, Salzburg and Carinthia have a high potential for conflict, while in the east, primarily urban areas like the city of Vienna are showing elevated levels of COPO. However, local variation is also evident in the western federal states.

4.3. Combined habitat and conflict hotspot model

A west-east gradient is also visible in the hotspot model. The alpine regions, e.g., in Vorarlberg, Tyrol, Carinthia and Salzburg stand out with large areas which are characterized by a high habitat and high COPO (blue colouring). Other areas in those federal states depict a high conflict but low habitat potential (purple colouring) (Fig. 4). The northern and central parts of the eastern Alps, however, are characterized by elevated habitat but low to medium COPO. The north-western parts in Upper Austria are characterized by rather low habitat and COPO, while the northern parts of the federal states Lower Austria and Upper Austria hold higher values for habitat potential but lower values for COPO. The urban and peri-urban areas surrounding larger cities (Vienna, Graz, Salzburg, Linz) exhibit high COPO but offer little habitat for wolves.

5. Discussion

5.1. Modelling COPO and corresponding variables

The five most influential variables, as characterized by the delegates, were *livestock depredation susceptibility*, *protectability of livestock*, *red deer feeding sites*, *protective forests*, and *human population density*. Interestingly, these variables represent four of the five stakeholder groups, namely agriculture,

hunting, forestry, and the general public. Tourism (*Number of overnight stays (summer & winter)*) plays only a minor role (Table 2). The spatial prediction of the conflict model shows a clear west-east gradient, with an apparent correlation to the boundaries of the Alps. Beyond the Alps, urban areas and cities exhibit increased COPO, whereas remote areas in eastern Austria have the lowest values. A similar trend is visible in the hotspot model. Western Austria shows high levels of both habitat potential and COPO. While COPO decreases to the east, leading to a mosaic of areas with high habitat and very low to medium COPO, northeastern Austria is characterized by high habitat but low COPO. The surroundings of the city of Vienna are an exception, with very low habitat potential, but high to very high COPO.

The variable *human population density* had a medium effect on the model. A higher population density might lead to a higher number of humans who fear or disagree about wolves and their management (Linnell and Allean 2016; Behr et al. 2017), which is, however, influenced by their place of residence (Trebo et al. 2025). The variable's importance for the COPO might be explained by the low tolerance towards wolves in Austria (Bele et al. 2022) and activity of organized anti-wolf groups and political parties, which campaign against wolves and exacerbate the urban-rural divide (Rode et al. 2021; Zscheischler and Friedrich 2022).

Red deer feeding sites are a widely used tool to steer red deer away from vulnerable and valuable forest stands and to raise the economic viability for red deer, which can reduce the conflict between forestry and hunting (Arnold et al. 2018). Wolves present an external factor influencing current ungulate management with partially unknown effects on ungulate behaviour, population density and space use, evoking a range of projected hopes and fears (Kuijper et al. 2024). The delegates communicated a high level of conflict due to the uncertainty of wolf effects on ungulates and therefore their potential impact on feeding sites and the (economic) value of red deer hunting. The very high *conflict contribution* of the variable *protective forests* likely reflects the dependency on the protective function of forests. Wolves can lead to changes in the space use of ungulates and, as a result, indirectly influence the protective function of forests, either positively or negatively (Kuijper et al. 2024). In the corresponding discussions, the representatives underlined the high valuation of protective forests by the local inhabitants and furthermore the identification with protective forests and livestock grazing on alpine meadows as being part of the rural identity, local culture, and maintenance of the landscape.

Livestock depredation susceptibility was assessed as the variable with the highest *variable weighting* and the highest *conflict contribution*. *Livestock protectability* had the second-highest relevance but could not be used in the final model due to the lack of countrywide data and precise geographical locations for implemented protection measures. An approximation via the variables *livestock predation compensation payments* (assessed *contribution*: low) and the *funding for livestock protection measures* (assessed *contribution*: medium) was intended. However, both variables could not be integrated into the final modelling due to missing spatially explicit datasets and policy changes that rendered them obsolete. This overall medium-to-high assessment of livestock-related variables by the delegates aligns with scientific perspectives indicating that the burden of coexistence with wolves is highest for agriculture, particularly livestock farming (Ostermann-Miyashita et al. 2025). Not only are farmers the most affected,

they also tend to show a higher emotional component, constituting fear, anger and frustration compared to the general public (Trebo et al. 2025).

