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Research article

Reports of abnormal animal behavior in relation to earthquakes in Colombia

Reportes sobre comportamiento animal anómalo con relación a sismos en Colombia

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ABSTRACT

Interactions among components of the Earth System are well exemplified by the behavior of animals around the time of earthquakes, and the abundant published data and long-standing oral tradition on animal reactions to seismicity have become hard to ignore, these are important facts that provide opportunities for cross-disciplinary research. A compilation of reports on abnormal animal behavior in relation to earthquakes in Colombia covering the period 1610-2019 was produced by a rigorous two-stage search of cases using online resources. The reports localities follow the spatial distribution of epicenters and the main tectonic features of the Colombian territory. Both, the first and second-stage searches revealed that, for 41 destructive earthquakes, there are 138 reports of animals reacting to seismicity, most of which fall into phylum Chordata, class Mammalia, order Carnivora, family Canidae, genus Canis, species *C. familiaris*. The first-stage search indicates that coseismic reactions of the species *C. familairis, B. taurus*, and *E. caballus* dominate over preseismic and postseismic manifestations, in contrast to results from the news media-based second-stage search, which indicates dominance of preseismic behavior. It is concluded that in this region animals have reacted persistently to earthquakes and that folklore and oral tradition deserve some degree of credibility in this phenomenon.

Keywords: Abnormal Animal Behavior, Historical earthquakes, anomalous reactions, coseismic, postseismic, preseismic, oral tradition

RESUMEN

Las interacciones entre los componentes del sistema Tierra son bien ejemplificadas por el comportamiento de los animales alrededor del tiempo de los sismos; y los abundantes datos publicados y la tradición oral acerca de reacciones animales a la sismicidad han llegado a ser difíciles de ignorar; estos son hechos importantes que ofrecen oportunidades de investigación transdisciplinar. Se ha producido una compilación de reportes sobre comportamiento animal anómalo en relación a sismos en Colombia cubriendo el período 1610-2019 por medio de dos etapas de búsqueda rigurosa de casos utilizando recursos en línea. Las localidades de los reportes siguen la distribución espacial de epicentros y los principales rasgos tectónicos del territorio colombiano. Tanto la primera como la segunda etapa de búsqueda revelaron que, para 41 sismos desctructivos, existen 138 reportes de animales que reaccionaron a la sismicidad, la mayoría de los cuales pertenecen a filo Chordata, clase Mammalia, orden Carnivora, familia Canidae, género Canis, especie *C. familiaris*. La primera etapa de búsqueda indica que las reacciones cosísmicas de las especies *C. familairis, B. taurus, and E. caballus* dominan sobre las manifestaciones presísmicas y postsísmicas, en contraste con los resultados de la segunda etapa de búsqueda basada en información de medios noticiosos, la cual indicó dominio del comportamiento presísmico. Se concluye que en esta región los animales han reaccionado persistentemente a los sismos y que el folclore y la tradición oral merecen algo de credibilidad en este fenómeno.

Palabras clave: comportamiento animal anómalo, sismos históricos, reacciones anómalas, cosísmicas, postsísmicas, presísmicas, tradición oral.

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1. INTRODUCTION

Throughout the history of seismology, the reports of abnormal animal behavior (herein AAB) around the time of earthquake occurrence abound. In fact, the earliest documentations on strange animal reactions before earthquakes, date back to the first millennium B. C., during ancient Chinese, ancient Greek, and pre-Roman Etruscan cultures, found in sources as the Chronicles of the Dynasties, and writings by both Greek philosopher Plutarch and Roman naturalist Pliny the Elder (Tributsch, 2005).

A well-known report can be traced back to Greek historian Diodorus of Sicily, a source that appeared in the classical book "On the Characteristics of Animals" (Book XI) written by Roman author Claudius Aelianus (c. 170-235 CE) reporting on the earthquake and tsunami in 373 BC that caused the demise of the Greek city of Helike (Scholfield, 1959; see also Data and Resources). Many documents include reports of AAB before, during and after seismic events (Mueller, 1909; Buskirk et al., 1981; Tributsch, 1982; Fidani, 2013).

The possible relation of AAB to earthquakes has been analyzed mainly in the contexts of forecasting, early warning, and prediction (Kirschvink, 2000; Grant and Halliday, 2010; De Liso and Fidani, 2014; Wikelski et al., 2020) and less frequently the topic has been mentioned or studied from journalistic, historical, and environmental perspectives (Gori, 1993; Turner, 1982; Hough, 2006; Fan, 2018). It is widely acknowledged that the subject of animals acting strangely during seismic activity may, at best, be considered as folklore, but the persistence of reporting has prompted scientists around the world to reexamine data and to perform controlled experiments in search of cues to the likely causes of AAB, only to find that there are so many variables at play that establishing a solid link is complicated.

Some of the variability comes from the reliability of the information, for example, lack of access to primary sources, or simply because it is of human and animal nature to react differently to environmental stimuli during earthquakes and because people tend to associate phenomena or "detect" signals in hindsight.

Although media reports and scientific documentation on AAB and earthquakes are extensive, no consensus has been achieved on whether there is a real connection. In some cases, studies strongly suggest AAB as a valuable precursor (Wood, 1911; Simon, 1976; Raleigh et al., 1977; Buskirk et al., 1981; Evernden, 1982; Nikonov, 1992) whereas in others, the relationship between earthquakes and animal reactions is considered superstition and the clarity of the causes of AAB and its value as a precursory tool has been deemed as weak (Howell, Jr. and Richter, 1977; Raleigh, 1982; Chen and Wang, 2008; Woith et al., 2018). The multiple mentions of AAB in relation to earthquakes have been located mainly in media reports and refereed publications. Usually, one precedes the other and following an earthquake, the animal reactions are first reported in the news, which in occasions prompts scientific enquire.

In the first group the written formats have included newspapers, gazettes, magazines, and more recently online news sites; in the second group the formats have traditionally been conference abstracts, research papers, internal reports, and books. Although one might think that only scientific literature is significant to give credibility to a subject, it is important to keep in mind that information of AAB in the media also deserves attention, particularly for its long-standing tradition and the perseverance of the reports during millennia. Also, the common knowledge and observations of the layperson (which frequently are the source of information in the media) are also hard to ignore: one only has to go out to the countryside and talk to people to realize that the topic of AAB in relation to earthquakes has taken root amidst many communities.

Around the world, the data of AAB related to earthquakes has attracted both the general public and the scientific community, so much that entire conferences have been dedicated to this intriguing concept: in 1976, the USGS held the "Abnormal Animal Behavior Prior to Earthquakes I Conference" in California, where accounts of AAB and its plausible causes were analyzed (Gans, 1976).

A second conference on AAB was held in Galveston (Texas) in 1979, introducing controlled-experimental data on the effects of seismic geophysical and geochemical stimuli on animals (Kreithen, 1980; Kalmijn, 1980; Moulton, 1980). Graduate theses have been written and books on the subject published (see for example Gordon, 1977; Tributsch, 1982; Ikeya, 2004; Dust, 2017); as well as journal articles and special issues (see References section).

Colombia is located in the tectonically-complex setting where three plates interact: Caribbean, Nazca, and South American. The region is quite seismically active and has a rich history of earthquakes that oftentimes have caused devastation. Despite this, no scientific works have been dedicated to AAB in relation to earthquakes in this region, which always appears as a blank in wider-coverage studies (Tributsch, 1982; Grant and Conlan, 2013; Woith et al., 2018).

In this paper, a compilation is presented of reports on AAB extracted from scientific literature and complemented with information from written news sources online. The reports found in scientific literature date back to the early seventeenth century and

the media sources include articles on AAB and earthquakes starting in 1994. The main objectives of this work are: To offer, for the first time, a detailed database on AAB reports for Colombia; to fill the knowledge gap on AAB related to earthquakes in this region; and to provide foundations to foster further, hopefully multidisciplinary, research on this controversial yet important topic.

2. METHODS

The collection of data on AAB reports was achieved in two stages. First, a systematic search was done in available documents on historical and recent earthquakes in Colombia and neighboring regions. Most of the documents were downloaded from internet sites maintained by local or foreign authoritative institutions: Universities, research institutes, government offices, and the like. A few documents were available in printed format.

Scientific literature included references to primary sources (for example original letters or witnesses´ accounts) but there was no access to these documents and as such, the search was restricted to the secondary sources, many of them refereed publications (for a complete listing of documentary sources where AAB reports were found, see Text S1 in the electronic supplement to this article – Annex 1).

The sources used include professionally-edited documents and some of them are well-known seminal works in the subject of Colombian historical seismicity. A main source of data, for example, was the Information System for Colombian Historical Seismicity (Sistema de Información de Sismicidad Histórica de Colombia-SISHC), administered by Servicio Geológico Colombiano-SGC (see Data and Resources), which includes a listing of damaging earthquakes with historical references, macroseismic intensities, and seismological assessments starting in the XVII century.

When several sources mentioned AAB for the same earthquake, a comparison of the reports was made to select the most complete one and to ensure that all details of AAB were summarized into a consistent unique case report, always providing the appropriate references. In one case, a direct witness provided information on AAB, this report was deemed as reliable because of the details given and the confirmed association with one of the earthquakes analyzed, and was also included in the database. This first-stage search resulted in a set of 41 earthquakes with 138 associated reported cases of AAB covering the period 1610-2016 (Fig. 1). For a complete list of AAB reports related to destructive earthquakes in Colombia, see Spreadsheet S1 in the electronic supplement to this article (Annex 2).

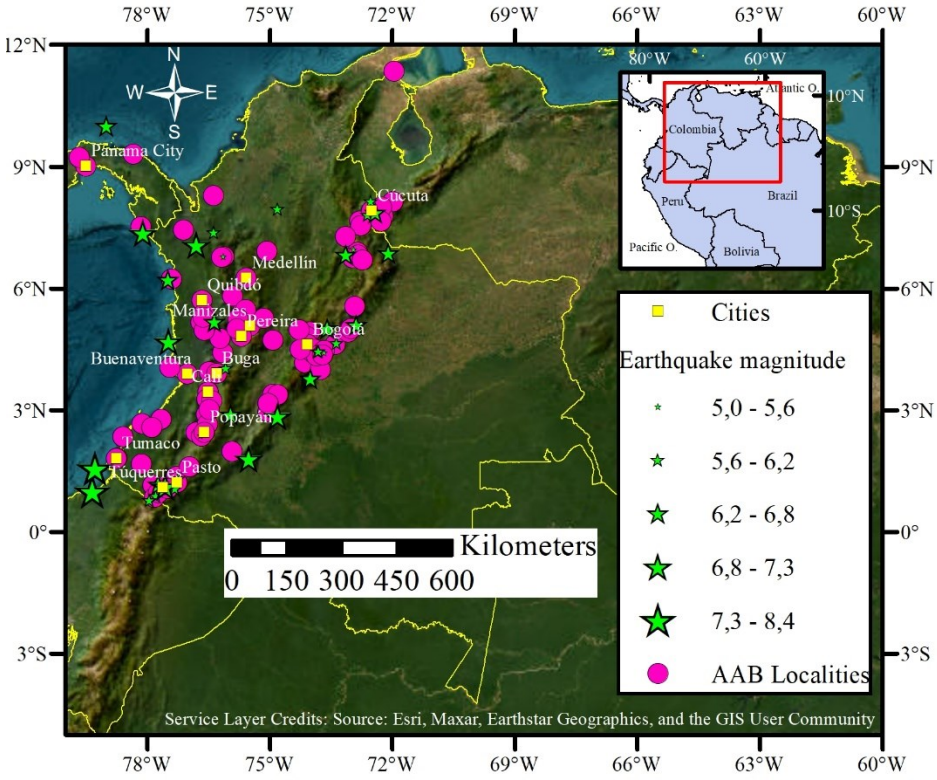

Figure 1. Map of northwestern South America showing the locations of earthquake epicenters (stars) during the period 1610 - 2016 with associated reports of AAB (circles). Some main cities marked with squares are included and labeled for reference.

