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A B S T R A C T

Ticks are amongst the most important zoonotic disease vectors affecting human and animal health worldwide. Tick-borne diseases (TBDs) are rapidly expanding geographically and in incidence, most notably in temperate regions of Europe where ticks are considered the principal zoonotic vector of Public Health relevance, as well as a major health and economic preoccupation in agriculture and equine industries. Tick-borne pathogen (TBP) transmission is contingent on complex, interlinked vector-pathogen-host dynamics, environmental and ecological conditions and human behavior. Tackling TBD therefore requires a better understanding of the interconnected social and ecological variables (i.e., the social-ecological system) that favor disease (re)-emergence. The One Health paradigm recognizes the interdependence of human, animal and environmental health and proposes an integrated approach to manage TBD. However, One Health interventions are limited by significant gaps in our understanding of the complex, systemic nature of TBD risk, in addition to a lack of effective, universally accepted and environmentally conscious tick control measures. Today individual prevention gestures are the most effective strategy to manage TBDs in humans and animals, making local communities important actors in TBD detection, prevention and management. Yet, how they engage and collaborate within a multi-actor TBD network has not yet been explored. Here, we argue that transdisciplinary collaborations that go beyond research, political and medical stakeholders, and extend to local community actors can aid in identifying relevant social-ecological risk indicators key for informing multi-level TBD detection, prevention and management measures. This article proposes a transdisciplinary social-ecological systems framework, based on participatory research approaches, to better understand the necessary conditions for local actor engagement to improve TBD risk. We conclude with perspectives for implementing this methodological framework in a case study in the south of France (Occitanie region), where multi-actor collaborations are mobilized to stimulate multi-actor collective action and identify relevant social-ecological indicators of TBD risk.

1. The global burden of tick-borne disease

Emerging infectious diseases (EIDs) - either newly appearing or rapidly growing in incidence or geographic range [1] - have increased in unprecedented ways over the last century. The most recently discovered EIDs in humans are largely dominated by zoonoses, of which vector-borne diseases (VBDs) constitute a disproportionate share [2–4]. Although advancements in VBD surveillance and knowledge have

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influenced this increase by improving vector-borne pathogen (VBPs) detection and VBD diagnosis [5], it is argued that interconnected anthropogenic and ecological factors, such as human population growth, global trade and travel, rapid urban expansion, intensified livestock production, wide-scale biodiversity loss and global climate change [2,5–7] will continue to drive VBP (re)-emergence through (1) the introduction of exotic pathogens to new regions and/or (2) endemic pathogens that have increased in incidence or started to infect humans for the first time [8]. For these reasons, emerging VBPs represent complicated health problems linking humans and animals (wild and domestic) within their shared ecosystems.

Amongst the list of emerging VBPs, those transmitted by hard ticks (family: Ixodidae, subsequently referred to as "ticks") represent 40% of documented emerging VBDs [3]. Indeed, ticks harbour and transmit the highest diversity of pathogens amongst blood-sucking arthropod vectors and are the most important disease-causing vectors for human and animal health worldwide [9–12]. Additionally tick-borne diseases (TBDs) represent some of the world's most rapidly expanding VBDs, most notably in Europe where ticks are considered the principal vector of zoonoses affecting public health [13]. Due to a combination of climatic, ecological and anthropogenic factors, the geographic ranges of many tick species are growing in latitude and altitude throughout temperate regions in Europe, while the overall abundance of ticks in the environment in also rising [14,15]. As ectoparasitic pathogen vectors, ticks are the source of particularly complex health problems that arise at the human-animal-environment interface as TBD zoonotic cycles involve a diversity of wild and domestic animals, as well as humans [16]. TBD (re) emergence is therefore contingent on complex vector-pathogen-host dynamics, which are in turn determined by the surrounding social and biophysical (i.e., social and ecological) conditions that allow for successful pathogen transmission and subsequent disease [17]. In the face of globalization, it is widely accepted that the interconnectedness of socio-economic and ecological risk factors will continue to act as drivers for disease emergence at the human-animal-environment interface [2,8] by altering the biophysical environment in which vector-pathogen-host dynamics take place and increasing interaction opportunities between humans, non-human animals, vectors and pathogens [14,15,18]. However, due to knowledge, technology and institutional coordination gaps in TBD epidemiology, in addition to the absence of effective, accepted and environment-friendly tick and tick-borne pathogen (TBP) control measures, it is argued that tick bite prevention at the individual and local level is the most effective strategy to combat illness in both humans and animals [19–21].

