Open Journal of Earthquake Research, 2014, 3, 30-42
Published Online February 2014 (http://www.scirp.org/journal/ojer)
http://dx.doi.org/10.4236/ojer.2014.31005

Seismic Precursory Phenomenology in Unusual Animal Behaviour in Val Pellice, Western Piedmont, in Comparison with Anomalies of Some Physical Parameters

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Received December 20, 2013; revised January 19, 2014; accepted February 9, 2014

ABSTRACT

The unusual animal behaviour, often observed before earthquakes in a moderate seismic area in Western Piedmont (NW Italy), can be connected with the anomalies of some physical parameters, recorded in a multiple parameters monitoring. Physical phenomena such as radioactive decay, gas emission, soil temperature increase, water pH variations in creeks and lakes, magnetic declination anomalies, air electricity and infra-sound, can generate damages to biological structures or, sometimes, death. A multiple parameters physical monitoring started recently in Western Piedmont, which is useful to propose the study of seismic precursors possibly linked to animal behaviour. Observations of unusual animal behaviour as vocal communications and movements were collected in the same area. A statistical analysis of strange behaviours in dogs and cats may indicate the probable early warning factor of the sense of smell.

KEYWORDS

Unusual Animal Behaviour; Earthquake Early Warning; Radon Monitoring; Electromagnetic Monitoring; Sound Monitoring; Temperature Monitoring

1. Introduction

The unusual animal behaviours, often observed before earthquakes in a moderate seismic area in Western Piedmont (NW Italy), and the observation of anomalies of some physical parameters, induced the Authors to create the "Seismic Precursors Study Centre" (SPSC). SPSC is located in de Liso's house, in Torre Pellice (44˚49'23"N, 7˚12'04"E, Western Piedmont, NW Italy) at 699 m above sea level on Vandalino Mountain, not too far from an abandoned iron mine, near a particular "geological sanctuary" on "Castelluzzo" peak [1] and Bonnet, which are rich in augen-gneiss, of eruptive origin, biotite, ophiolite, zeolite, pechblenda and "Luserna Stone" (gneiss) [1].

SPSC is also close to a forest, at a distance of 70 m from the Biglione creek, 600 m from a graphite mine, and 12 km far from the talc mines of Prali. The moderate seismic activity (the recent classification of the seismic risk for this area is 3S) in a region of intrusive rocks with geothermal activity, local emission of Radon^{222} and sulphurous gases, "mistpoeffers", Earthquake Lights (EQL), can give Vandalino Mountain a good opportunity to be an excellent area to study pre-seismic phenomenology, with contemporaneous observations of unusual animal behaviours and monitoring of some physical parameters.

It must be remembered that Val Pellice was the theatre of historical earthquakes with great magnitudes, as the famous seismic event of April 2nd 1808, with a magnitude M recently estimated in 5.7 [2]; regarding this earthquake, we have an interesting relation of physicist G. Eandi and of Captain L. Garola about pre-seismic anomalous animal behaviours and weather anomalies [3], similar to

those we observed now. Despite the fact that the earthquake destoryed most of the houses, only four were the victims. At the moment of the earthquake, most farmers were outside, working in the fields. Some people inside houses saved themselves, due to the agitation of their cows, a few seconds before the seismic shock. This information appears both in the oral tradition and in a few letters [4]. It is notable that two centuries later, as reported in the observational section of this work, observations regarding similar phenomena were made before earthquakes in the same region.

Generally, local seismic events are seldom announced by anomalous animal behaviours [5]. Unfortunately, we do not understand animal languages or their meaningful vocal modulations. Moreover, many animal alarms are not acknowledged. A number of animal and human observations in Northern Italy are reported, which can suggest physical observations potentially connected with seismic events. The study of seismic precursors is still in its infancy and the error margin on temporal and spatial forecast is still large and must be evaluated. Being so, a multiple parameter physical monitoring started recently in Western Piedmont, which is useful to propose the study of seismic precursors possibly linked to animal behaviours. Electric and magnetic detectors were operating together with alpha particle and acoustic detectors, while a collection of anomalous biological and meteorological observations was taken. In case of some local unusual animal behaviours, the occurrence of a local seismic event with epicentre distance ≤ 100 km can be suggested. Statistical information on warnings from local dogs and cats is resumed and discussed.