The earthquakes found with associated AAB reports had magnitudes in the range 5.0 – 8.4 and depths in the range 10 - 120 km (Fig. 2). Most of the earthquakes (38 out of 41) are listed in the SISHC (see Data and Resources). Two earthquakes were found in Ramírez (1975), a classical reference for historical seismicity in Colombia and neighboring regions, and one additional earthquake with unknown date, presumed to have occurred sometime in early 1940, was included because, according to literature, may have been linked to the death of a large number of grease fish of a rare species, now extinct, in Lake Tota (Boyacá) (Miles, 1942; Mojica et al., 2012; see also Data and Resources).

For each reported AAB case, information was extracted regarding the corresponding earthquake: date and time; estimated or measured intensity; magnitude, depth, epicenter location; and the name of a populated center nearest to the epicenter area (or the name of the general region where the earthquake was reported). Also the following information was produced concerning the AAB: English translation of the report(s); timing classification of report (e.g. stating if the AAB was preseismic, coseismic, or postseismic); additional notes when needed, and the references to the data (Spreadsheet S1 and Text S1).

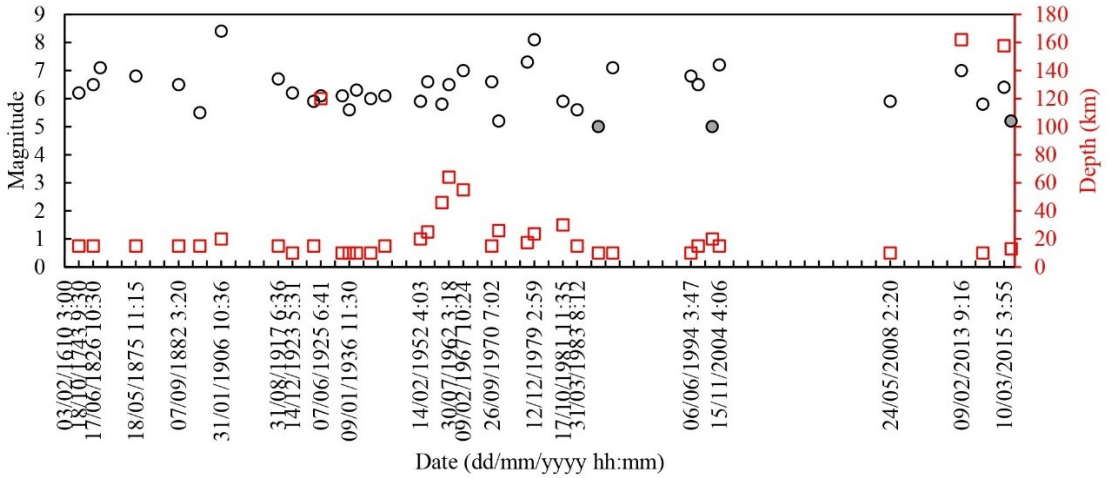

Figure 2. Figure 1. Magnitudes (black circles) and depths (red squares) of earthquakes with associated AAB reports, plotted with respect to their origin time. Data are reported in the Sistema de Información de Sismicidad Histórica de Colombia-SISHC, Servicio Geológico Colombiano-SGC. All magnitudes are Mw, except for three earthquakes represented with solid gray circles, which are reported as MS (19/03/1988) and ML (04/03/1995 and 30/10/2016). Some labels for the dates on the horizontal axis have been omitted for clarity.

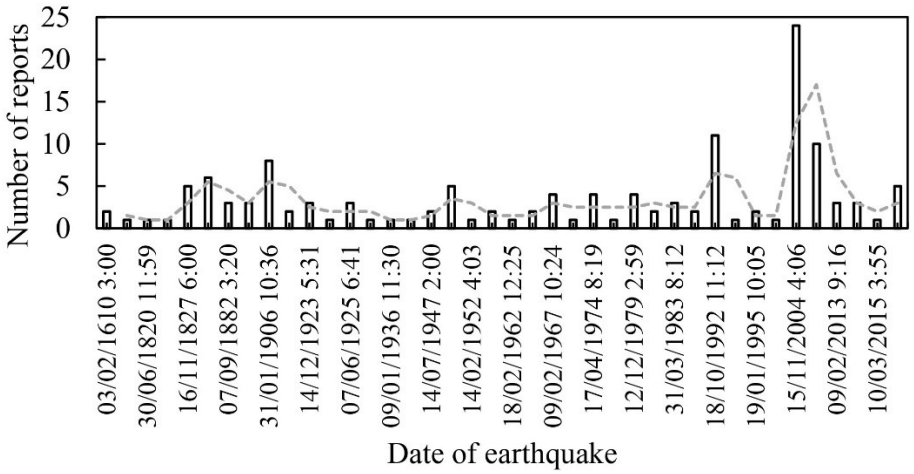

Figure 3. Bar graph of the number of AAB reports through time. The dashed gray line is the 2-period moving average of the number of reports. Some labels for the dates of earthquakes have been omitted for clarity.

The number of AAB reports varied among the earthquakes. Fourteen earthquakes (34%) had only one report associated and the remaining 27 earthquakes (66%) had two or more reports. The maximum number of 24 AAB reports was found in association with the Mw 7.2 earthquake on November 11th, 2004, near Pizarro (Bajo Baudó, Chocó). A graph showing the number of reports through time is shown in Fig 3.

Graphs of number of reports vs. magnitudes, intensities, and depths of earthquakes, were produced to get a sense of the relationship between these physical parameters and the occurrence of AAB. The plots are shown in Fig 4.

During the second-stage search, systematic queries were conducted in online versions of newspapers and magazines with both local and national coverage with advanced searches using the sites´ search tool (most of which are powered by Google™). The main key terms used in the advanced searches where: "earthquake", "Colombia", and "animals", which were used individually or in double or triple combinations (for example: "animals + earthquakes + Colombia").

Variations of searches used alternative terms such as: Singular vs. plural form (for example "animal" vs "animals"); "prediction" and synonyms of main terms: "tremor", "seism". For completeness we also performed queries with terms for specific animals that have been reported in association to earthquakes or that were extracted from the previously described first-stage data search: dogs, cows (cattle), horses, mules, sheep, pigs, fish, hens, pigeons (birds), toads, frogs, scarabs, earthworms, and cockroaches.

During this stage, articles were found related to the general topic of AAB and earthquakes (citing cases from places other than Colombia), which were included because they demonstrate that the topic is significant enough to be published in media with national or local coverage. The second-stage systematic search in online media produced a list of 22 recent mentions of AAB, or animals in general, or other live beings, in relation to earthquakes, in newspapers and magazines published between 1994 and 2019.

For each entry, was recorded: the publication date; the name of the newspaper or magazine; title of the article; observations; and the appropriate credits (for a summary of the main aspects of AAB reports in relation to earthquakes, in Colombia and around the world, extracted from recent online newspapers and magazines, see Table S1 in the electronic supplement to this article – Annex 3). During both stages of AAB search, a total of 3211 different documentary sources were consulted (Fig. 5).

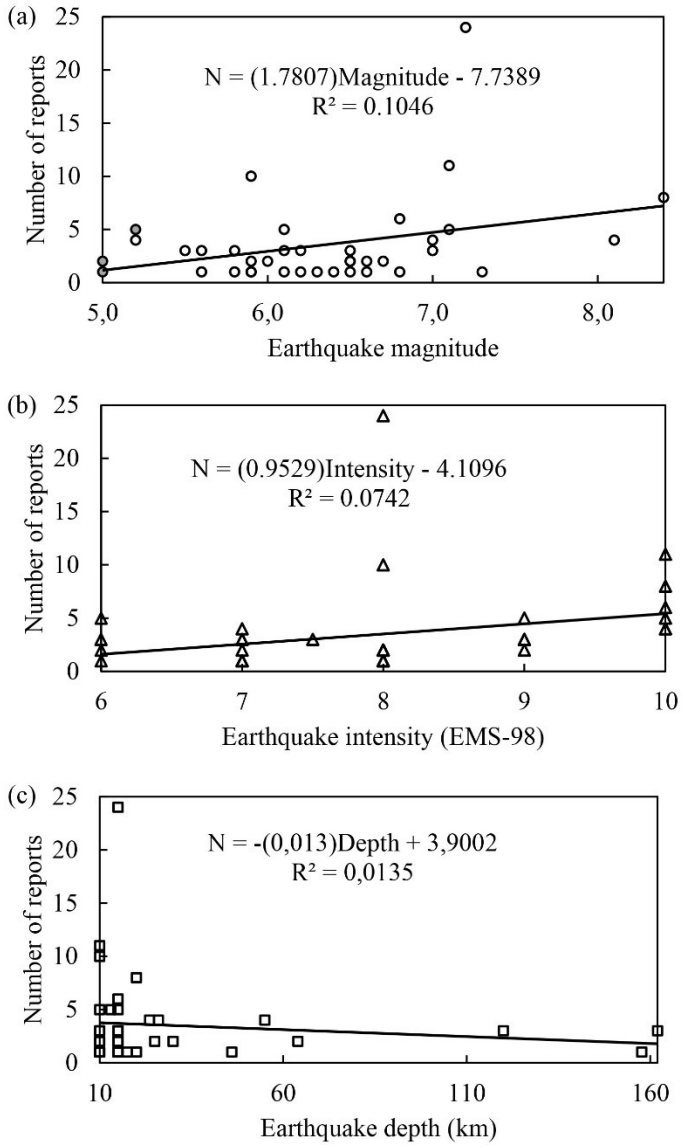

Figure 4. Dispersion graphs relating the number of AAB reports vs. the earthquake magnitude (a), intensity (b), and depth (c). In (a) most magnitudes are Mw and the three data points marked by filled circles are MS or ML. In (b) all intensities are EMS-98. The number of reports is weakly correlated with the parameters of the earthquakes with the AAB.

Once the database on AAB reports was consolidated, all the animals mentioned were classified into taxonomical categories, down to the species level, whenever possible, to provide a formal view of the biological diversity (for a detailed listing of all taxonomical classifications of animals that reacted to earthquakes in Colombia, see Spreadsheet S1 in the electronic supplement to this article) and the possible relationship with the timing of reactions in relation to the earthquakes.