2. Tick-borne diseases: A one health problem

As obligate hematophagous ectoparasites, ticks rely on blood meals lasting hours long from a diversity of wild mammals, birds and reptiles to metamorphose (i.e., larva, nymph, adult) and complete their life cycle [16]. In nature, the TBPs that affect human and domestic animals commonly circulate between wildlife and ticks in a state of equilibrium, maintaining pathogen populations by acting as reservoir and amplifier species [12]. While humans and domestic animals have become integrated in the tick's life cycle, they are considered "accidental hosts" that only become parasitized when entering into tick habitats [16] or moving tick-infested animals into previously tick-free environments [12].

Ticks were first illustrated as disease vectors for livestock in the late 19th century [22,23] and continue to be a major preoccupation concerning livestock health, notably in developing countries, due to the direct (e.g., skin lesions) and indirect (e.g., TBDs) burden of tick bites on animal morbidity and mortality, as well as subsequent economic loss due to compromised livestock production [12,24]. TBDs also have negative consequences on companion animal health (e.g. dogs and horses) and economic ramifications on the equestrian industry regarding importation regulations [12,25]. This inherent association between domestic animals and ticks is reflected in the vernacular names of many common tick species, such as "the sheep tick" for *Ixodes ricinus*, "the dog tick" or "the cow tick" for *Dermacentor reticulatus*, and "the dog tick" for *Rhipicephalus sanguineus*.

The negative consequences of tick bites and TBPs for human have relatively recently incited public health concern, dating back to the identification of the bacteria *Borrelia* spp. in the late 19th century as the pathogenic agent of Lyme borreliosis, the multisystem inflammatory infection associated with a recent tick bite [26,27]. Since its discovery, Lyme borreliosis has become the most common TBD affecting public health in temperate zones of the northern hemisphere [14,27], Tick-borne Encephalitis (TBE) is considered Europe's most important neuro-invasive TBD [16,28] and the highly fatal Crimean-Congo haemorrhagic fever (CCHF) is at serious risk of increasing its geographic distribution into new areas throughout Europe [29–32]. Additionally, some TBDs in humans can be contracted in absence of a recent tick bite. This is the case for TBE where virus transmission can occur through contaminated raw milk product consumption [28] and CCHF through contact with virus infected body fluids of CCHF patients or animals [33]. Many tick-borne diseases are therefore considered important for public health, veterinary health and commercial agriculture reasons [16,23,27,34,35], requiring integrated, systemic and holistic approaches that consider various transmission routes in shared ecosystems where humans, domestic animal, wildlife and ticks meet [36,37].

Integrative approaches to health that recognize the interdependence of human, animal and ecosystem health became an important paradigm at the turn of 21st century to tackle complex health problems occurring at the human-wildlife-environment interface, such as increasingly urgent emerging infectious disease incidence [2,38,39]. Amongst the numerous proposed integrative health concepts, One Health remains the most studied and institutionally implemented as an appropriate paradigm to guide zoonoses and infectious disease research, surveillance and control [39] as it recognizes the interconnectedness of the health of humans, animals and the ecosystems in which they live and calls for interdisciplinary, cross-sectoral and multi-level collaboration to address health challenges [40]. The significant increase of TBDs in the most recent decades has incited demand for more efficient prevention and control strategies [41]. Multiple studies argue that a One Health approach for TBD risk can (1) provide a promising bridge between the often divided human and veterinary medicine sectors (i.e., multi-sectoral), (2) assess all possible components of localized epidemiological chains of TBDs (i.e., interdisciplinary) and (3) foster integrated TBD surveillance, communication and control systems that can improve improve diagnosis, treatment and prevention measures at local, regional and national levels (i.e., multi-level) [24,35,42,43].

3. Gaps in knowledge, technology and institutional coordination for tick-borne diseases

In Europe, TBD cases, such as Lyme borreliosis and TBE are increasingly identified despite many advancements in TBP and TBD prevention, surveillance and clinical knowledge, largely due to a combination of global climatic, ecological, landscape and anthropogenic drivers [17,18,44,45] impacting tick population expansion into new geographic regions, increasing tick presence in endemic areas (i.e., abundance and density) and multiplying human-tick contact opportunities [3,14,15,46]. In addition to the macro-scale social, environmental and ecological drivers impacting TBD emergence, tick host-seeking activity and life cycle are highly seasonal and microclimate-dependent; consequently, habitat-specific biotic, abiotic and human behavioral factors can impact complex vector-pathogen-host dynamics at the local-scale, in turn affecting pathogen transmission and subsequent disease [3,17,47–49]. This spatiotemporal heterogeneity of TBD risk adds additional complexity to tick bite prevention and TBP control programs [12,16,43] and emphasizes the importance of surveillance efforts adapted to localized social and ecological contexts.

