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SHORT COMMUNICATION

# A questionnaire survey for the assessment of wild–domestic pig interactions in a context oedema disease outbreaks among wild boars (*Sus scrofa*) in South-Eastern France

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## Abstract

Pig outdoor farming is gaining popularity and commercial success in the European Union, and its expansion, together with an increasing wild boar population, facilitates interactions between domestic and wild suids. In the Southern French Department of Ardèche, several episodes of mass mortalities due to infection with an enteropathogenic strain of *Escherichia coli* causing oedema disease (OD) were reported in wild boar populations between 2013 and 2016. In order to investigate a potential link between those events and the frequency of interactions between wild boar and domestic pig, we analyzed regional vegetation and hunting bag data and implemented a semi-structured questionnaire survey among a total of 30 outdoor pig farmers and 30 hunters distributed inside and outside the identified area of OD emergence. One third of interviewed farmers (11/30) had experienced intrusions of wild boars in domestic pig premises during the previous year. Similarly, 23% of interviewed hunters reported interactions between wild boar and feral free-ranging pigs in recent years, and 60% reported the observation of free-ranging pigs with a phenotypic feature of Vietnamese pot-bellied pigs (55%). Our analysis identified that in the OD emergence area, several factors could facilitate the transmission of pathogens between wild and domestic suids including a predominance of forested vegetation, a higher estimated wild boar density, weaker levels of farm biosecurity, a higher level of reported wild boar intrusions in pig farms and several reports of feral pot-bellied pig presence. Although our sample was limited, our study suggested a widespread occurrence of situations facilitating the transmission of pathogens between wild and domestic suids. Similar studies in other rural regions in the European Union are recommended, in order to promote preparedness for the emergence and circulation of shared swine pathogens.

KEYWORDS
disease transmission, interactions, pig production, *Sus scrofa*, wild boar

## 1 | INTRODUCTION

Wild boar (*Sus scrofa*) populations have been growing in high numbers for several decades both in Europe and other countries in the northern hemisphere generating serious ecological, economic and sanitary costs (Massei et al., 2015). At the same time, the number of outdoor pig farms is increasing because of consumers' demand for higher quality products originating from animal friendly production practices (Åkerfeldt, Gunnarsson, Bernes, & Blanco-Penedo, 2021). These two parallel developments facilitate an increasing occurrence of interactions between domestic pig (DP) and wild boar (WB) populations, which can have several sanitary and environmental consequences. Belonging to the same species, WB and DP can share a large diversity of pathogens through a diversity of pathways (Jori, Payne, Stahl, Nava, & Rossi, 2018). In Southern France, several fatal outbreaks have been reported in WB, caused by a strain enterotoxemic *Escherichia coli* (serotype O139K82), with virulence markers and symptoms characteristic of oedema disease (OD) in DP (Decors et al., 2015; Petit et al., 2020). These emerging events in wild boar populations highlight the need to explore the factors associated with those outbreaks, including the potential importance of direct or indirect interactions between WB and DP.

Therefore, the goal of our study was (i) to report on the predominant pig farming patterns in the continental French region of Ardèche, (ii) to examine the potential importance of DP–WB interactions in this rural context and (iii) to explore the potential association with previous mortality outbreaks attributed to OD among the local wild boar populations.

## 2 | MATERIAL AND METHODS

### 2.1 | Study area

Ardèche is a territory of South-Eastern France (Figure 1a) covering an area of 5.500 km$^2$ with an altitude ranging between 140 and 1750 m asl and crossed by a large network of rivers and streams, a forest vegetation cover (52%) of exceptional diversity combining oak, acorn, chestnut, wild pine and red beech forests (see Figure 2). Its climate is predominantly Mediterranean (0–28°C) and annual rainfall ranges between 30 and 200 mm/month. The region is representative of a rural Southern French environment with a strong cultural heritage where traditions are preserved, including ancestral outdoor pig farming under fruit forest trees such as oak or chestnut and wild boar hunting. In addition, a large area of abandoned chestnut trees benefits pig farmers. Animals can therefore eat chestnuts throughout the fall season, at no cost to the farmer. Likewise, forest cover provides ideal conditions for the establishment of wild boar, which feeds in abundance on acorns, chestnuts and beechnuts (Baubet, Vassant, Brandt, & Maillard, 2008; Schley & Roper, 2003). Based on the detected cases of wild boar carcasses presenting lesions, clinical signs and bacteriological or genetic evidence of OD between 2013 and 2016 (Perrat et al., 2022), a polygon of 1981 km$^2$ was spatially identified and designed throughout the study, as OD area (Figures 1–3).