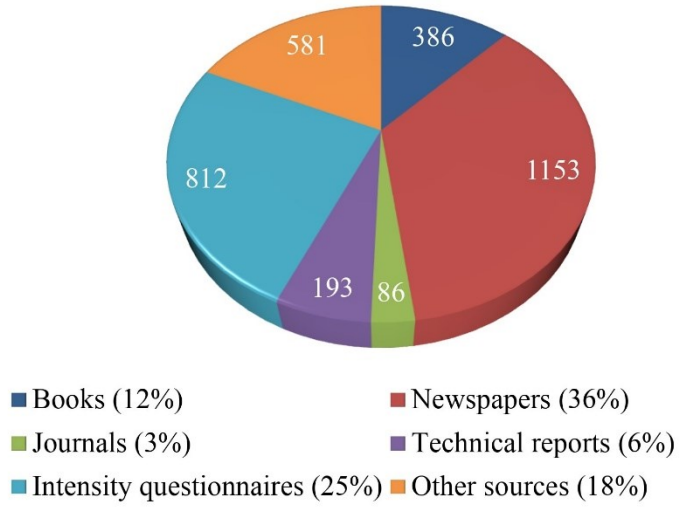

Figure 5. Summary of documentary sources consulted during the search for AAB reports. The category labelled "Other sources" includes handwritten documents, telegrams, theses, abstracts in conference proceedings, and electronic documents.

3. RESULTS

The first-stage search resulted in the compilation of a database of reports of AAB related to damaging earthquakes in Colombia and neighboring regions (Spreadsheet S1, Fig. 1). It was found that, since the early XVII century, many earthquakes have been firmly linked to hundreds of situations in which different animals purportedly were affected by or reacted to, the most likely complex stimuli produced during earthquakes.

The second-stage search, on the other hand, provided a much smaller number of mentions of animals reacting to earthquakes, the link between animals´ reactions and earthquake activity in these cases was less formal and sometimes even anecdotal (Table S1) and for these reasons emphasis in the analysis of information was placed on the more rigorous data from the first-stage search.

What animals have been reported?

The 138 reports of AAB found in the first-stage search include, at least, 32 different animals. Many times, a report mentioned various animals and often times the descriptions were not specific enough to distinguish among various taxa (for example, some reports would simply state "Animals were restless" or "Unrest of birds", Spreadsheet S1). Fig. 6 shows graphs specifying animals that were mentioned in association with earthquakes.

The second-stage systematic search of AAB in recent online media (1994-2019) resulted in ten mentions of animal reactions related to earthquakes in Colombia, which included at least eight different animals (Fig. 7).

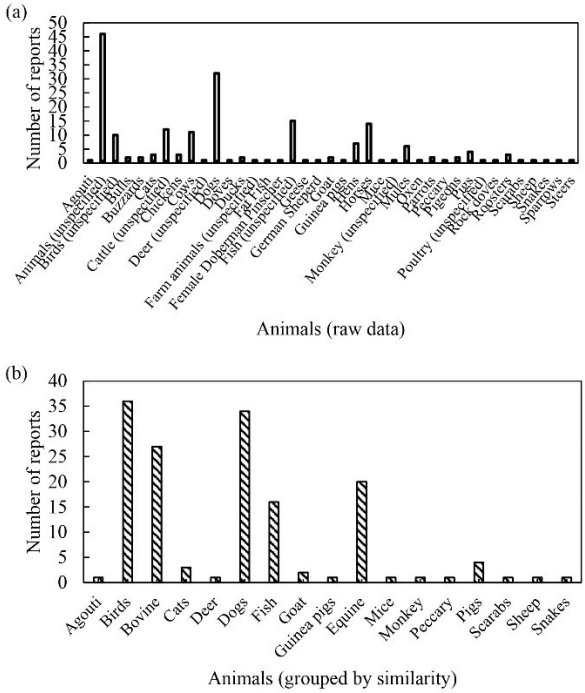

Figure 6. Bar graphs showing the frequency of reporting of the various animals (ordered alphabetically) found through the first-stage search in documents on historical and recent earthquakes in Colombia and neighboring regions. (a) The raw data on AAB reporting. (b) Reports by grouping animals. This is a layperson grouping in the sense that the "Birds" category includes unspecified birds, buzzards, chickens, doves, ducks, geese, hens, parrots, pigeons, unspecified poultry, rock doves, roosters, and sparrows; and the "Bovine" category includes bulls, unspecified cattle, cows, oxen, and steers. Similar groupings were used in other cases.

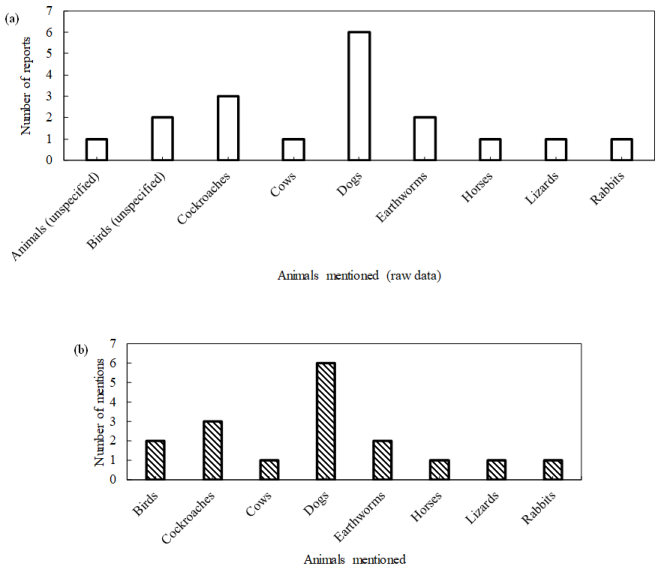

Figure 7. Bar graphs showing the frequency of mentions of the various animals (ordered alphabetically) in association to earthquakes in Colombia, found through the second-stage search in recent (1994-2019) online newspapers and magazines. (a) The raw data on AAB mentions. (b) Number of mentions by groups of animals

To analyze the data on AAB reporting, the formal taxonomic hierarchy is used. This allows for an appreciation of the variety of animals that react to earthquakes (the full listing of taxonomical categories is included in Spreadsheet S1 in the electronic supplement to this article). Table 1 summarizes the numbers of different taxonomical categories that are reported with AAB.

Table 1. The numbers of different taxonomical categories found with AAB in relation to earthquakes.

Taxonomical category	Number*
Phylum	3
Class	6
Order	16
Family	21
Genus	20
Species	19

*These are minimum numbers because in many instances it was not possible to establish the classification because the details vary among the different reports

Fig. 8 shows the distributions of numbers of reports according to the different taxonomical groups that were achieved.

Spatial distribution of AAB reports

For the analysis of spatial distribution of AAB reports, emphasis is placed on the data from the first-stage search, for which the most accurate locations were obtained. Given the diversity of animals that react to earthquakes (Fig. 6, 7, 8, Table 1) and the combinations of taxonomical categories documented for each report (Spreadsheet S1), the general maps showing the locations of AAB reports for all animals, are difficult to interpret (Fig. 9).

Between the two phyla represented, the Chordata dominates the reporting. However, in order to analyze the details of spatial extent or the spatial variability of AAB reports for more specific taxonomical categories (class to species) it is necessary to plot the locations of reports for each individual class, order, etc. (PowerPoint Presentation S1 in the electronic supplement to this article – Annex 4).

As seen in Fig. 9, at the class level, Mammalia shows the largest spatial distribution, followed by Aves and Osteichthyes which also exhibit significant coverage. Among the orders represented, Artiodactyla, Carnivora, and Perissodactyla show the widest geographical extent, with the Galliformes also being significantly reported. From the families that are represented, Bovidae, Equidae, Canidae, and Phasianidae have large spatial coverage. The genera Bos, Equus, Canis, and Gallus have the most important coverage or reporting. At the species level the largest spatial coverage is seen for B. taurus, C. familiaris, E. caballus, G. gallus, and E. mulus.

Do animals react before, during, or after earthquakes?

The timing of AAB behavior was found to include a variety of categories, with a dominance of the coseismic reactions (41% of reports), followed by preseismic reactions (14% of reports), and postseismic (12%). The distribution of different timing categorizations that could be determined based on the raw data from the first-stage search is shown in Fig.10.

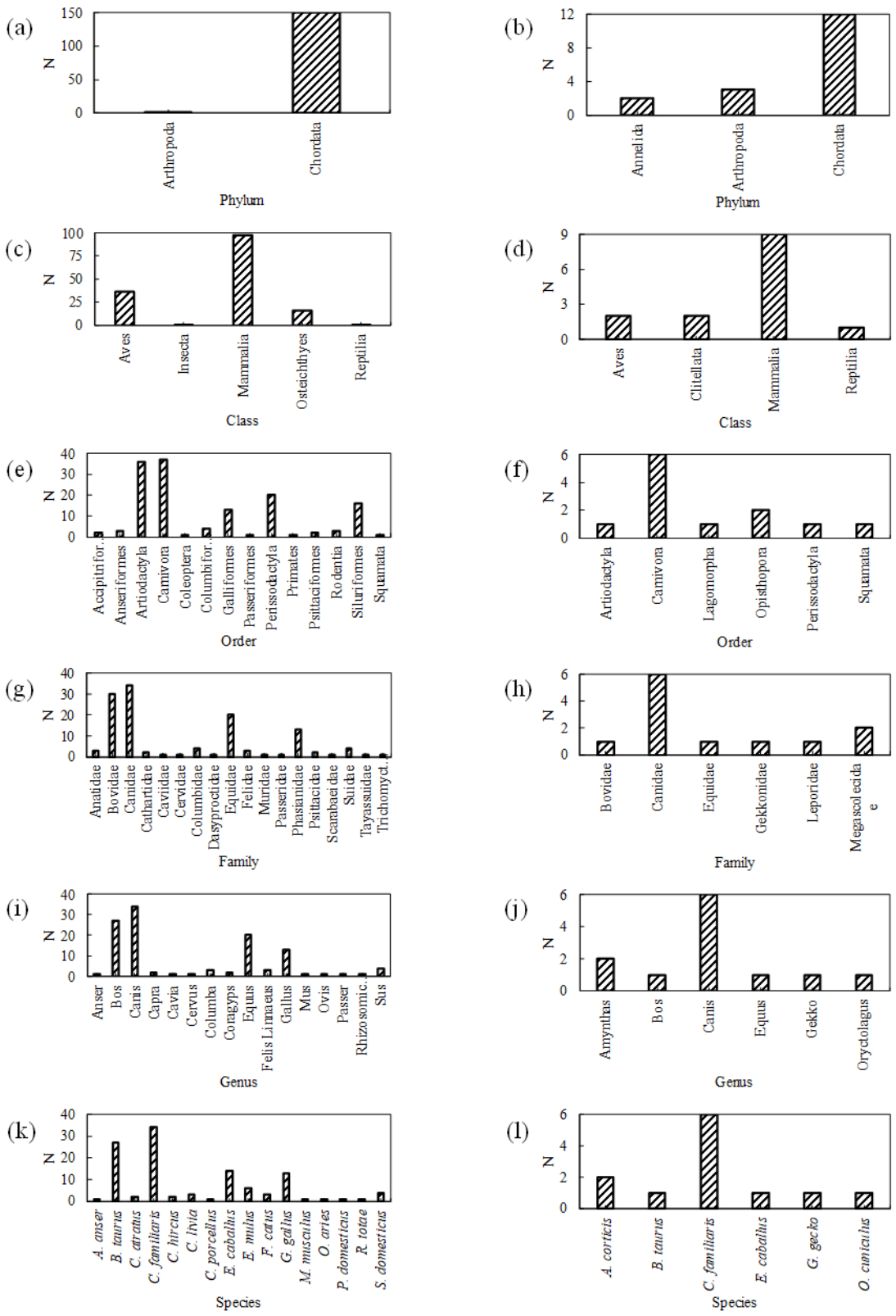

Figure 8. Bar graphs showing the various taxonomical groups, from phylum to species, that are represented in the AAB data. (a, c, e, g, i, k, in left column) Reports of AAB found through the first-stage search in documents on historical and recent earthquakes in Colombia and neighboring regions. (b, d, f, h, j, l, in right column) Mentions found through the second-stage search in recent (1994-2019) online newspapers and magazines.