In Europe disease incidence is heterogeneous across and within countries (i.e., infranational, national and subnational scales) [45,50]. According to a systematic review of Lyme borreliosis incidence in Europe, Burn et al. [50] found that Belgium, Finland, the Netherlands, and Switzerland had the highest incidence of reported cases at the national level, while France and Germany showed markedly higher incidences at the subnational level in comparison to their respective low national level incidence. Regarding TBE incidence in Europe, Van Heuverswyn et al. [45] showed that inherent differences of TBE surveillance system between European countries (e.g., TBE case definition, case reporting policies) and incomplete epidemiological information in some countries (e.g., NUTS administrative level) may under-represent the actual number of TBE infections throughout Europe, whereas differing public health policies (e.g. diagnostic methods, TBE vaccination access) may also influence the spatiotemporal heterogeneity of TBD case trends. These findings indicate that overall TBD incidence estimates may not accurately reflect disease burden throughout the continent, while national level reporting may not accurately reflect local-level disease risk [45,50,51].

In regions where ticks may pose a serious threat to animal health and livestock production, local application of acaricides is a commonly used tick bite prevention tool to limit host-seeking ticks on animals and humans [52,53]. However acaricide use remains a small-scale, short-term solution and is not considered feasible or acceptable for large-scale use due to the potential adverse consequences for human, animal and environmental health [53–55], increasing acaricide resistance emergence in ticks and the economic burden of repetitive application [12,52,56]. It is therefore generally accepted that large-scale tick eradication is unrealistic, largely due to the complexity of tick ecology dynamics [12].

Despite improvements in tick bite prevention and TBD surveillance activities, Eisen and Stafford [19] argue that there remains a lack of extensive epidemiological data within diverse social and ecological contexts, and therefore significant gaps in our understanding of the complex, systemic nature of tick bite and TBD risk. An example are the recent insights surrounding public health implications of TBP co-infections (i.e., multiple pathogen infection in a vertebrate host following tick bite(s)) [57], for which the absence of data and poor understanding of the clinical consequences and the populations at risk further complicate disease diagnosis and clinical management [58]. As societies are increasingly confronted with the social, environmental and ecological complexity of TBDs, Eisen & Stafford [49] conclude that prevention and management will be the responsibility of individuals at small-scale and local levels until effective public health tick management programs are being developed.

Alternative TBD surveillance and prevention approaches that integrate non-institutional and local community actors, while considering diverse social and ecological contexts at risk are therefore necessary for early disease detection and to guide appropriate prevention and management measures. Epidemic intelligence, which merges traditional, indicator-based disease reporting with unstructured, event-based data (e.g., social and expert networks, online media), offers an effective baseline framework for anticipatory detection, assessment and monitoring of disease threats at different geographic scales and to enhance surveillance systems in the context of intensifying globalization [59]. With regard to TBDs, epidemic intelligence informed by integrative health paradigms can provide an innovative framework to identify relevant social and ecological indicators of tick bite and TBD risk for local communities. The combination of these health frameworks can encourage informed decision-making regarding TBD risk surveillance policies by fostering: (1) collaborations between a diverse network of stakeholders from various geographic levels (i.e., departmental, regional, national), including, but not limited to, scientific, medical, political, and educational actors, as well as the general public and, importantly (2) knowledge sharing and knowledge building for collective action [20,60,61].

4. Tick-borne diseases: Toward transdisciplinary social-ecological systems approaches

The One Health concept has been proposed as an effective approach to assess various aspects of the TBD epidemiological chain [24] and better manage TBDs through increased communication between physicians, veterinarians and interdisciplinary research actors [42,43]. However, after more than a decade since the One Health concept was established and is now widely accepted, it remains criticized for its overall ability to be operationalized. Regarding VBDs (and by extension, TBDs) sectoral and disciplinary barriers continue to inhibit joint medical and veterinary surveillance, communication and control networks, as well as interdisciplinary data sharing and production. Destoumieux-Garzón et al. [62] argue that the medical and veterinary sectors are not only divided between themselves, but also disconnected from ecology and evolutionary and environmental sciences; yet when the ecosystem interface is integrated in holistic health reflections, the biotic and abiotic components are simply regarded as the scene of transmission without understanding the underlying processes for disease. Likewise, the behavioral and political drivers of disease (re)-emergence are often minimized due to the lack, or insufficient integration, of social sciences [60,63].