Areas with high susceptibility to depredation should be protected when livestock grazing occurs simultaneously with wolf presence (Kunz et al. 2026), a point that was, however, disputed among the delegates. These different perceptions might be explained by the strong influence of individual experiences on the effectiveness of compensation schemes (Naughton-Treves et al. 2003; Hemminger et al. 2025). The compensation of damages is recommended to be linked to the existence of functional protection measures (LCIE 2007), while political decisions terminated the funding for compensation measures (Kutal et al. 2025). The lack of political support could lead to low acceptance of interventions if their outcomes are perceived as unsuccessful or if they do not align with the beliefs and norms of livestock owners (Eklund et al. 2020) or politicians. This constitutes a wicked problem due to a lack of willingness for negotiations (Alfredson and Cungu 2008). Thus, the compensation for livestock losses to wolves might have no positive effect on the conflict (Naughton-Treves et al. 2003) because other indirect costs are not compensated (Widman et al. 2019), e.g., higher psychological distress among farmers (Zahl-Thanem et al. 2020; Rode et al. 2021).

Compensation often covers only financial aspects, not the farmers' goals, such as reducing animal pain, caring for their animals, managing alpine pastures as a service to society, and maintaining their own cultural heritage and social identity (Chapman and Deplazes-Zemp 2023). Nevertheless, compensation and lethal management are two actions often used by authorities to resolve conflicts over wildlife (IUCN 2023). This is likely to preserve the status quo or even intensify conflict between or within stakeholder groups, as they are not addressing the underlying drivers of the conflict (Manfredo et al. 2003; Pooley et al. 2017). Training and capacity building, flexible political support and solving general economic challenges of specifically small farms could reduce conflict (König et al. 2020; Petridou and Kati 2025). A decline in alpine pastures in Austria was already being reported before wolves re-established, with economic viability consistently identified as the central determinant (Hackländer et al. 2019). Although wolves were initially considered irrelevant as a cause of abandonment, more recent interviews indicate that farmers increasingly perceive them as a potential additional burden, albeit still subordinate to long-standing economic and structural challenges (Hackländer et al. 2019). This also underlines that universal and monocausal solutions and approaches are likely to fail in complex socio-ecological systems, such as Central European cultural landscapes (Redman et al. 2004; Dressel et al. 2018).

These ambiguous and diverse perspectives on the conflict show that COPO should not be equated with the realized conflict. Conceptually, COPO is based on the idea of landscape ecological habitat potential (Suchant et al. 2003) but derives from socio-economic and socio-ecological conditions that shape wolves' impacts on humans and human conflicts. Depending on local conditions, humans are more or less intensively affected by wolves' presence. By this, COPO describes the potential influence of wolves on humans, while individual, cultural, or local adaptations (including livestock protection measures) and personal perception can lead to deviations from COPO. As such, examination of the variation between COPO and the realized conflict would be most informative. Additionally, the elicitation results suggest

that uncertainty about wolves' ecological effects influences COPO in Austria, suggesting the need for further research on the interaction between wolves and land use.

5.2. The participatory and transdisciplinary approach

We specifically aimed to gather unbiased opinions and prevent a “tyranny of the minority” (López-Bao et al. 2017) by involving governmental officials in the assessment process. The thematic background of our delegates may shape their assessments; officials working in nature conservation may prioritise different aspects than those embedded in agricultural or hunting administrations (Silberzahn et al. 2018). Political contexts at the federal-state level may also subtly affect judgments, as suggested by research linking political orientation, voting behaviour and attitudes toward wolves (Clemm von Hohenberg and Hager 2022). Despite these potential influences, many officials are, however, bound by an oath of office, implying impartiality. In practice, they often serve as focal points for both bottom-up processes initiated by citizens and top-down directives from political institutions. Engaging with these representatives, therefore, allowed us to identify gaps in the socio-ecological and socio-political systems (Lute and Gore 2014), while acknowledging their central role in decision-making and their position at the interface between politics and the broader public (Lécuyer et al. 2024). To further raise trust in the model results and increase the understanding of the strengths and weaknesses, more advanced participative approaches could be applied as well (Salvatori et al. 2020; Young et al. 2022). Specifically in complex decision contexts structured engagement methods like multi-criteria decision analysis have proven effective to inform and engage (Mattsson et al. 2019; Marino et al. 2021). Such intensive engagement can reduce or quantify uncertainties about the contribution of variables and variable levels to the conflict including their variation and the precision of the predictions. Such an extension would strengthen the transdisciplinary knowledge transfer and improve systematic understanding of the socio-ecological system.