### 2.2 | Study design

A cross-sectional study was conducted from March to June 2018, among stakeholders located inside and outside the OD area. The sampling frame was based on databases of hunters and pig farmers provided by the regional authorities. In the case of hunters, a list containing 200 names of the leaders of the local hunting teams was provided by Regional Association of hunters from Ardèche. A total of 30 hunters were randomly drawn from a list of 200 names: 20 hunters from the OD area and 10 hunters from outside this area. As the participation to interviews was volunteer, if some people drawn refused the interview, the next names on the list were selected.

The selection of farmers was targeted towards those individuals practicing at least partial outdoor farming in a part of their facilities and therefore, potentially exposed to wild boar incursions (Figure 1). Based on this list of people, two farmers were aimed by municipality. The selection of the farmers was based on information obtained from other farmers on potential additional candidates, following a systematic snowball process until reaching a total number of 30 farmers for our survey. Each candidate was preliminarily contacted by phone to request his/her availability to participate in the survey. The 30 pig farms interviewed were distributed within the OD area ($n = 21$) and outside ($n = 9$) on a 'first available, first interviewed' basis (Figure 1c).

In addition, to assess environmental conditions facilitating potential interactions, vegetation type and wild boar abundance were assessed in the vicinity of pig farms (1 km radius) based on geographical information and vegetation cover data available and hunting information provided by departmental hunter's association (Supporting Information 1).

### 2.3 | Data collection

Data collection was based on semi-structured interviews conducted among hunters and pig farmers giving the opportunity to develop their answers but also to give their point of view (Relun et al., 2015). The questionnaires used during interviews consisted of 30 questions for hunters and 50 for pig farmers, and the time required to answer the various questions of the two questionnaires was estimated at 20 and 30 min, respectively. This questionnaire was previously tested with a hunter and a breeder to verify the understanding of the different questions and the response times. Before beginning the interview, the interviewer explained the aim of the study and emphasized that the information the hunters and the farmers provided would be processed anonymously. Both questionnaires are available as Supporting Information 1.

The questionnaire designed for farmers included a section on biosecurity measures to assess the types of fences used to protect pig farms