Additionally, One Health frameworks often omit “non-traditional” (i.e., non-academic, non-medical, non-political) actors [39] who are not only confronted by the problem (e.g., TBDs) on the ground (i.e., locally), but may also play integral roles in identifying relevant risk indicators, as well as determining and implementing solutions adapted to the social and ecological context in which they live [20,60,64,65]. According to Aguirre et al. [66], a lack of coordinated efforts amongst research, health institutions, governments and society has led to a failure to address the linked societal and biophysical drivers of TBDs within their specific social-ecological context. It is therefore argued that collaborations beyond specialists are needed to simultaneously ensure the health of people, animals, plants and entire ecosystems. This can be achieved through (1) transdisciplinarity, (2) social-ecological systems (SESs) approaches and (3) participatory processes to improve surveillance, management and control of complex VBDs [20,65], such as Lyme borreliosis [66].

TBD risk exist within complex social-ecological systems, in which the dynamic, interconnected and nested social and environmental dimensions reveal high degrees of uncertainty [67,68] and for which management strategies can be improved through the willingness amongst local actors to cooperate toward a common goal (i.e., collective action, according to Ostrom [69]). Transdisciplinarity allows for a better understanding of the social and environmental dimensions which inform TBD risk as it goes beyond scientific disciplinary and sectoral boundaries, requiring knowledge sharing and knowledge building between academic experts, practitioners, politicians, business professionals and the general public, amongst other stakeholders affected by or interested in a problem [20,60,61,65,66]. Transdisciplinary social-ecological systems approaches therefore include a diverse group of stakeholders who are considered active participants, or “actors”, working cooperatively toward a co-defined common and shared objective within a social-ecological system. Aided by participatory tools [70,71], local actor integration can be optimized in the knowledge sharing, knowledge building and decision-making process to collectively identify relevant social groups, their interests and incentives [60], as well as facilitate mutual understanding and operationalize collaborations [61].

5. Tick-borne disease risk in Europe

TBDs in Europe represent a growing problem, despite prevention, diagnosis and treatment advancements [44,45] requiring novel surveillance, management and control strategies. Throughout temperate regions of Europe, *Ixodes* spp. and in particular *Ixodes ricinus*, are considered the most prevalent, widespread and burdensome tick species, as the vector of many pathogens for both humans and animals [14,16,27]. TBDs of major health concern transmitted by include Lyme borreliosis, the most common TBD in Europe [72] and TBE. Similar to the disease vector [14,15], Lyme borreliosis and TBE cases continue to increase in distribution (i.e., latitudinal and altitudinal expansion) and incidence in many European countries [18,44,45,51,73]. In addition, *I. ricinus* is responsible for transmitting an array of bacteria (e.g., *Anaplasma phagocytophilum, Rickettsia* spp.) and parasites (e.g., *Babesia* spp.) that can simultaneously provoke serious illness in domestic animals (i.e., cattle, dogs) and humans [16,23,27,34,41].

Along with *Ixodes* spp., the European Centre of Disease Control (ECDC) consider *Hyalomma* (species: *Hyalomma marginatum* and *Hyalomma lusitanicum*), *Dermacentor* (species: *Dermacentor reticulatus)* and *Rhipicephalus* (species: *Rhipicephalus sanguineus*) as important tick genera for human and animal health across the continent [27], for which European-level surveillance of tick populations has been conducted since 2014 [74]. *Dermacentor* and *Rhipicephalus* ticks are known vectors for (re)-emerging tick-borne rickettsiosis diseases (bacteria *Rickettsia* spp.) in humans and domestic animals [16,27,75], as well as parasitic diseases (e.g., *Babesia* spp., *Theileria* spp.) affecting equine and livestock health [41,76]. *Hyalomma* spp., is a thermophilic species that is of particular interest to European public health institutions due to its role as the main vector of the CCHF-virus, causing serious illness and high mortality in humans [77], as well as *Theileria* spp., important for equine and livestock health [41,76]. *Hyalomma* spp. therefore pose serious risk for TBD emergence in humans and animals in naïve regions of Europe. Historically present throughout North Africa, Asia, the Middle East and South-east Europe, *Hyalomma* spp. has recently spread to the previously uncolonized regions of the Mediterranean, including southern France, due to warming climates and likely through migratory birds [29,31,78].