5.3. Practical application

The hotspot model is functioning as a visual and analytical basis for context-sensitive wolf management, while including ecological habitat potential and visualizations of socio-economic and cultural conflict potential. It can support human adaptation via a spatial prioritization of actions related to livestock protection, public relations and stakeholder inclusion processes. Human adaptation to coexist with wolves is a conundrum that needs adaptations on both sides, by humans, including every stakeholder group, and by wolves (Pettersson and von Essen 2025), and it needs to be treated in a dynamic manner (Carter and Linnell 2016). Inference of wolf management priorities based on our hotspot model anticipates coexistence by implementing measures before incidents and subsequent conflicts occur. While social conflicts are essential for coexistence and part of a democratic process (Hill 2021), they should not be used as an excuse for environmentally destructive behaviour through management (Chapron and López-Bao 2020). To assess the legitimacy of management measures, this study constitutes a first approximation to quantify the extent of COPO, while a further extension of input data and realized conflict intensity is desired and enabled through the expandable model formulation (Fig. 2).

The bivariate hotspot model enables the identification of areas with both increased habitat and increased COPO. If this model is being used for wolf management, one has to keep in mind that our classification of habitat and conflict classes was based on natural breaks. However, both the selection of those breaks and the definition of classes heavily influence the ratio of hotspots to cold spots. In particular, hotspots are not necessarily displayed on the map when viewed from, e.g., a livestock-protection perspective, despite their high ranking. Clear communication of the limitations and interpretations of such models requires cooperation among science, nature conservation, politics, and practitioners, particularly livestock owners (Ostermann-Miyashita et al. 2025), to achieve practical usefulness. This can ensure that multiple objectives are met, that policies are intersectoral and coherent (de Boon et al. 2021), and that governance and management gain legitimacy (Sjölander-Lindqvist et al. 2015). In the best case, this results in a transfer of ownership and responsibility for conflict-solving solutions, which are far more sustainable than mere top-down approaches, which are likely to result in win-lose or lose-lose situations and therefore correspond with the status quo (Redpath et al. 2013; Dickman et al. 2013; Redpath et al. 2017; Lécuyer et al. 2024).

6. Conclusion

By developing a hotspot model, we quantified priority areas for wolf management to support evidence-based decisions. With the presented methodology, we show that it is possible to model conflict in a spatially explicit way, while building on socio-economic and ecological variables. The observed spatial patterns can lay the groundwork for a deeper examination of current policies and inform recommendations for necessary adaptations in management strategies for the WBC solution. By implementing an inclusive approach with delegates from federal and national institutions, we not only covered individual opinions but were also able to visualize the underlying framework through an expert based, spatially explicit modelling approach. When addressing challenges in wolf management, the scope extends beyond ecology and requires transdisciplinary approaches that incorporate the social sciences and practitioners. When working on solutions for WBC, the focus should shift from mere numbers of wolves and livestock depredations to working with stakeholder groups who see themselves threatened by the mere presence of wolves. Given the complexity of WBC, the need for evidence-based research and cross-disciplinary collaboration among stakeholders becomes clear.

Declarations

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Conflict of interest – LF started his employment at the provincial government of Vorarlberg after this study was carried out. Provincial delegates were involved in the validation process of the models; however, the employer had no role in the design of the study, in the collection, analysis or interpretation of data, or in the writing of the manuscript. All other authors declare that they have no conflicts of interest.