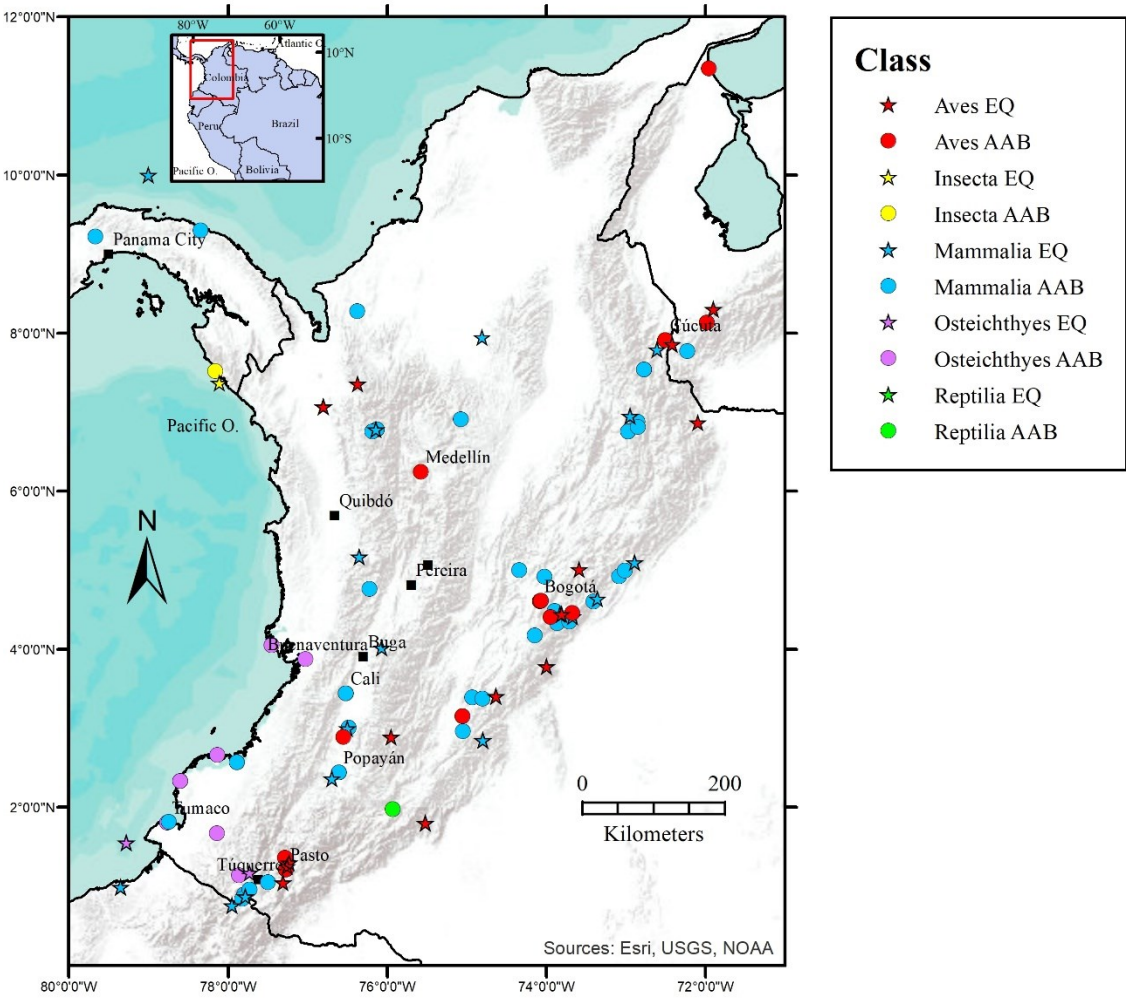

Figure 9. An example of a map showing the locations of AAB reports, grouped according to the class taxonomical category. In this map, only are plotted those reports for which the classes were uniquely identified. Combinations of classes (e.g., reports of animals of the Aves and Mammalia classes reacting simultaneously) and the "unspecified" category were left out. For lower taxonomical categories (e.g., order, family, genus, and species), the maps become increasingly hard to interpret due to the larger variety involved. See PowerPoint Presentation S1 for maps with the spatial distribution of AAB reports, according to each taxonomical category.

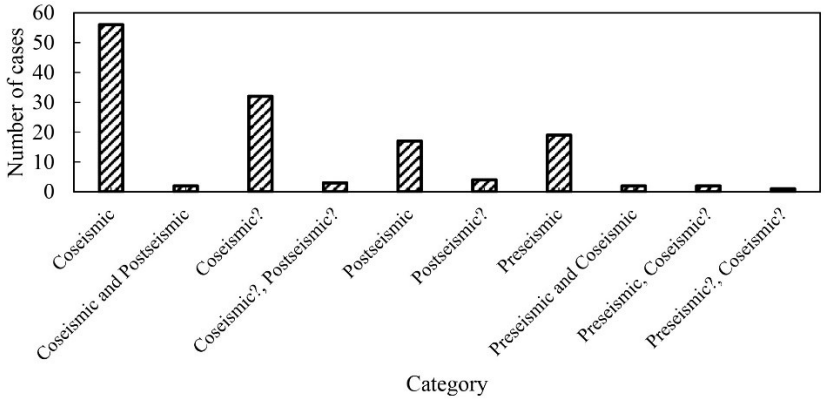

Figure 10. Timing character found for AAB reports, based on data from the first-stage search. See Spreadsheet S1 for details.

Among the taxonomical categories with large spatial distribution (Fig. 11), at the phylum level the coseismic reactions of Chordata animals dominate (Arthropoda only has one preseismic report). At the class level both Mammalia and Aves show the same pattern, with prevalence for coseismic reactions, followed by preseismic and postseismic behavior; there are no reports of preseismic reactions in Osteichthyes and the postseismic behavior dominates over the coseismic. Among the main orders there is prevalence for coseismic behavior in Artyodactyla, Carnivora, and Perissodactyla, but only in Carnivora the preseismic reactions are more important than postseismic; there are no reports of postseismic behavior in Galliformes and they show the same number of coseismic and preseismic reports. For families with a large geographical distribution, dominance of coseismic response is seen for Bovidae, Canidae, and Equidae, whereas only for Canidae the preseismic reactions are more numerous than postseismic ones. At the genus level, the coseismic response is seen for Bos, Canis, and Equus; the Canis and Bos genera show dominance of preseismic over postseismic reactions. Among the species with wide distribution of cases, coseismic response is the most relevant for *B. taurus*, *C. familiaris*, and *E. Caballus* and is the only response seen for *E. mulus*; only *C. familiaris* and *B. taurus* show prevalence of preseismic response with respect to postseismic (for the full matrixes with the types of responses found for all animals, including de "Unspecified" taxonomical categories, see Spreadsheet S1 in the electronic supplement to this article).

Timeline of AAB reporting

To show the evolution of AAB reports throughout the history of earthquake occurrence in the NW corner of South America, plots of symbols marking the dates of reports were constructed for the main taxonomical categories represented (those with the largest geographical coverage, Fig. 12).

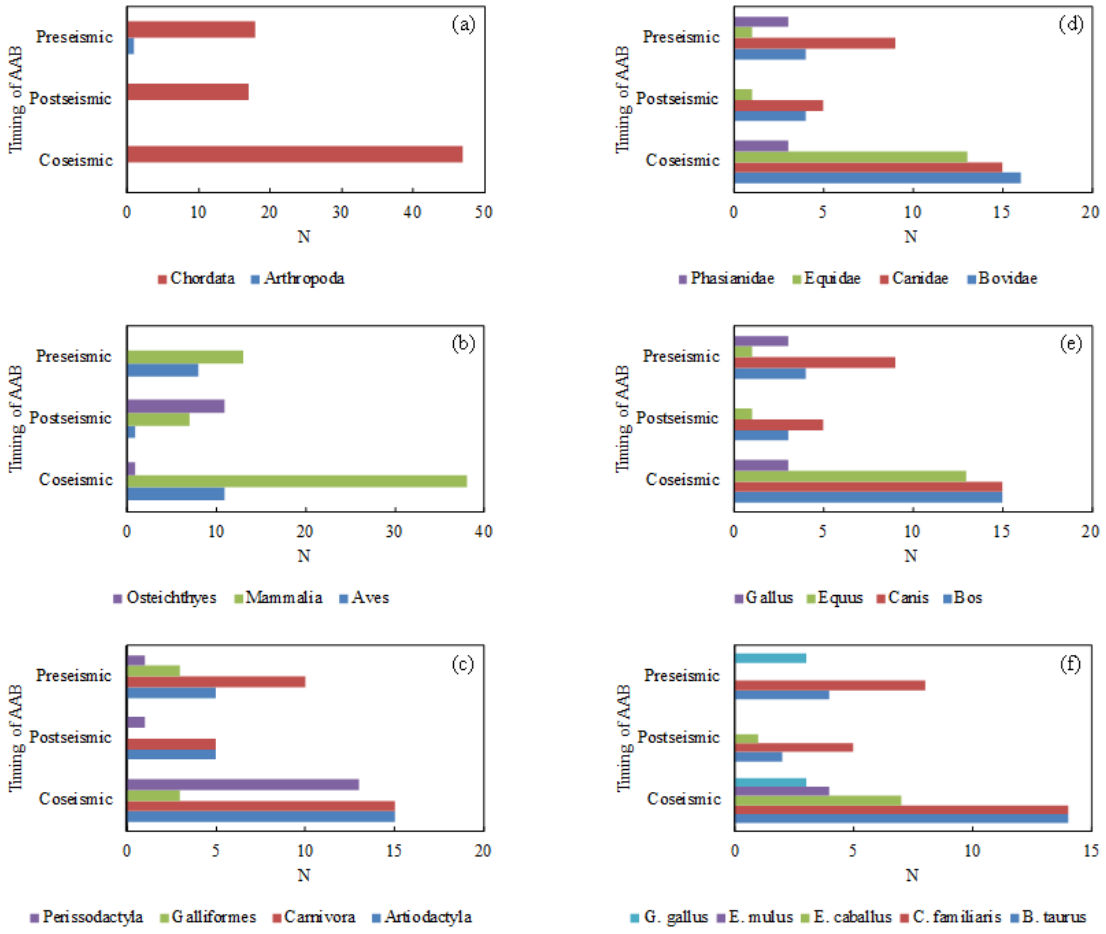

Figure 11. Bar graphs of the distribution of AAB timing for each taxonomical group with large geographical coverage. Combined timing categories or unclear timing categories (e.g., "Preseismic and Coseismic" or "Postseismic?") are omitted for clarity. The reader is referred to Spreadsheet S1 for the full matrixes including all timing categories and scarcely represented taxonomical groups.