5.1. Tick-borne diseases within the French context

Throughout France, TBDs pose serious risks for both human and animal health due to the diversity of tick species that are prevalent and widely distributed in urban, suburban and natural ecosystems and the diversity of pathogens they can transmit to both humans and animals [16]. Lyme borreliosis is considered endemic and present in all regions of the country, whereas both reoccurring and novel hot spots of TBE outbreaks are becoming increasingly frequent in the north-eastern regions [16,45,79,80]. Mediterranean spotted fever, tularaemia, human granulocytic anaplasmosis and babesiosis cases are also reported throughout the country, but are considered relatively rare [79]. However, due to a lack of coordinated and institutionalized surveillance and control measures, the true burden of TBDs within the country may be significantly underestimated (Unpublished Master's thesis, 2020).

TBP emergence is also a growing concern in France, notably with respect to the recent establishment of *Hyalomma marginatum* in the southern Mediterranean regions and its potential to continue expanding its geographic distribution northward in response to changing climate conditions and continued introduction through migratory birds [29,31]. Although present in the French island of Corsica for many decades, its establishment in southern continental France is worrisome for both public and animal health due to its role in CCHFv transmission to humans, as well as the causal agents of Theileriosis, a serious and poorly understood parasitic disease in horses and cattle [25,30,81]. While no human cases of CCHF have been observed in France, serious case diagnoses have been reported in bordering Spain [82] putting French health officials on high alert [81].

The lack of understanding regarding the complexity of tick ecology and TBD epidemiology for TBDs have sparked debates and disagreement amongst the scientific and medical community and uncertainty amongst politicians and the general public in France due to a general absence of knowledge, accurate TBD diagnostics, and differing treatment approaches compared to surrounding European countries [83]. Due to growing frustration amongst the population, the French government collaborated with various public health agencies, TBD patient associations and professionals confronted with TBD risk to introduce a national action plan against Lyme borreliosis and other tick-borne diseases, with the primary goal of raising awareness for tick bite prevention measures amongst the general public and advancing research [84]. Since the inauguration of the national plan in 2016, various surveillance and research activities have been developed to identify emerging TBD threats (e.g., *H. marginatum* expert working group), assess disease incidence amongst the general public (e.g., *Sentinelles* network of public health professionals for Lyme borreliosis) and survey tick vectors and tick bite risk through participatory citizen science (e.g., CiTIQUE project). However, the surveillance and research activities remain poorly coordinated with regional and departmental health actors, relying on top-down communication, organization and implementation that is not always standardized across regions, nor adapted to local social and ecological contexts (Unpublished Master's thesis, 2020).

6. From theory to action: Implementation of a transdisciplinary social-ecological systems framework for tick-borne diseases

Inspired by De Garine-Wichatitsky et al. [20] operational framework regarding actor engagement in diverse health problems within social-ecological systems, we argue that a transdisciplinary social-ecological systems approach is necessary to improve TBD risk detection, prevention and management. This framework facilitates local actor participation in a multi-actor network to identify social-ecologically relevant TBD risk indicators, co-construct a shared representation of tick bite and TBD issues and promote individual and collective action decision-making, all within and adapted to the local social-ecological system in question. Here, we propose an operational and iterative methodological framework to implement a transdisciplinary social-ecological systems approach using social science data collection and analysis methods and participatory tools to identify the social and ecological aspects of TBD risk, inventory the local actor's needs, priorities and perceptions and create an environment for exchange to foster collective action (Fig. 1).

6.1. Diagnostic phase: The social-ecological system

This process begins by diagnosing the social-ecological context within which a participatory intervention for TBD risk is relevant. Because social-ecological systems are composed of linked social and ecological subsystems [67,85,86], delineating a biophysical zone in which the social-ecological system exists is an important first step as it provides the spatiotemporal and social context in which TBD risk occurs and will inform the following steps. According to Ostrom's social-ecological system framework [67], system boundaries defined by environmental conditions are a key variable for effective and successful management. Barreteau et al. [87] argue, however, that a "*territoire*" (in French) is more than just its environmental aspects and extends to its economic, ecological, ideological and political dimensions. To consider these societal aspects, Delgado-Serrano and Ramos [88] suggest specifying both the natural and anthropogenic boundaries of the system in question.