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Figures

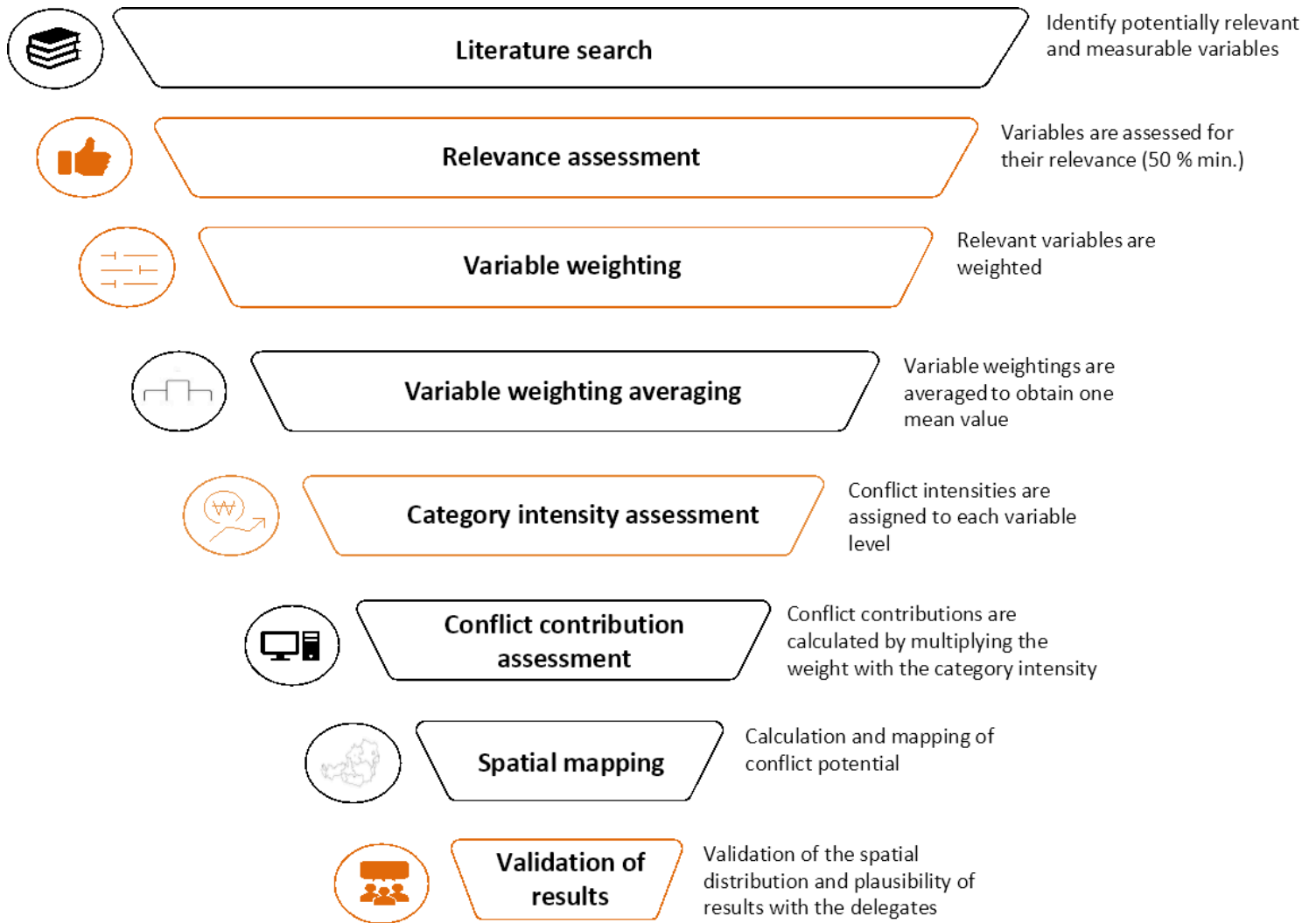


Figure 1

Conceptual framework and workflow including disciplinary (conducted solely by scientists; marked in black) and transdisciplinary steps (conducted together with the delegates; marked in orange) for the variable identification and assessment process