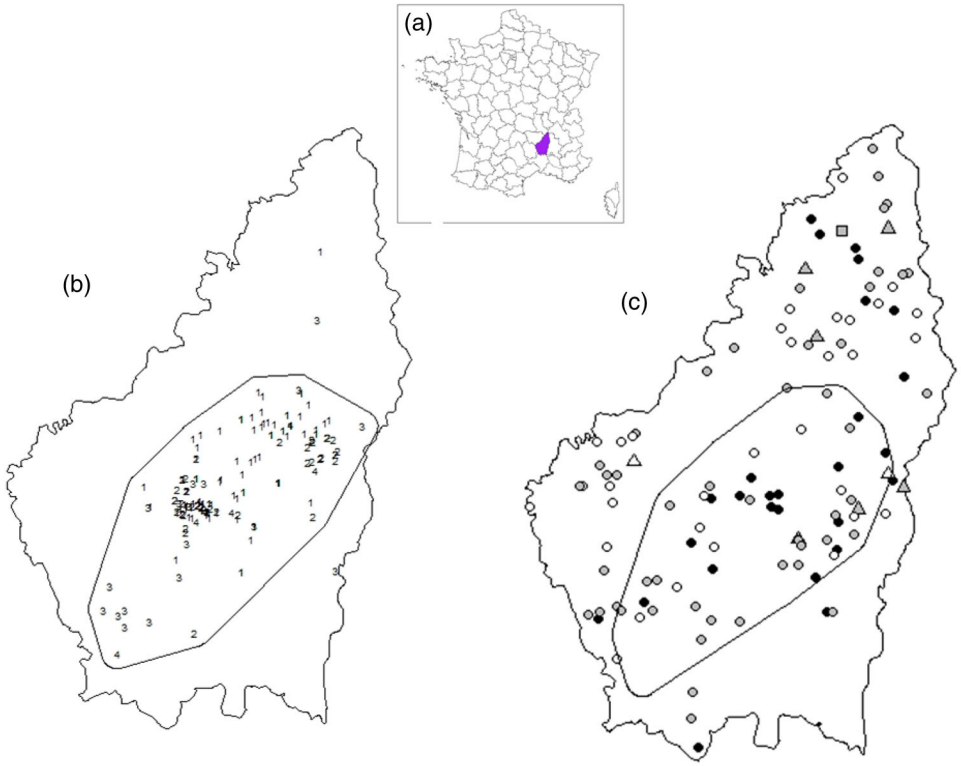


**FIGURE 1** Maps of the Ardèche Department showing (a) its location within the French territory. (b) The location of the wild boar oedema disease (OD) cases detected between 2013 (labelled 1) and 2016 (labelled 4). The envelope containing most of the detected cases is defined as the OD outbreak area. (c) The distribution of pig farmers in the territory. Black filled symbols stand for surveyed farms (which are all outdoor farms), close grey symbols for outdoor farms that were not surveyed, open symbols for indoor farms, circles for farms rearing pigs for consumption, triangles for pet pig farms and squares for wild boar farms. The envelope defines the OD outbreak area.

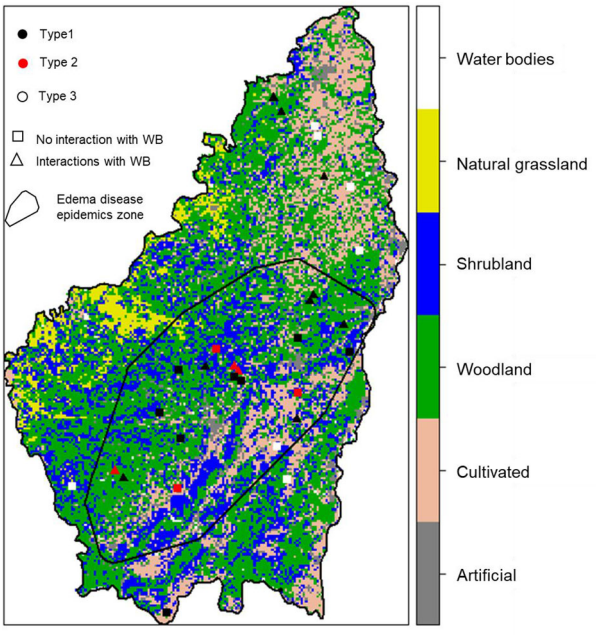


**FIGURE 2** Locations of surveyed farms characterized by their type in the multiple factor analysis/hierarchical cluster analysis (MFA/HCA) (colour) and reporting of interactions with wild boar (WB) (sign type) on a landcover background

from wild boar incursions. A wild boar incursion was defined as the fact of observing a wild boar in the farm or observing any evidence of potential visits (broken fence, tracks, birth of hybrids). An interaction was defined as the direct observation of WB or DP mating, fighting or foraging together within the farm. Reports of incursions and interactions were merged together into a single 'contact' variable for the analysis. Finally, observations of WB by the farmers around their farms were also recorded during the survey.

Farm biosecurity information recorded during the farmers' survey (number and type of fence and the electric wires) was integrated into a three-level variable reflecting protection against wild boar intrusions.

The hunter's questionnaire assessed the observation of contacts between both populations in hunting areas and the presence of DP or cross-bred individuals in hunting grounds during the last 10 years. For the farmer, a list of criteria suggesting potential hybridization features was provided including white spots in the fur, shape of the body, short snout, falling ears, thick fat layer and large litters. The questionnaire requested to qualitatively characterize the frequency of observation as 'low' if only one observation was reported, 'medium' if less than five observations were reported and 'high', if more than five observations were reported.