As this the diagnostic phase is also the phase in which the problem's context is being explored, the preliminary delineation of the biophysical zone can first be based on anthropogenic aspects, such as administrative zoning (i.e., region, department, commune) and validated through secondary sources (e.g., previous research projects, multi-actor projects) and participatory tools and methods, (e.g., expert consultations). The combination of these two approaches will verify that the zone responds to the study criteria, including environmental, ecological and socio-demographic characteristics that make TBD risk relevant to the local zone identified, as well as verify important logistical considerations including access and actor participation likelihood. As the process is iterative, the boundaries of the social-ecological system can continue to be refined by the local actors throughout the process during the

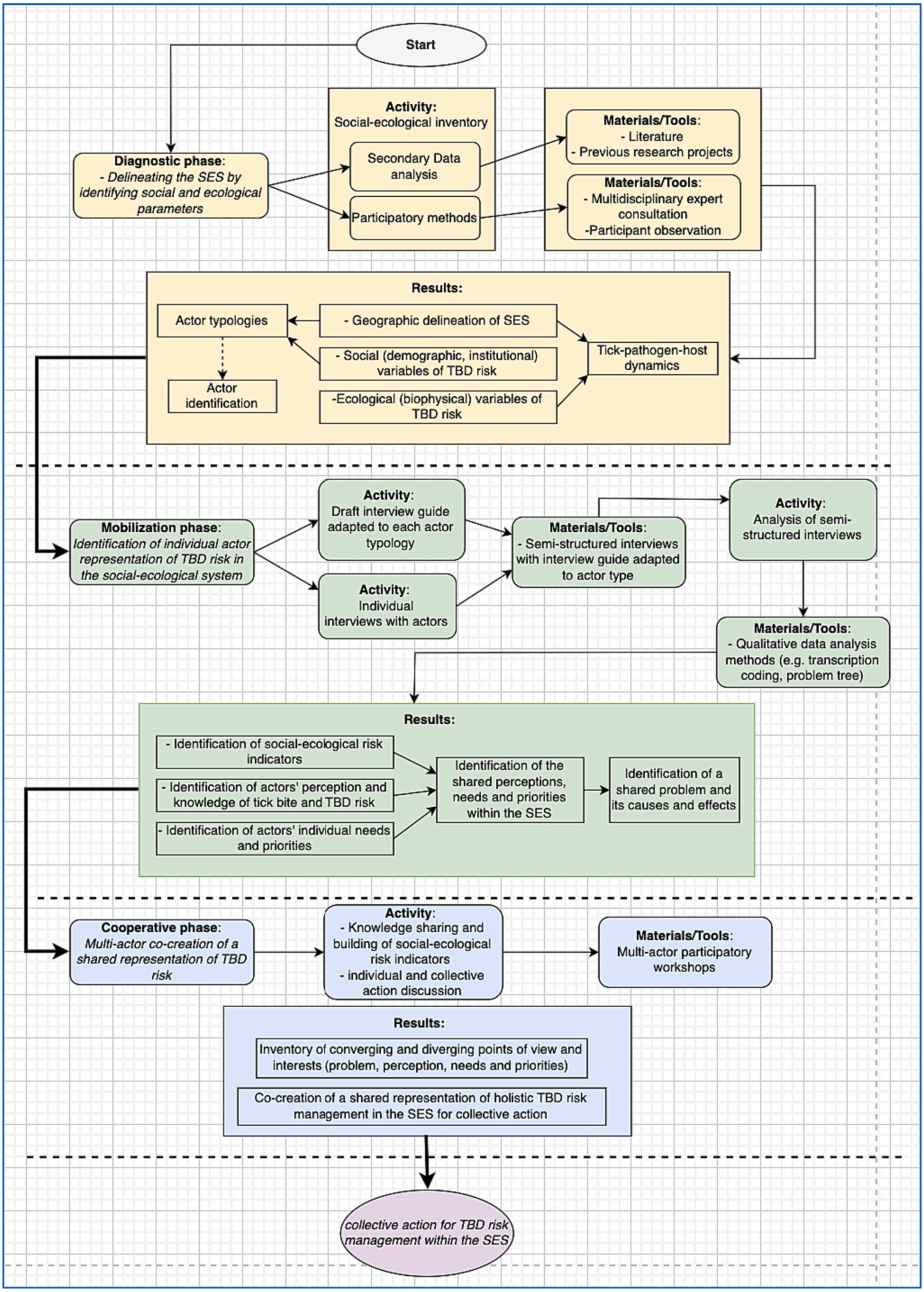

Fig. 1. Transdisciplinary social-ecological systems methodological framework.

interview and cooperation phase.