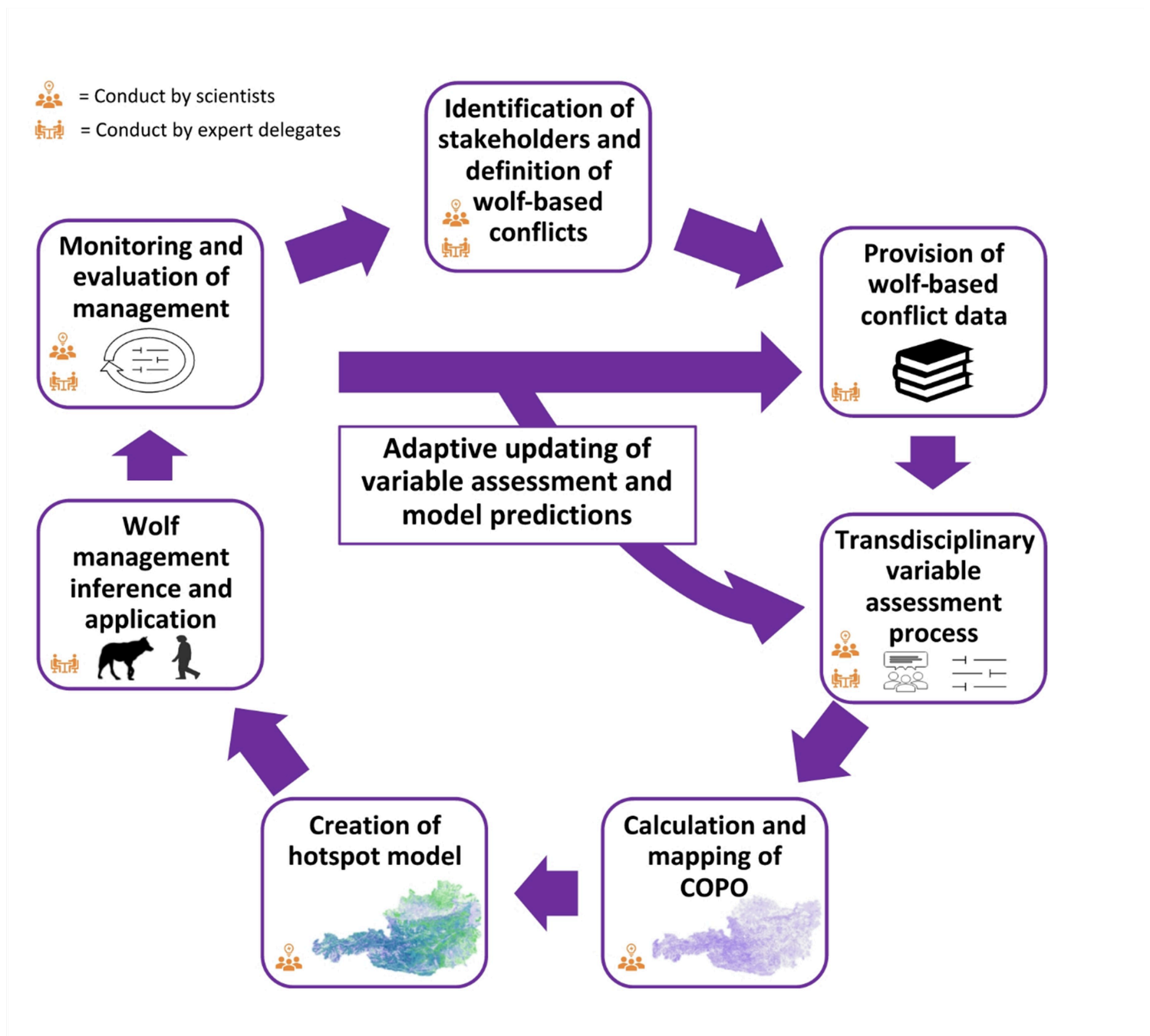


Figure 2

Theoretical process of adaptively creating the COPO and hotspot models to inform wolf management and adaptively update the results. Orange icons represent the implementation of the step either by expert delegates, scientists or together in a participative and transdisciplinary approach. The steps “Wolf management inference and application”, “Monitoring and evaluation of management” and the “Adaptive updating of variable assessment and model predictions” were not part of the presented case study, but constitute logical progressions