In addition to those systematic questionnaires, various interviews were carried out either opportunistically in face-to-face or by telephone interviews and in order to obtain certain additional information

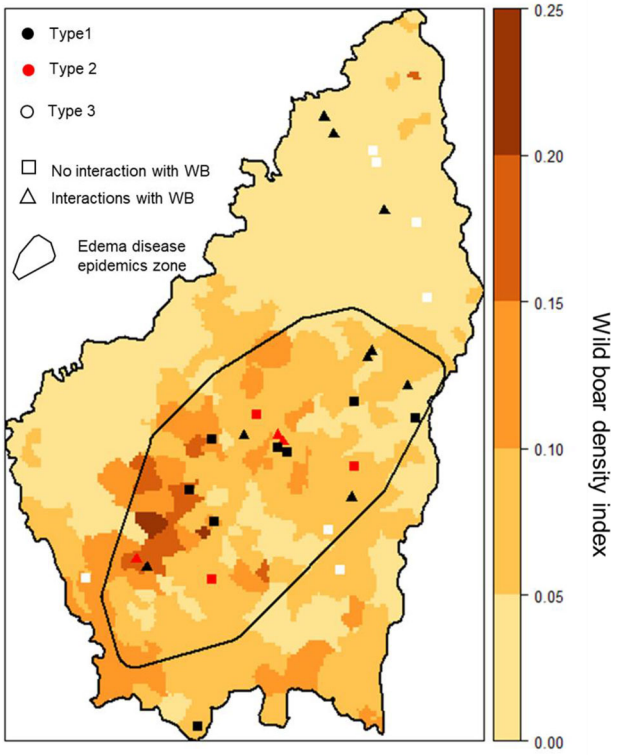


**FIGURE 3** Locations of surveyed farms characterized by their type in the multiple factor analysis/hierarchical cluster analysis (MFA/HCA) (colour) and reporting of interactions with wild boar (WB) (sign type) on a wild board density background

from animal health authorities, farmers associations or wildlife management authorities. The objective was double and consisted of (i) collecting additional information but also (ii) cross-cutting the preliminary results obtained by the hunters and farmers questionnaires.

### 2.4 | Statistical analysis

A descriptive analysis of farming practices, environmental context (i.e., landscape, wild boar density) and risk factors with regard to potential pathogen transmission characteristics and interactions with WB was first performed. For this analysis, outdoor surface, number of pigs in the farm and the wild boar density indexes were categorized using breaks in the distribution as cut-off points when no break was clearly visible. The farms were then classified in different groups using a multiple factor analysis (MFA) followed by a hierarchical cluster analysis (HCA). This approach allowed the identification of groups of farm types that have similar farming practices, environmental context, biosecurity levels and reported events of incursions or interactions with WB (see Supporting Information 2).

## 3 | RESULTS AND DISCUSSION

General information on predominant hunting and farming characteristics in the study area is available as Supporting Information 3. The results obtained during this study suggest that small scale outdoor farming initiatives are widespread in the Ardèche territory. A third of the interviewed farmers reported intrusions or attempts from WB to enter the farm, whereas 23% of them observed some evidence of direct interactions. Taking the previous year as a reference, 66% of the farmers had observed WB in proximity of the farm at a distance ranging between 1 and 200 m. Those included reports of sexual interactions (reported by 8/30 farmers), fights (3/30) and trophic interactions (2/30) between DP and WB. Five farmers (17%) reported experiencing hybrid litters as a result of sexual interactions between male WB and their respective sows. There was a certain seasonality in terms of proximity of WB to farms: incursions of WB in DP farm premises were mainly reported in autumn (29%) and there was a significant difference between interactions reported in that season, compared to other seasons ($p < .05$). This season coincides with the most active reproductive season of male WB in Europe, reported between November and January (Drimaj et al., 2019), during which they can be easily attracted by sows on heat in outdoor farming paddocks, as observed in a diversity of locations in the European Union (Jori et al., 2017; Malmsten, Jansson, Lundeheim, & Dalin, 2017; Wu et al., 2012).

The MFA/HCA approach allowed the identification of three types of DP farms, which are shown in Table 1. Type 1 ($n = 17$) includes farrow to finish farms with intermediate biosecurity measures against wild boar incursions located in woodlands (Figure 2) areas with high to medium wild boar densities (Figure 3). Half of these farms reported incursions or interactions with WB and most of them were located in the OD outbreak area. Type 2 ($n = 6$) included farms located in high wild boar density areas and characterized by weak biosecurity measures against wild boar intrusions. Half of them reported incursions or interactions with WB, and all of these farms were located in the OD outbreak area. Type 3 ($n = 7$) included farms highly protected against intrusions of WB and located in cultivated areas. None of these farms reported incursions or interactions with WB and most of them were located outside the OD outbreak area.