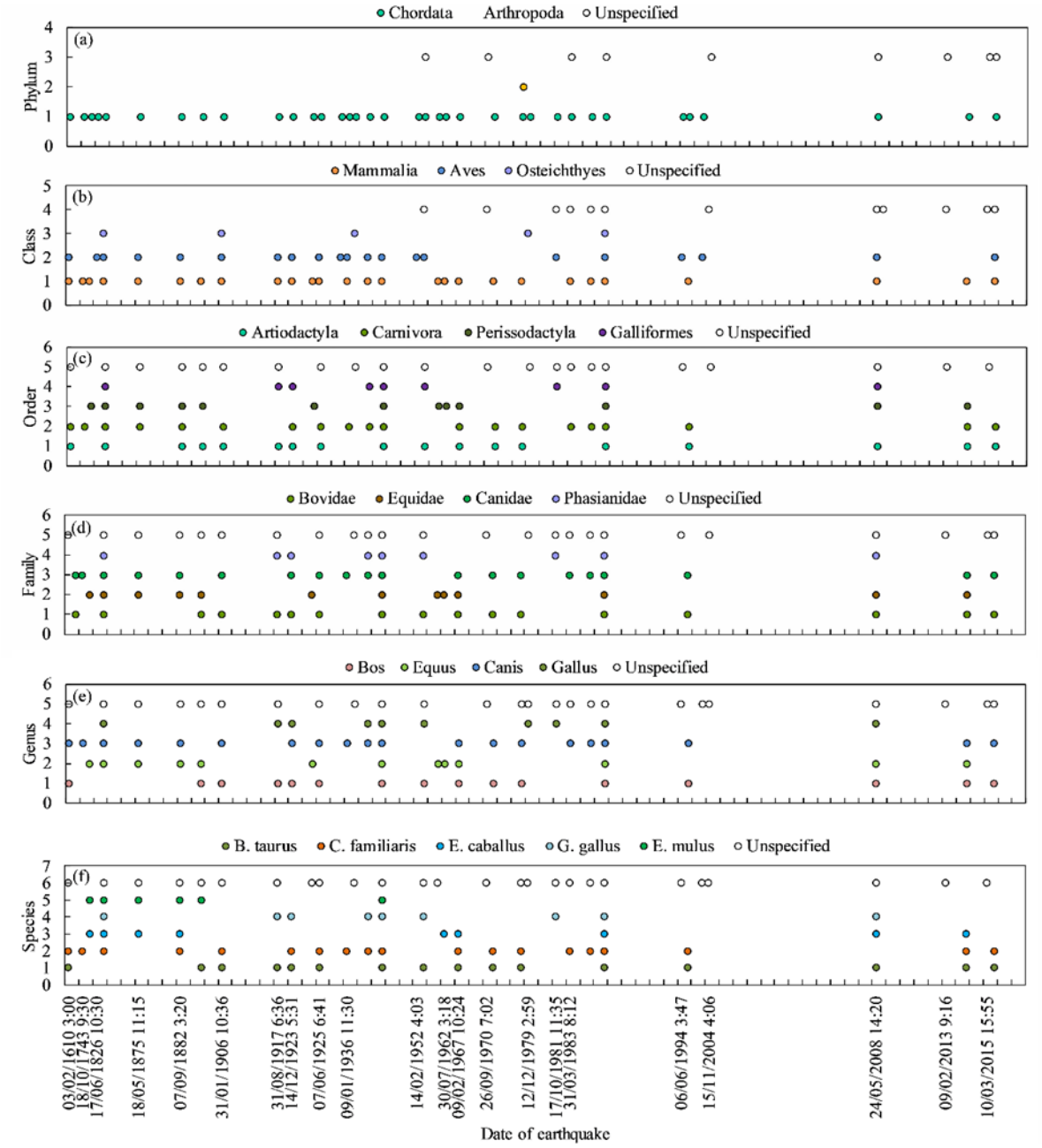

Figure 12. Timelines of AAB reporting for the main groups represented within each taxonomical category, from phylum (top) to species (bottom). During 1610 - 2016 a total of 40 earthquakes with known origin time had some animal response associated. Each symbol drawn represents all reports of AAB for a particular taxonomical group. Some labels have been omitted in the horizontal axis for clarity. See Spreadsheet S1 for details.

4. DISCUSSION

Reports of animal reactions related to earthquakes have been mentioned in the modern scientific literature for decades (Raleigh et al., 1977; Buskirk et al., 1981; Tributsch, 1982; Feng and Jiang, 1992; Ikeya, 2004; Woith et al., 2018), emphasizing the possible use of AAB as an earthquake precursor. Tantalizing as it sounds, using animals as earthquake predictors is yet to be widely accepted as a scientifically proven idea, in spite of several rigorous studies of animal behavior, including: instrument-based monitoring or systematic observations, and experiments in controlled conditions (Gordon, 1977; Simon, 1976; Kreithen, 1980; Fay, 1980; Kenagy and Enright, 1980; Skiles et al., 1980; Fidani, 2013; De Liso et al., 2014; Wikelsli et al., 2020).

Determining whether animals are earthquake predictors is beyond the scope of this paper. Instead, it is aimed at filling a literature and data gap on animal behavior around the time of earthquakes for northwestern South America (Fig. 1) and foster cross-disciplinary studies that may, in the future, contribute to solve the question posed.

To find AAB reports in association with earthquakes a two-stage search approach was followed: first a systematic review of the available documental sources on historical earthquakes (1610-2016) was done, this gave a solid academic compilation of 41 earthquakes with hundreds of AAB observations of many different animals reacting throughout the earthquake cycle (Spreadsheet S1 and Text S1); secondly a systematic online search of mentions of AAB in newspapers and magazines (1994-2019) provided another view of the phenomena that even though being more anecdotal in nature, is still valuable because it basically concerns the oral tradition on the subject (Table S1).

Characteristics of the earthquakes

The list of 41 earthquakes in Spreadsheet S1 was formed after a review of all available information on 84 damaging earthquakes that have affected Colombia during historical times (81 of these are listed in the SISHC, see Data and Resources, and three earthquakes are from alternative sources), which implies that there is a 49% chance of having AAB in association to earthquakes for this region. The earthquakes have magnitudes in the range 5.0 – 8.4 (classified as light to great earthquakes) with depths that are between 10 and 120 km (shallow to intermediate depths) but most of them are shallower than 30 km which means many are shallow crustal earthquakes (Fig. 2). In map view, the epicenters locate mostly along the Eastern, Central, and Western cordilleras, as well as along the Pacific coast (Fig. 1), these are the regions where the interactions between the Nazca, Caribbean, and South American tectonic plates drive the motions of many faults (Gómez et al., 2020).

Characteristics of AAB reports

The first-stage search produced a listing of 138 distinct reports coming from localities that follow the general spatial distribution of epicenters (Fig. 1). The epicenter-localities distances are in the range 0.9 – 497.2 km and the mean distance is 115.5 km (median distance is 61 km). Trend lines in graphs of magnitudes versus distances to AAB reports localities and maximum intensities versus distances do have positive slopes, but the size of the earthquakes and their shaking violence are only weakly correlated with the distances to the localities where AAB were noticed (Fig. 13).

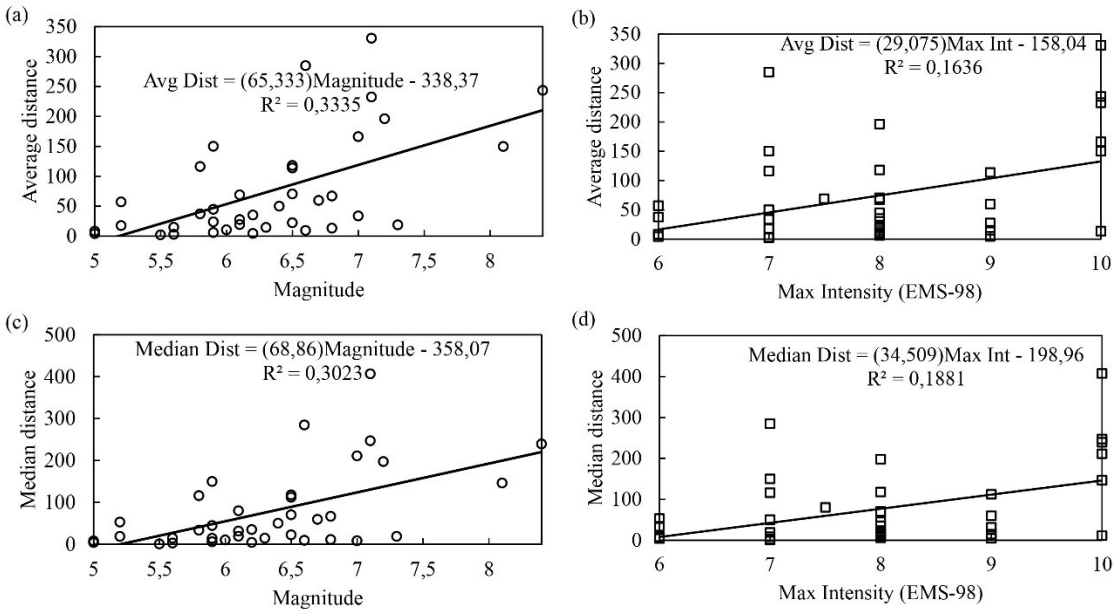

Figure 13. (a, c) Graphs of the magnitudes of earthquakes versus average or median distances to AAB reports localities. (b, d) Maximum EMS-98 intensities versus average or median distances. For any earthquake there can be a number of AAB reports (between 1 and 24), located at variable distances from the epicenter, average distances or median distances were calculated to obtain the central measure.