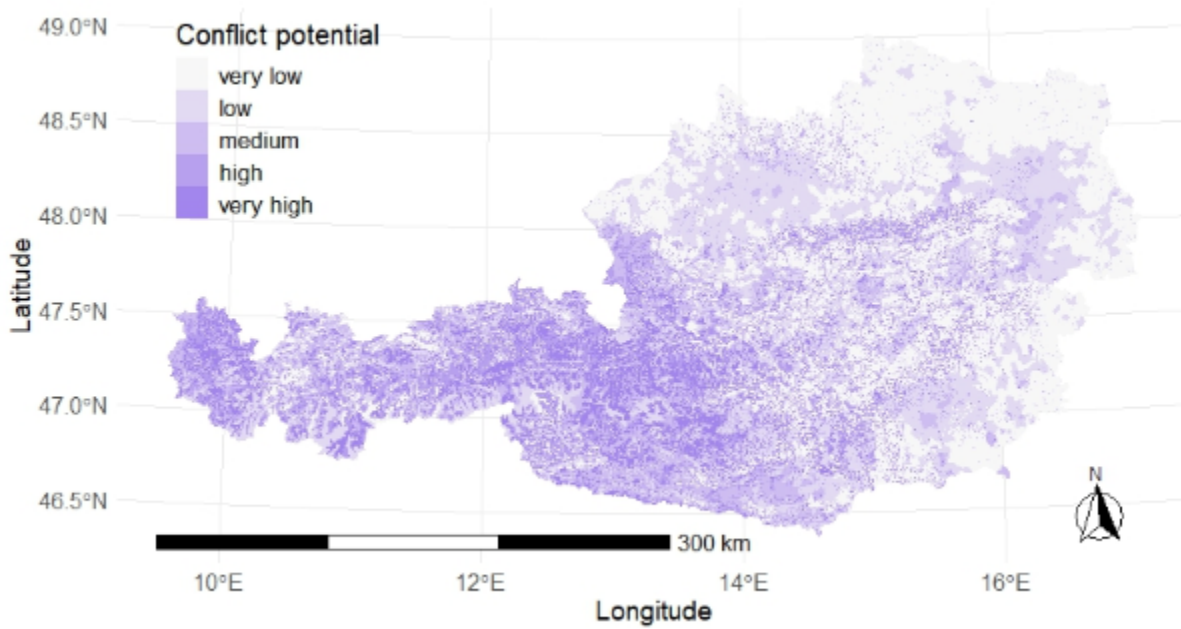


Figure 3

The COPO model represents the potential intensity of socio-economic conflict with wolves in Austria. The level of conflict is displayed in five classes, with darker violet colours depicting a higher COPO

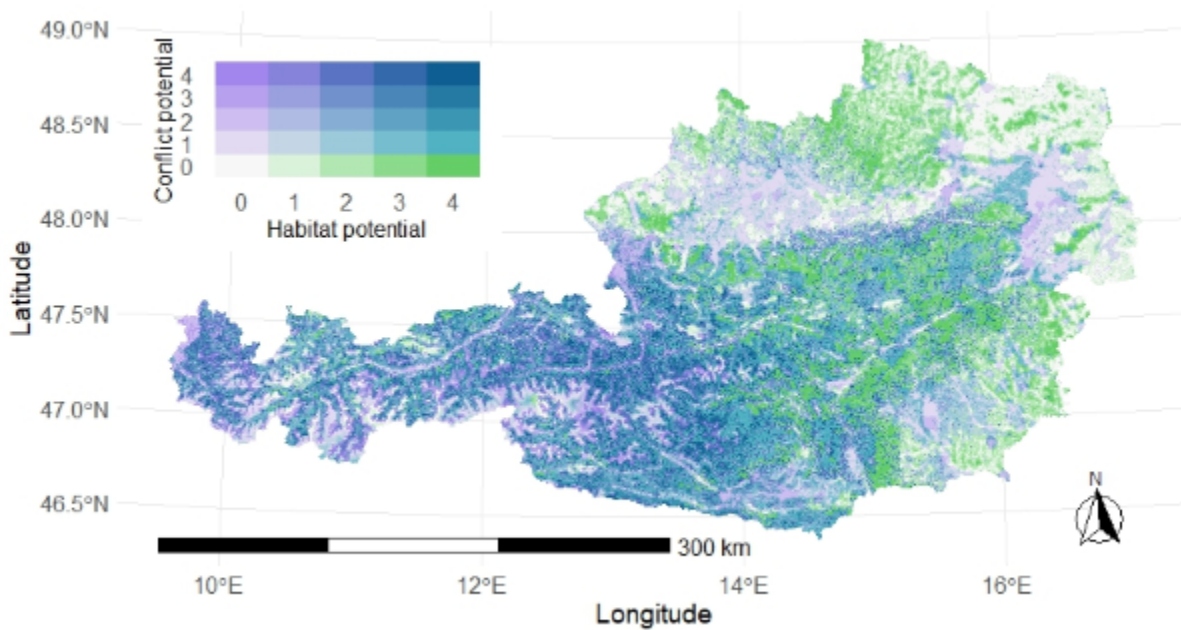


Figure 4

The bivariate hotspot model illustrates the potential habitat and intensity of socio-economic conflict with wolves in Austria. The level of habitat and COPO is displayed in 25 classes, with darker violet colours depicting a higher COPO and low habitat potential, darker green colours depicting a higher habitat

potential and low COPO and turquoise to dark blue colours depicting both a high conflict and habitat potential

Supplementary Files

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