Most of the farms (Table 1) were significantly located inside the OD area and appeared significantly associated with a forested habitat ($p = .025$), a higher estimated density of wild boar ($p = .06$), a low-to-intermediate biosecurity index ($p = .0001$). Several risky farming practices were found to be more common in the OD area than in the rest of the department. These risky farming practices included abandonment of waste in the wild ($n = 4$), slurry spreading ($n = 4$) and presence of WB in the slurry spread area ($n = 3$). Similarly, a larger proportion of farms with low to intermediate levels of biosecurity (21/30) were located inside the OD area (Table 1, Figures 2 and 3). Those included total or partial absence of fence or farms were only partially protected with a single fence or partial electrification.

It is likely that reported figures of interaction through questionnaires are underestimated for several reasons. First, an important proportion of them occurs during night time and are difficult to be witnessed directly by farmers, but rather detected by the observation of damages in the fence or the observation of cross-bred offspring a few weeks later. Further studies using ecological tools (camera traps and/or telemetry devices with proximity loggers) could be useful to

**TABLE 1** Classification of the farms in farm types and *p*-value indicating significant association between the farm types and the categorical and quantitative variables defining the typology

| Typology of domestic pig farms | Type 1 | Type 2 | Type 3 | *p*-Value |
|---|---|---|---|---|
| Number of farms | 17 | 6 | 7 | |
| Dominant landscape type within a 1 km radius (cultivated/shrublands/woodlands) | 3/1/13 | 1/2/3 | 5/1/1 | .025 |
| Mean wild boar density index within a 10 km radius (low/medium/high) | 3/6/ 8 | 0/1/5 | 4/2/1 | .06 |
| Speciality (farrow to finish/finisher) | 15/2 | 2/4 | 3/4 | .03 |
| Protection against wild boar intrusions (low/intermediate/adequate) | 0/17/0 | 6/0/0 | 1/1/5 | <.0001 |
| Report of wild boar incursions in the farm or of observed interactions between DP and WB (no/yes) | 8/9 | 3/3 | 7/0 | .05 |
| OD epidemics zone (outside/inside) | 3/13 | 0/6 | 5/2 | .008 |

Abbreviations: DP, domestic pig; OD, oedema disease; WB, wild boar.

confirm and quantify more accurately wild boar incursions in farms from the study area (Kukielka et al., 2013; Triguero-Ocaña et al., 2021). In addition, a certain level of recall bias could have influenced some of the responses. In fact, hunters struggled more than farmers to place the observed events in time. In addition, a third of farmers (9/30) expressed some mistrust towards the questionnaire, despite insisting that responses would be anonymous. Indeed, a majority of farmers admitted having observed sexual or trophic interactions, mostly towards the end of the questionnaire, when a higher level of trust had been achieved. Certainly, the fear of sanctions from local authorities for not following legal requirements could have motivated underreporting the frequency of interactions in the farms. Indeed, local animal health authorities can control the farms and engage substantial sanctions if the infrastructure is not up to standard. In addition, since the sexual interactions reported were those leading to the birth of hybrids, a certain number of interactions not resulting in cross-bred offspring could have been underestimated.

Our study did not confirm a direct correlation between wild and domestic suid and the emergence of OD in WB. Nevertheless, the occurrence of factors facilitating interactions (insufficient biosecurity, improper management of carcass remains or slurry spreading) in the OD area was highly significant (Table 1). A recent molecular study on the samples collected from WB in the study area suggests that WB populations in the South of France are genetically predisposed to OD (Perrat, Branchu et al., 2022) and that the strain of *E. coli* causing mortality in WB, was previously undetected in domestic pigs, and has evolved for a long time in this WB population (Perrat, Petit et al., 2022). There was no genetic similarity between the isolated WB strain and any of the available *E. coli* strains isolated from DP farms in France. Nevertheless, it is important to stress that local DP strains from Ardèche were not available for a potential comparison. Based on this information and the results from this study, DP farms with low biosecurity levels in the study area are exposed to the risk of becoming infected with OD as a result of direct or indirect interactions with WB.