Surprises revealed by data

The largest earthquake in the catalog (the January 31st 1906, Mw 8.4 Esmeraldas, Ecuador, earthquake) ranks among the largest earthquakes in recorded history (see Data and Resources). Although initially its magnitude was estimated as Mw 8.8 (Kanamori, 1977) this value has been recalculated to be in the range 8.4 - 8.6 in recent works (Yoshimoto et al., 2017; Yamanaka et al., 2017). Contrary to expectations, the data shows that the farthest AAB report corresponds to that of roosters and cattle in Paraguaipoa (Zulia, Venezuela) reacting to a moderate-to-strong earthquake on April 21st, 1957, Mw 6.6 located near Málaga (Santander, Colombia). The nearest AAB report is not associated to the smallest earthquake in the catalog either, but to the light-to-moderate earthquake on December 1st, 1903, Mw 5.5 located near Frontino (Antioquia, Colombia), where cattle and a mule were reported to react to postseismic surface effects of shaking. Additionally, the highest number of reports are documented for a strong subduction earthquake near Pizarro (Bajo Baudó, Chocó) on November 15th, 2004, Mw 7.2.

The variety of animals that react to earthquakes

According to data obtained during the first-stage search, at least 16 different species of animals have been observed to react to earthquakes, though the number of species increases to 19 if the data from the second-stage search are included (Table 1, Fig. 6, 7, 8). Thus, for centuries a fair variety of animals, domestic and wild, big and small, flying animals or those that live on the ground or below it, or in the water, show sensitivity to the effects of earthquakes. Among all the animals that show AAB, birds, dogs, cattle, and horses stand out in their abundances of reports and widespread character. This has also been observed elsewhere (Buskirk et al., 1981; Tributsh, 1982; Nikonov, 1992; Ikeya, 2004; Fidani, 2013; Fan, 2018). Some animals, on the other hand, represent rather unique AAB reports, not commonly mentioned in other studies or not mentioned at all: buzzards (*C. atratus*), doves (no particular species identified), fat fish (*R. totae*), guinea pigs (*C. porcellus*), oxen (*B. taurus*), peccary (no particular species identified), and scarabs (no particular species identified) (Spreadsheet S1, Fig. 6).

In this work no attempts are made to: (1) establish whether animals can be used in earthquake forecasting or prediction or (2) explain the likely causes of AAB in relation to earthquakes. In order to achieve this, high-resolution systematic observations of animal behavior and networks of instruments to detect geophysical signals would be necessary. The nature of AAB descriptions found does not permit detailed analysis of time-dependent behavior. Regarding the timing of reports, however, it was possible to establish that the animals reacted before, during, or after mainshocks (and a few aftershocks) and these timing manifestations were named preseismic, coseismic, and postseismic. According to descriptions, animals sometimes exhibited reactions that were noted in two parts of the seismic cycle (e.g., preseismic and coseismic; coseismic and postseismic) and often times the timing of the AAB was doubtful (Fig. 10). Preseismic behavior has been of interest in literature because it could be useful in earthquake warnings and although in this study, for the animals that dominate the reporting and show ample geographical distribution, it is found that coseismic behavior is most common (Fig. 11), some species do show noticeable preseismic reactions: dogs (*C. familiaris*), cattle (*B. taurus*), and birds (*G. gallus*). The preseismic behavior of these species has also been documented for a long time around the world (Mueller, 1909; Henting, 1923; Anderson, 1973; Fidani, 2013, see also Data and Resources). In this work additional species are reported as exhibiting preseismic reactions, though their number are much less significant (Spreadsheet S1): Guinea pigs (*C. porcellus*), cats (*F. catus*), sparrows (*P. domesticus*), pigs (*S. domesticus*). The results of the first-stage search indicate as well that a number of unspecified animal species in Colombia and neighboring regions reacted in anticipation to earthquakes.

Coseismic and postseismic reactions are much more abundant: out of 16 different animal species, 11 showed AAB during the earthquakes and 6 reacted after the shocks. These do not include the noticeable numbers of unspecified animals that reacted either coseismically or postseismically. Of note, among all the AAB reports in Spreadsheet S1, there was only one case in which animals apparently did not react at all to the surface effects of an earthquake. The report, from La Vega (Supía, Caldas), involved five different animals (goats, mules, a horse, a dog, and a cat) and it indicated that they just continued with their normal activities during the November 16th, 1827, Mw 7.1 earthquake near Altamira (Huila). The distance between the epicenter of this strong and shallow earthquake and the report locality is approximately 406 km and, interestingly, four other reports from different localities, one of them from Bogotá (~352 km from the epicenter, hens lying with their wings open, grasping the ground), indicated reactions to the earthquake. This goes to say that, reports of animals not reacting to earthquakes can also be found here and there: on May 18th, 2015, the author interviewed people of Los Alcaparros rural settlement in Firavitoba (Boyacá) two days after an earthquake was felt in the region. One resident of Los Alcaparros mentioned hearing rumblings that were different to those coming from the house during shaking and stated that she did not notice

any reaction on dogs, hens, cows, and sheep, that were in the surroundings. The earthquake in mention corresponds to a very shallow (depth stated as 0.0 km in catalog) Mw 4.4 earthquake on the morning of May 16th, 2015, located near Paipa, in the State of Boyacá (see Data and Resources) and the distance between said earthquake and the report site is 17 km.

AAB reporting through time

The AAB reports in Spreadsheet S1 were compiled by systematic search of information related to destructive earthquakes that have affected Colombia and its vicinity since the early XVII century, most of which are listed in the SISHC. For felt earthquakes that did not cause damage, no documentation of AAB exists, apart from the occasional accounts from witnesses found during the second-stage search in newspapers and magazines (Fig. 7, 8, Table S1). Information on damaging earthquakes abounds (Fig. 1) and a rigorous inspection of every available document was performed to locate AAB cases (Fig. 5), thus a fairly significant sample of animal reactions to earthquakes is presented that covers both the historical period and the instrumentation-based period of earthquake detection which, for Colombia, started in 1923 thanks to the efforts made by the Jesuit Order, when the first seismological station was set up in Bogota. The modern instrumentation of the National Seismograph Network started in mid-1993. Considering this and analyzing the data in Fig. 3, an oscillatory character of AAB reporting through time is apparent with peaks around the time of important earthquakes: May 18th, 1875 (Mw 6.8 near Cúcuta); January 31st, 1906 (Mw 8.4 near Esmeraldas, Ecuador); July 8th, 1950 (Mw 6.1 near Arboledas); October 18th, 1992 (Mw 7.1 near Murindó) and November 15th, 2004 (Mw 7.2 near Pizarro, Bajo Baudó). Also, the mean number of AAB reports during the two periods of 1610-1988 and 1992-2016 are, respectively 2.5 and 6.1 (median numbers of AAB are 2 and 3, respectively), which suggests an increase of AAB reporting starting around the time of the deployment of the Colombian National Seismograph Network and also when intensity questionnaires were commonly available. There may also be increased awareness of people because of mass-media dissemination of information and the advent of widespread internet and social media use.

Regarding the persistence (or lack thereof) through time of AAB in certain types of animals, the timeline graphs presented in Fig. 12 reveal that, at the class taxonomical level, while Mammalia and Aves persist more or less regularly during the entire study period, the last report of Osteichthyes (also known informally as bony fishes) was documented for the October 18th, 1992 Murindó earthquake, meaning that for decades there have been no observations of fish being affected by, or reacting to, earthquakes in Colombia. Of note, during the fish-less period (1994-2016) there have been moderate to strong earthquakes that affected both large drainage systems and coastal areas, such as the June 6, 1994, Mw 6.8 earthquake near Páez (Belalcázar) or the November 15th, 2004, Mw 7.2 near Pizarro. It is unlikely that the "unspecified" animal category may be attributable to Osteichthyes because, when describing earthquake effects, people generally do make distinction between statements such as "animals were frightened" and "dead fish everywhere". At the order level, Galliformes became absent from the reporting after the May 24th, 2008, Mw 5.9 earthquake near Quetame (Colombia), but in this case there is slight chance that among the "unspecified" order (and subsequent lower-level taxonomical groups) some of these farm animals were lumped together with others when people used generic descriptors such as "animals ran". At the species level, the last unequivocal AAB report involving *E. mulus* was documented for the July 8th, 1950 Mw 6.1 earthquake near Arboledas, after which E. caballus continued appearing in reports. Again, it is likely that the "unspecified" species category contains some cases of the missing equine.

Folklore on AAB and recent publicity: the second-stage search

Folklore encompasses the traditional stories, beliefs, and customs of a group of people, it is an ample concept where a large variety of things can be lumped together: myths, songs, legends, rituals, and handcrafts, just to name a few. Likewise, the group dimension of folklore is also large, it exists in nations, neighborhoods, families, and even within a circle of friends. It can manifest in oral or written form and can be represented in objects and traditions (Klein, 2001; Sims and Stephens, 2005). To many, the subject of animal reactions related to earthquakes may contain elements of folklore, and often times the way in which the information is presented conveys the idea of a story being exaggerated or fantastic. For the layperson, the information on AAB and earthquakes is more informal, and newspapers and magazines may be a more attractive read than scientific papers devoted to the topic.

To get a sense of how the topic of animals reacting to earthquakes is presented in mass media, a series of systematic online searches in newspapers and magazines was performed. Every time a "hit" was produced, the story was translated to English in its entirety with the ultimate purpose of conforming a supplementary material piece available to readers around the world interested in the subject. When the proprietors of the stories were contacted to request permission for making the material available in

an academic publication, no response was obtained, which implied that it was not possible to share the information.

The decision was made to produce Table S1, a summary of the main points addressed in each of the press articles. The earliest online mention in a Colombian media of animals in relation to earthquakes dates back to 1994 and the last was in 2019. A total of 22 articles were found, and they all have the unmistakable signature of folk tradition.

Nineteen of them mentioned animals in the context of earthquake prediction (preseismic behavior), two reported coseismic reactions of rabbits, dogs, and unspecified animals, and only one reported no reaction of dogs and unspecified animals to the strong shaking of a nearby earthquake. Thus, from the mass media standpoint, it is apparent that the main interest is on anticipating earthquakes and what animals can tell us about it and not much interest on coseismic or postseismic reactions, whose relevance have also been documented in scientific literature (Papastamatiou, 1983; Kirschvink, 2000).

Specifically, from the 13 articles that applied to the Colombian territory, five were mostly of anecdotal character and only seven described AAB related to actual earthquakes: February 8th, 1995; Mw 6.4 near Calima (Darién); July 24th, 2005, ML 3.0 near La Virginia; April 21st, 2013 (a small-magnitude volcanic earthquake) near Nevado del Ruiz; July 29th, 1967, Mw 6.8 near Betulia; January 25th, 1999, Mw 6.1 near Armenia; and December 24th, 2019, Mw 5.9 near Lejanías. The Calima (Darién), Betulia, and Armenia earthquakes are listed in the SISHC (see Data and Resources), but no reports of AAB were found associated to them during the first-stage search.

Comparing the results with those of the first-stage search (Spreadsheet S1), some interesting aspects are highlighted: (1) Earthworms can be added to the spectrum of animals in Colombia that appear to show AAB in relation to earthquakes, this means a wider taxonomical variety with phylum Annelida, class Clitellata, order Opisthopora, family Megascolecidae, genus Amynthas, and species *A. corticis*.