Once the biophysical limits of the social-ecological system have been delineated (e.g., an administrative unit, a geographic zone, a protected area), it is necessary to contextualize the TBD risk within its social (i.e., cultural, institutional, political) and ecological dimensions through the use of participatory tools and methods, including expert consultations (e.g., multi-actor TBD working groups, research labs), participant observation (e.g., actors in the field), intermediary objects (e.g., serious role-playing game) and participatory modelling (e.g., actor interaction diagrams). The elements to be identified are through these methods are: (1) actors and stakeholders: individuals, organizations or institutions that are directly or indirectly affected by tick bite and TBD risk, and who may positively or negatively contribute to prevention and management efforts and (2) environmental factors that may influence the enzootic and zoonotic cycle of TBDs. Through participatory approaches (mentioned above), actor typologies are created through interdisciplinary collaboration with tick and TBD experts having in-field knowledge relating to how each actor is confronted with TBD risk, as well as the nature of their current (or possible) implication in TBD risk detection, prevention and management. Actor typologies can be supplemented with social science data collection methods, such as participant observation and interview data which provides first-hand understanding of how each actor type is confronted with and manages TBD risk, and allows the identification of new actors previously overlooked. Individual actors can be further identified as the process continues by the actors themselves using semi-structured interviews in the mobilization phase.

Using the combination of these participatory tools and methods, the social-ecological system diagnosis results in the identification of specific individuals who are representative of their respective actor typology. These individuals will be mobilized to participate in the cooperative phase, where the objective is to collectively confront diverse viewpoints, define shared objectives and discuss new ideas necessary for subsequent co-construction of a shared representation of the TBD problem and collaborative decision-making [70].

6.2. Mobilization phase: Actor participation

To properly guide the cooperative phase, we must first understand the diversity of the actors' needs, priorities and perceptions regarding TBD risk (both within the actors' shared SES, as well as in a global sense) so that participatory interventions are adapted to the social-ecological context and meet local actor expectations [70]. The actors identified in the previous diagnostic phase are contacted to participate in individual semi-structured interviews to discuss their perception of TBD risk and how collective reflection and action with different actors within their region can improve risk management. Semi-structured interviews, accompanied by an interview guide (produced based on the data collected during the first phase and adapted to each actor typology), offer an effective open framework that allow the actor to expresses their vision and interests concerning TBD risk freely, while providing information that may not be accessible in a more structured context, such as a questionnaire. Qualitative analysis methods, including thematic analysis of interview transcripts and problem tree analysis of actors' responses, can then be used to analyze each actor's needs, priorities and perceptions. This information is important to enhance the social-ecological system diagnosis and identify converging and diverging viewpoints and interests to be addressed collectively in the cooperative phase.

6.3. Cooperative phase: Participatory workshops

The conclusions that emerge from the mobilization phase analysis can then be translated into participatory tools and methods used to organize and guide knowledge building and knowledge sharing during participatory multi-actor workshops. To provide the proper environment for collective discussion, it is suggested that least one person from each actor typology who was previously interviewed is present. This allows collective discussion of the converging and diverging perspectives and interests, as the objective is to work toward a shared understanding of TBD risk, to identify social-ecologically relevant risk indicators and determine desired TBD risk detection, prevention and management strategies, co-decided by the actors. It is an iterative and adaptive process [70] in which the social and ecological elements of TBD risk are continually defined with each participatory intervention and new social-ecological indicators of TBD risk can be identified. Each participant's contribution therefore helps redefine and re-contextualize TBD risk within the social-ecological system. These participatory workshops aim to assure that each actor gains an awareness of the individual and collective actions possible to better manage TBD risk within their shared social-ecological system. The workshops therefore serve as an incubator for co-decision-making amongst diverse local actors and collective action development.