Although our farm sample was small, there was a predominance of infrastructures and practices allowing the incursion of WB into farms in the territory, including those areas with high estimated densities and favourable wild boar habitat. Indeed, an intermediate level of biosecurity appeared strongly correlated ($p < .05$) with the risk of WB incursion and trophic interactions. In that respect, it is important to underline that fences are expensive for farmers, and if the farming surface is important, their maintenance across the whole perimeter can represent a serious financial and technical constraint for the farmer. In the context of the African swine fever threat, it is likely that French outdoor pig farmers will be confronted with the obligation of increasing biosecurity measures, and mediation processes might be required to facilitate their local acceptance and implementation (Gisclard, Charrier, Trabucco, & Casabianca, 2021).

Regarding hunters, only one reported direct (trophic) interactions in the forest. Despite none of them observed direct agonistic interaction, six acknowledged that this kind of contacts could occur. Two hunters had heard or observed of wild boar incursions in some farms in the region and two had observed the presence of DP in hunting grounds. Eighteen hunters (60%) recalled observing the presence or hunting hybrid pigs, and two-thirds of these observations were dated between 2013 and 2016. The large majority of those reports (10/18) referred to animals with a phenotype compatible with pot-bellied pigs. The practice of keeping and breeding pot-bellied pigs, frequent in many EU countries, was identified in eight leisure states among the list of 230 registered farms. Complementary interviews with local authorities confirmed an escape incident with a farm of several specimens of pot-bellied pigs from the study area in 2015. Considering that sexual interactions reported by hunters had occurred in proximity of this farm, the possibility of crossbreeding between WB and feral pot-bellied pigs is a plausible scenario. In many EU countries, there are numerous reports of abandoned pot-bellied pig individuals. However, the purchase and ownership of pot-bellied pigs are rarely regulated by national administrations, despite there is evidence that abandoned pot-bellied pigs have the capacity to form feral sounders that remain in natural habitats in Southern Europe and interact with wild boar populations increasing the population of hybrids. This is becoming a common phenomenon in many countries where pot-bellied pigs are sold as pets and has been currently described in rural areas of Southern and Northern Spain (Delibes–Mateos & Delibes, 2013; Soler, Casas, Closa-Sebastià,

Sanz, & Martorell, 2021). Based on our results, this kind of interaction is worth reporting in this study, to raise awareness about this phenomenon and encourage French and EU authorities to monitor similar incidents and their impact among WB populations.

## 4 | CONCLUSIONS

This study allowed us to identify that practices and conditions facilitating interactions between WB and DP and the transmission of shared swine pathogens were common and widespread in our sample of farms from the Ardèche Department. This information can be used to target preparedness for the emergence and circulation of shared swine pathogens such as OD. Despite our sample was limited, many of those factors were more important in the OD emergence area than outside. Those included ecological aspects, but also anthropic factors related to pig farming such as a significantly higher presence of farms with leaky biosecurity measures that were confirmed by the presence of a higher number of reported incursions and episodes of interaction. Moreover, our study highlights the potential importance of abandoned pot-bellied pig pets which can allow the development of free-ranging feral pig populations and the development of a new and unsuspected wild–domestic suid interface, which deserves higher attention and further investigation about its potential epidemiological impact

### AUTHOR CONTRIBUTIONS

FJ conceived the presented idea, analyzed the raw data and wrote the manuscript. GP and FCh and FC designed the sampling approach. NC implemented the questionnaires in the field. VG and FJ analyzed the data. BC encouraged and AD supervised the findings of this work and corrected the manuscript. All authors discussed the results and contributed to the final manuscript.

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### CONFLICT OF INTEREST

The authors declare no conflict of interest.

### DATA AVAILABILITY STATEMENT

Due to privacy and ethical concerns, neither the data nor the source of the data can be made openly available. Further information about the data origin and analysis is provided as Supporting Information. In addition, conditions for access can be obtained by contacting the corresponding author.

### ETHICS STATEMENT

Ethics statement was not applicable since only questionnaires from humans have been gathered, and no sample collection experimental activities were necessary for this work in France.

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## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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