The scarcity of earthworms AAB reports in Colombia (Fig. 7, 8) contrasts with results from studies around the world where they have traditionally been documented (Tributsch, 1982; Ikeya, 2004; Fidani, 2013; Hayakawa, 2013; Grant and Conlan, 2015); (2) rabbits were not found in any of the reports of the first-stage search and showed up in the second-stage search, adding the following taxonomical groups: Order Lagomorpha, family Leporidae, genus Oryctolagus, and species O. cuniculus (Fig. 7, 8). Again, AAB reports involving rabbits have been frequently mentioned (Wallace and Teng, 1980; Verrillo, 1980; Tributsch, 2005; Tributsch, 2013); (3) dogs are mentioned more than other animals (Fig. 6, 7, 8), a commonality with the results of the first-stage search.

Thus, in spite of the scarcity of cases and the noise that characterized the second-stage search, some clean data may be recoverable, which implies that folklore regarding animals and earthquakes deserves consideration and can be given some degree of credibility (Wallace and Teng, 1980; Tributsch, 1982; Turner, 1982; Hédervári, 1983; Chen and Wang, 2010).

Abnormal versus normal animal behavior

In this investigation many reports of a variety of animals reacting to earthquakes have been compiled and any documented observation was dubbed Abnormal Animal Behavior (AAB). Other terms have been used in the literature to describe animal behavior that deviates from normal: Unusual animal behavior (Buskirk et al., 1981; De Liso et al., 2014); abnormalities of activities in animals (Feng and Jiang, 1992); anomalous animal behavior (Ikeya et al., 1997); changes in animal activity (Grant et al., 2015); irregular animal behavior (Fidani, 2013); chaotic behavior of animals (Narayan et al., 2002); restless behavior of animals (Hédervári, 1983); peculiar animal behavior (Wang et al., 2006).

To formally or quantitatively state whether an animal exhibits abnormal behavior, a systematic monitoring of its biological signs or activities during a reasonable time would be needed to establish reference values that could be called base levels, and then, any data differing significantly from those may then be called abnormal. But this type of study is beyond the scope of this work. How abnormal is it for a dog or a group of dogs to bark in unison some night? How strange is it for the hens in a pen to cluck simultaneously? Dogs bark for many reasons: a territorial fight, food competition, a stranger approaching the boundaries of the farm. Hens may cluck because a rat or another predator came in to the pen.

Many of the AAB reports documented (Spreadsheet S1) where found in intensity questionnaires which contained a section entitled “Effects on objects and animals” with a nine-item list with check boxes that included the question: Did you notice any fright reaction in animals? Often times people just marked with an “x” indicating that they in fact observed that animals were showing signs of unrest (this is why many reports were assigned the “unspecified animal” denomination) and sometimes people complemented their answer explaining, in few words, what reaction they have seen, for example “the cows kneeled”.

Table 2. Summary of documented animal reactions found during the first-stage search. Only clearly described behaviors are included.

Timing	Animal	Reaction observed
Preseismic	Agouti	Fled in large groups towards the mountains, away from the sea.
	Birds (unspecified)	Did not alight; many died during the previous night, others agonized, fluttered, chirps turned into screeches.
	Cattle (unspecified)	Ran wandering about, knocked down fences; pawned the ground; bellowed.
	Chickens	Extremely noisy.
	Cow	Walked around the stake.
	Deer	Fled in large groups towards the mountains, away from the sea.
	Dogs	Howled, barked persistently.
	Doves	Showed indifference to food.
	Guinea pigs	Squealed.
	Hens	Clucked.
	Monkey (unspecified)	Fled in large groups towards the mountains, away from the sea.
	Peccary	Fled in large groups towards the mountains, away from the sea; some dove into the sea, disoriented.
	Pigs	Unique jumpiness.
	Scarabs	Came out from burrows.
	Sparrows	Chirped.
Coseismic	Birds	Flew in alarm.
	Bulls	Became restless and wanted out of their corrals.
	Buzzards	Flew in circles as if frightened; flew from roof of buildings seeking safety.
	Cattle (unspecified)	Came into town, mingling among people in the square; fled terrified; mooed, kneeled down; broke out of their corrals; wanted out of their corrals; fled; went to a different corral; crossed wire fences.
	Chickens	Ran.
	Cows	Got stunned while grazing; mooed;
	Dogs	Barked, howled; ran frenzied; disoriented German Shepherd attacked owner; wanted out of corral; went into the house.
	Fish (unspecified)	Died in large numbers.
	Goats	Bleated.
	Hens	Grasped the ground with their wings.
	Horses	Remained still with rigid legs; ran about the town´s square; pulled on the ropes to break free and neighed; bucked; kneeled and rose again; threw rider to the ground; stomped over a young girl; kneeled down.
	Mice	Died asphyxiated by gases.
	Mules	Lost equilibrium; fell and rolled over; bent their front legs.
	Parrots	Came down from their stands.
	Pigeons	Flew away from nests.
	Pigs	Snorted.
	Poultry (unspecified)	Squawked and flew leaving their roosts.
	Roosters	Behaved raucously.
	Snakes	Died asphyxiated by gases.
	Steers	Wanted out of their corrals.
Postseismic	Bulls	Approached town mooing and bellowing.
	Cattle (unspecified)	Fled frightened and mooed; bleated
	Cows	Approached town mooing and bellowing.
	Dogs	Howled persistently; increased number of bites, remained on debris of ruined house.
	Fish	Died in muddy river waters; died in large numbers and ended on the beaches.
	Horses	Died by fire from mud volcano explosion.
	Pigeon	Fluttered over debris.
	Pigs	Died by fire from mud volcano explosion.
	Sheep (lamb)	Bent their forelegs.

Table 3. Summary of documented animal reactions found during the second-stage search. Only clearly described behaviors associated to real earthquakes are included.

Timing	Animal	Reaction observed
Preseismic	Earth-worms	Clews of earthworms desperately crawled on the sidewalks to die in the open.
Coseismic	Dogs	Ran aimlessly, very frightened.
	Rabbits	Ran aimlessly, very frightened.

As compared to reports from around the world, commonly described preseismic AAB include: Dogs persistently barking and howling; cattle walking or running around the stake, and cattle bellowing. Likewise, commonly documented coseismic reactions include: dogs attacking their owners; cattle bellowing, cows mooing; uneasiness of pigs; horses and cattle trying to break free; horses that refuse to move or to be ridden; horses behaving wildly; parrots acting strangely; fish showing up ashore; pigeons leaving nesting places; hens becoming quiet; roosters crowing excessively; and crawling out of worms (Deng et al., 1981; Tributsch, 1982; Nikonov, 1992; Fidani, 2013; Tributsch, 2013).

Known postseismic reactions include dogs barking after seismic events; horses neighing louder after a mainshock, twittering of birds following a mainshock and before aftershocks; fish found dead in lakes after a mainshock, and sheep acting nervously (Fidani, 2013). Some preseismic reactions reported here, but not commonly documented elsewhere, are: mules that fall and roll over, horses and mules that bend their forelegs, and scarabs coming out of their burrows. Finally, an unusual coseismic reaction reported here was that of hens grasping the ground with their wings.

5. CONCLUSIONS

The judicious two-stage documental search for reactions of animals around the time of earthquakes in Colombia and its vicinity and the analysis of data lead to the following conclusions:

Between the early XVII century and 2016 there have been many damaging earthquakes with hundreds of associated Abnormal Animal Behavior (AAB) reports that occurred specially during the coseismic times. Preseismic reactions, which have been a subject of research for decades, represent a minor percentage of the data from the first-stage search and the nature of the reports precludes determining more precisely the timing for precursory reactions.

In the second-stage search allusions to preseismic reactions dominate, but they are mostly deemed as anecdotal. The localities of AAB reports coincide with the orientation of main tectonic features and follow the general spatial distribution of epicenters. Considering only the AAB reports found in the first-stage search, there is a variety of animals that react to earthquakes, represented by two phyla, five classes, 14 orders, 18 families, 16 genera, and 16 species. Among the latter, *C. familiaris* and *B. taurus* always stand out in numbers of reactions throughout the seismic cycle. E. caballus shows noticeable coseismic behavior whereas G. gallus does react during coseismic and preseismic times. The AAB reports have persisted for centuries and their frequency is marked by peaks around the time of very destructive earthquakes in 1875, 1906, 1950, 1992, and 2004.

At the class level, Mammalia, Aves, and Osteichthyes show noticeable reports, but the latter apparently stopped after the 1992 Murindó earthquake. The second-stage search produced a smaller sample of credible AAB reports, but highlighted the relevance of oral tradition.

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DECLARATION OF CONFLICT OF INTEREST

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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SUPPLEMENTARY DATA

Annex 1. Text S1.doc
Annex 2. Spreadsheet S1.xlsx
Annex 3. Table S1.doc
Annex 4. Presentation S1.pptx
Ver: https://doi.org/10.32685/0120-1425/bol.geol.51.1.2024.716

DATA AND RESOURCES

A report on abnormal animal behavior from ancient Greece was consulted from http://www.helike.org/paper.shtml (last accessed on July 15, 2023).

The Report of the State Earthquake Investigation Commission for the 1906 San Francisco earthquake was consulted using

https://oac.cdlib.org/view?docId=hb1h4n989f&query=&brand=oac4 (last accessed on July 15, 2023).

Recent information on the Fat Fish was obtained from https://www.ictiologiaycultura.com/finding-the-fat-fish (last accessed on July 15, 2023).

The Information System for Colombian Historical Seismicity (Sistema de información de sismicidad histórica de Colombia-SISHC) database was searched using http://sish.sgc.gov.co/visor/ (last accessed on July 15, 2023).

The seismicity catalog of the Colombian National Seismological Network (Red Sismológica Nacional de Colombia) was searched using http://bdrsnc.sgc.gov.co/paginas1/catalogo/Consulta_Experta/consultaexperta_2.php (last accessed on July 15, 2023).

A class research paper on Abnormal animal behavior and the prediction of earthquakes was consulted using http://www.ltpaobserverproject.com/uploads/3/0/2/0/3020041/abnormal_animal_behavior_and_the_prediction_of_aerthquake.pdf (last accessed on July 15, 2023).

The database of the twenty largest earthquakes in the world since 1900 was consulted using https://www.usgs.gov/programs/earthquake-hazards/science/20-largest-earthquakes-world-1900 (last accessed on July 15, 2023).

Additional files are available as Supplementary Material in the online version of this article. Supplementary Material is composed of four files: Spreadsheet S1, Text S1, Table S1, and PowerPoint Presentation S1.

REFERENCES

Anderson, C. J. (1973). Animals, earthquakes, and eruptions, Field Mus. Nat. His. Bull. 44, 9-11.

Raleigh, C. B., G. Bennett, H. Craig, T. Hanks, P. Molnar, A. Nur, J. Savage, C. Scholz, R. Turner, and F. Wu (1977). Prediction of the Haicheng earthquake, Eos Trans. AGU. 58, 236–272.

Buskirk, R. E., C. Frohlich, and G. V. Latham (1981). Unusual animal behavior before earthquakes: Review of possible sensory mechanisms, Rev. Geophys. Space. Phys. 19, 247–270.