While it is not expected that collective discussion regarding TBD risk should provoke conflict between actors, as one could associate with common pool resource management [68,69], diverging perspectives and interests surrounding relative risk importance and methods of reducing such risk within its One Health dimensions require a comfortable environment for expression and exchange so that diverging perspectives and interests can be documented and convergences can become starting points for future collective action. However, power dynamics regarding status and gender may explicitly and implicitly impact the participatory process and should be considered. An objective of this framework is the bring together a diverse group of actors composed of community members and organizational or institutional representatives that are directly or indirectly affected by tick bite and TBD risk, and who may positively or negatively contribute to prevention and management efforts (e.g., academia, administration, public and animal health, agriculture, education, social organizations). A neutral moderator equipped with appropriate participatory tools and methods is required to guide the participants through discussion, ensure that all participants are able to contribute to the knowledge building and knowledge sharing process [70] and encourage awareness of other actors' perspectives, interests, practices, needs and overall risk perception. It is also recommended that the moderator is aware of these potential dynamics and equipped with tools to limit asymmetrical group dynamics and ensure balance between the participants (e.g., minimum of one actor from each typology present, limit the number of administrative and/or academic representatives). When these considerations are integrated into the process, actors can effectively work toward a shared vision of TBD risk and a sense of responsibility can emerge toward collective action to better detect, prevent and manage TBD risk at the local level.

7. Perspectives for a transdisciplinary social-ecological systems framework in practice: The social-ecological stakes of tick-borne diseases in the Occitanie region

The Occitanie region in southern France is an appropriate case study for exploring TBD risk within a social-ecological context, as it is richly diverse in landscapes and contrasted climates. It is home to multiple regional and national parks, vast mountainous ranges and Mediterranean beaches making Occitanie a highly visited region for travel and recreation. However, TBD risk could be considered a deterrent for future visitors. As France's top producing region for ovine agriculture, Occitanie is equally an important region in terms of agricultural production, producing around 70% of the country's milk supply and holding a protected geographical certification for the famous Roquefort cheese. As TBDs affect all livestock species important for the agriculture economy, tick bite prevention, as well as early detection, management and control measures are important to avoid severe economic and health consequences. However, as the top region in terms of organic farming, Occitanie also has high stakes regarding widespread acaricide usage as a preventive control mechanism for tick bites and TBDs. Therefore, significant socio-economic stakes must be taken into consideration when reflecting on tick bite and TBD prevention, management and control strategies relevant and adapted to the region.

All five important tick species in terms of public and animal health in France [16] can be found within the region: *Ixodes ricinus, Hyalomma marginatum, Dermacentor* spp. (*D. reticulatus* and *D. marginatus*) and *Rhipicephalus sanguineus*. Amongst these species, *I. ricinus,* the most prevalent tick species in France and *H. marginatum*, a newly established species in continental France (the Mediterranean basin), pose the most serious health risk to humans and animals within the region. The contrasted ecologies of these two species translate to very little geographic distribution overlap: *I. ricinus*'s distribution depends on temperate climates, high moisture and high vegetation presence [16,89], while *H. marginatum* does not seem to extend beyond open, dry habitats within Mediterranean-basin [90] and is expected in areas with year-long warm temperatures and low precipitation [29]. These contrasting ecological characteristics can be seen in the Hérault department where the gradual change in the ecological and environmental characteristics along the north-south and east-west gradient (i.e., from a hot, humid, Mediterranean climate toward a cool, humid, temperate climate), translate to a complementary trend of tick species present within this department. This is anecdotally explained as: *I. ricinus* along the north-western gradient and *H. marginatum* along the south-east gradient (Unpublished Climatick Projet Report, 2021 https://hal.inrae.fr/hal-02789712v1). For these reasons, health risks associated with tick bites are heterogenous throughout the region depending on the tick species present.

Due to the socio-economic stakes regarding current and potentially emerging TBD risk within the Occitanie region, an interdisciplinary research team, consisting of tick specialists, microbiologists, epidemiologists, agronomists and social scientists, has been working in collaboration with local actors in the region (e.g., farmers, livestock breeders, veterinarians and environmental education associations) to gain a better understanding of tick ecology, TBP presence and the overall state of complex TBD risks for humans and animals within the region.

8. Conclusions

This paper argues for the added value of a transdisciplinary social-ecological system approach for local-level TBD risk detection, prevention and management by providing a methodological framework that goes beyond interdisciplinary collaboration for the purpose of research and mobilizes local actor participants to better understand the social and ecological dimensions of TBD risk and explore the necessary conditions for collective action to improve TBD detection, prevention and management. A subsequent paper will model this framework in practice using local level TBD risk in the Hérault department of the Occitanie region as a case study to discuss the outcomes, lessons learned and how to articulate local TBD risk collective action with varying levels of society to foster holistic, interdisciplinary, multisector and multi-level strategies against health threats.

Declaration of Competing Interest

None.

Data availability

No data was used for the research described in the article.

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