Chen, Q., and K. Wang (2010). The 2008 Wenchuan earthquake and earthquake prediction in China, Bull. Seism. Soc. Am. 100, 2840–2857.

Deng, Q., P. Jiang, L. M. Jones, and P. Molnar (1981). A preliminary analysis of reported changes in ground water and anomalous animal behavior before the 4 February 1975 Haicheng earthquake, In Earthquake prediction: An international review David W. Simpson and Paul G. Richards (Editors), American Geophysical Union, Washington DC, 543–565.

De Liso, G., and C. Fidani (2014). Seismic precursory phenomenology in unusual animal behaviour in Val Pellice, Western Piedmont, in comparison with anomalies of some physical parameters, Open J. Earthquake Res. 3, 30–42.

De Liso, G., C. Fidani, and A. Viotto (2014). Multi-parametric monitoring system of associated seismic phenomenology and unusual animal behaviour in Western Piedmont, Adv. Res. 2, 303–319.

Dust, E. (2017). Possibilities and Limits of Earthquake Prediction Using of Animals, Epubli, Berlin.

Evernden, J. F. (1982). Earthquake prediction: What we have learned and what we should do now, Bull. Seism. Soc. Am. 72, S343–S349.

Fan, F. (2018). ¿Can animals predict earthquakes? Bio-sentinels as seismic sensors in communist China and beyond, Stud. Hist. Philos. Sci. 70, 58–69.

Fay, R. R. (1980). Sensory mechanisms for low-frequency vibration detection in fishes, In Conference XI Abnormal Animal Behavior Prior to Earthquakes II Ruth E. Buskirk and Jack F. Evernden (Editors), United States Geological Survey, Menlo Park, California, 63–91.

Feng, C., and J. Jiang (1992). Quantitative observation and study on rhythmic abnormalities of activities in animals prior to earthquakes, Acta Seismol. Sin. 5, 857–865.

Fidani, C. (2013). Biological anomalies around the 2009 L'Aquila earthquake, Animals, 3, 693–721.

Gans, C. (1976). Can animals predict earthquakes? Overview and proposal, In Conference I: Abnormal Animal Behavior prior to Earthquakes I Jack F. Evernden (Editor), United States Geological Survey, Menlo Park, California, 272–282.

Gómez, J., A. Núñez–Tello, D. Mateus–Zabala, F. A. Alcárcel–Gutiérrez, R. M. Lasso–Muñoz, E. Marín–Rincón, and M. P. Marroquín–Gómez, (2020). Physiographic and geological setting of the Colombian territory, In The Geology of Colombia, Volume 1 Proterozoic – Paleozoic Jorge Gómez and Daniela Mateus–Zabala (Editors), Servicio Geológico Colombiano, Bogotá DC, 1–16.

Gordon, D. M. (1977). Can catfish anticipate earthquakes: A study of the typical diurnal behavior of Ictalurus melas and Ictalurus punctatus, Master´s Thesis, Stanford University, 46 p.

Gori, P. L. (1993). The social dynamics of a false earthquake prediction and the response by the public sector, Bull. Seism. Soc. Am. 83, 963–980.

Grant, R. A., and T. Halliday (2010). Predicting the unpredictable; evidence of pre-seismic anticipatory behaviour in the common toad, J. Zool. 281, 263–271.

Grant, R. A., and H. Conlan (2013). Frog swarms:¿Earthquake precursors or false alarms?, Animals, 3, 962–977.

Grant, R. A., and H. Conlan (2015). Behavioral response of invertebrates to experimental simulation of pre-seismic chemical changes, Animals, 5, 206–213.

Grant, R. A., J. P. Raulin, and F. T. Freund (2015). Changes in animal activity prior to a major (M=7) earthquake in the Peruvian Andes, Phys. Chem. Earth. 85-86, 69–77.

Hayakawa, M. (2013). Possible electromagnetic effects on abnormal animal behavior before an earthquake, Animals, 3, 19–32.

Hédervári, P. (1983). Project on collection and evaluation of data on earthquake light phenomena, Bull. Seism. Soc. Am. 73, 889–890.

Hentig, H. V. (1923). Reactions of animals to changes in physical environment, J. Comp. Psychol. 3, 61–71.

Hough, S. (2006). Unsung heroine, Seismol. Res. Lett. 77, 742–743.

Howell, Jr., B. F., and C. F. Richter (1977). Second award of the medal of the Seismological Society of America, Bull. Seism. Soc. Am. 67, 1243–1247.

Ikeya, M., T. Komatsu, Y. Kinoshita, K. Teramoto, K. Inoue, M. Gondou, and T. Yamamoto (1997). Pulsed electric field before Kobe and Izu earthquakes from seismically-induced anomalous animal behavior (SAAB), Episodes, 20, 253–260.

Ikeya, M. (2004). Earthquakes and Animals: From Folk Legends to Science, World Scientific, Singapore.

Kalmijn, A. J. (1980). Research on electric and magnetic field detection, In Conference XI Abnormal Animal Behavior Prior to Earthquakes II Ruth E. Buskirk and Jack F. Evernden (Editors), United States Geological Survey, Menlo Park, California, 110–113.

Kanamori, H. (1977). The energy release in great earthquakes, J. Geophys. Res. 82, 2981–2987.

Kenagy, G. J., and J. T. Enright (1980). Animal behavior as a predictor of earthquakes? An analysis of rodent activity, In Conference XI Abnormal Animal Behavior Prior to Earthquakes II Ruth E. Buskirk and Jack F. Evernden (Editors), United States Geological Survey, Menlo Park, California, 178–197.

Kirschvink, J. L. (2000). Earthquake prediction by animals: Evolution and sensory perception, Bull. Seism. Soc. Am. 90, 312–323.

Klein, B. (2001). "Folklore", In International Encyclopedia of the Social and Behavioral Sciences, volume 8, Neil J. Smelser and Paul B. Baltes (Editors), Elsevier, New York 5711-5715.

Kreithen, M. L. (1980). Detection of sound and vibration by birds, In Conference XI Abnormal Animal Behavior Prior to Earthquakes II Ruth E. Buskirk and Jack F. Evernden (Editors), United States Geological Survey, Menlo Park, California, 13–28.

Miles, C. (1942). Descripción sistemática del "pez graso" del Lago de Tota (Boyacá), Caldasia, 5, 53–58.

Mojica, J. I., G. Galvis, I. Harrison, and J. Lynch (2012). Rhizosomichthys totae, Miles 1942, In Libro Rojo de Peces Dulceacuícolas de Colombia 2012 José I. Mojica, José S. Usma, Ricardo Álvarez, and Carlos A. Lasso (Editors), Instituto de Investigación de Recursos Biológicos Alexander von Humboldt, 53–55.

Moulton, D. G. (1980). Odorant emissions preceding earthquakes and odor detection and recognition in animals, In Conference XI Abnormal Animal Behavior Prior to Earthquakes II Ruth E. Buskirk and Jack F. Evernden (Editors), United States Geological Survey, Menlo Park, California, 156–177.

Mueller, R. (1909).¿Can animals predict earthquakes?Sci.Am.1754, 100.

Narayan, J. P., M. L. Sharma, and A. Kumar (2002). A seismological report on the 26 January 2001 Bhuj, India earthquake, Seismol. Res. Lett. 73, 343–355.

Nikonov, L. L. (1992). Abnormal animal behaviour as a precursor of the 7 December 1988 Spitak, Armenia, earthquake, Nat. Hazards, 6, 1–10.

Papastamatiou, D. (1983). Field report of an earthquake in Renaissance Europe, Bull. Seism. Soc. Am. 73, 1243–1251.

Raleigh, B. (1982). A strategy for short-term prediction of earthquakes, Bull. Seism. Soc. Am. 72, S337-S342.

Ramírez, J. E. (1975). Historia de los Terremotos en Colombia, Instituto Geográfico Agustín Codazzi, Bogotá (in Spanish).

Scholfield, A. F. (1959). Aelian. On the Characteristics of Animals, II, Books VI-XI. Harvard University Press, Cambridge, 385–387.

Simon, R. B. (1976). Preliminary report on experiments to record anomalous animal behavior as possible earthquake precursors, Earthq. Notes, 47, 10–11.

Sims, M. C. and S. Martine (2005). Living Folklore: An Introduction to the Study of People and their Traditions, Utah State University Press, Logan, 1-2.

Skiles, D. D., R. G. Lindberg, and P. Hayden (1980). An experimental search for correlations between anomalous activity of captive Fossorial Rodents and subsequent seismic events, In Conference XI Abnormal Animal Behavior Prior to Earthquakes II Ruth E. Buskirk and Jack F. Evernden (Editors), United States Geological Survey, Menlo Park, California, 198–224.

Tributsch, H. (1982). When the Snakes Awake. Animals and Earthquake Prediction. The Massachusetts Institute of Technology Press, Cambridge.

Tributsch, H. (2005). The bionic anticipation of natural disasters, J. Bionic Eng. 2, 123–144.

Tributsch, H. (2013). Bio-mimetics of disaster anticipation—learning experience and key-challenges, Animals, 3, 274–299.

Turner, R. H. (1982). Media in crisis: Blowing hot and cold, Bull. Seism. Soc. Am. 72, S19–S28.

Verrillo, R. T. (1980). Some aspects of vibrotactile responses in animals and man, In Conference XI Abnormal Animal Behavior Prior to Earthquakes II Ruth E. Buskirk and Jack F. Evernden (Editors), United States Geological Survey, Menlo Park, California, 30–62.

Wallace, R. E., and T. Teng (1980). Prediction of the Sungpan-Pingwu earthquakes, August 1976, Bull. Seism. Soc. Am. 70, 1199–1223.

Wang, K., Q. Chen, S. Sun, and A. Wang (2006). Predicting the 1975 Haicheng earthquake, Bull. Seism. Soc. Am. 96, 757–795.

Wikelski, M., U. Mueller, P. Scocco, A. Catorci, L. V. Desinov, M. Y. Belyaev, D. Keim, W. Pohlmeier, G. Fechteler, and P. Martin Mai (2020). Potential short-term earthquake forecasting by farm animal monitoring, Ethology, 126, 931–941.

Woith, H., G. M. Petersen, S. Hainzl, and T. Dahm (2018). ¿Can animals predict earthquakes? Bull. Seism. Soc. Am. 108, 1031–1045.

Wood, H. O. (1911). The observation of earthquakes: A guide for the general observer, Bull. Seism. Soc. Am. 1, 48–82.

Yamanaka, Y., Y. Tanioka, and T. Shiina (2017). A long source area of the 1906 Colombia–Ecuador earthquake estimated from observed tsunami waveforms, Earth Planets Space, 69, 163.

Yoshimoto, M., H. Kumagai, W. Acero, G. Ponce, F. Vásconez, S. Arrais, M. Ruiz, A. Alvarado, P. P. García, V. Dionicio, O. Chamorro, Y. Maeda, O. Chamorro, and M. Nakano (2017). Depth-dependent rupture mode along the Ecuador–Colombia subduction zone, Geophys. Res. Lett. 44, 2203–2210