2. Observations

The observation of animal behaviours began in 1991, when it was noted that some unusual recurrences in animal behaviour occurred before earthquakes. The modality of observation of animal behaviours can be resumed in the following: two dogs and four cats live within SPSC. Being so, their behaviours and vocal communications can be directly observed by the first Author thanks to their great feeling and closeness. Since 2006, their behaviours were observed for five days a week, at least five hours a day for dogs and four hours a day for cats. Moreover, since 2006, observations in the wood near SPSC were undertaken every night (at 1:00 - 2:00 a.m. LT) to observe the wild animals that would eventually come to eat the food that was provided in a place, always the same. Vocal language of animals was heard and noted, especially of birds of prey. Since 2006, for five days a week, the dead arachnids in SPSC were counted at 6:30 a.m. LT. Since 1991, the first Author conducted irregular observations of the behaviours of other wild animals that come near SPSC and hearings of farm animals (it is possible only to hear the vocal language of farm animals, as they live in farms or in pens not too far from SPSC). The observations of animals, which are resumed in **Table 1**, were recorded in a notebook and then compared "a posteriori" with a multiple physical monitoring and with seismic events. Observational results for animal behaviour and statistical features confirm the cases reported and discussed by Tsuneji Rikitake [6,7], even if not yet in a similar extended work.

These observations were supported by a multi-parameter monitoring gradually more complex since 1998 [8-10]. Starting in 2000, a daily monitoring for radioactivity and air temperature measurements have been undertaken at night in the forest near SPSC. The air temperature values were recorded from a little rock crack and water temperature measurements were intermittently recorded in the Biglione creek near SPSC. Since 2011, a continuous radon monitoring started in the basement of SPSC. Since 2012, irregular radon monitoring started by mean of dosimeters, located in some places inside and outside (garden) SPSC. Since May 2012, a station of the Central Italy Electromagnetic Network (CIEN), a ground thermometer and a meteorological station were installed in SPSC. Characteristic ELF signals are monitored in relation to seismic activity [11]. VLF and LF ranges allow monitoring several sub-ionospheric signals from different VLF and LF transmitters overlapping in the same channels, which is a necessary feature of a reliable system that is able to verify a single channel perturbation from at least two signals. Additionally, differently located sub-ionospheric channel monitoring stations of CIEN are able to realise overlapping [12]. Since July 2012, weekly measurements of water pH were started in the garden near SPSC and in the Biglione creek. The instruments in SPSC basement are resumed in **Table 2**.

3. Unusual Animal Behaviour before Earthquakes

Near SPSC there are several farms, so it is possible to observe farm and wild animals every day. Considering the behaviour, the animal language can be better understood if the farm and wild animals are observed in their habitual environment. When the epicentre distance to SPSC was inferior to 15 - 20 km, with a low magnitude ($M \leq 2$), some unusual animal behaviours were always noted, a few days, a few hours and a few seconds before the seismic event, with different modalities for the three cases described as follows. But the same unusual animal behaviours were observed before earthquakes with epicentre distances to SPSC progressively increasing, if there was also a progressive increase in the magnitude.

Table 1. Study of animal behaviour.

Animal species observed	Observation place	Observation period	Number of animals	Monitoring modality	Typology of observation place
Dog	SPSC	1991-2006	1	5 hours a day, for 7 days a week, for 10 months a year; living together	Basement
Italian wolf	SPSC	2001-2006	1	5 hours a day, for 7 days a week, for 10 months a year; living together	Basement
Dog	SPSC	2007-2013	2	5 hours a day, for 5 days a week, for 12 months a year; living together	Basement
Cat	SPSC	1991-2006	6	4 hours a day, for 7 days a week, for 10 months a year; living together	Basement
Cat	SPSC	2007	6	4 hours a day, for 5 days a week, for 12 months a year; living together	Basement
Cat	SPSC	2008-2013	4	4 hours a day, for 5 days a week, for 12 months a year; living together	Basement
Insects, arachnids	SPSC and garden near SPSC	1991-2006	Numerous	1/2 hour a day, for 7 days a week, for 10 months a year; visual observation	Cellar, basement, garden, wall of de Liso's house
Insects, arachnids	SPSC	2007-2013	Numerous	1/2 hour a day, for 5 days a week, for 12 months a year; visual observation	Cellar, basement, garden, wall of de Liso's house
Dog	Farms near SPSC	1991-2006	Numerous, over 30	Irregular hearing observations for 7 days a week, for 10 months a year	Farms, distance to SPSC from 300 m. to 1500 m.
Dog	Farms near SPSC	2007-2013	Numerous, over 30	Irregular hearing observations for 5 days a week, for 12 months a year	Farms, distance to SPSC from 300 m. to 1500 m.
Owl, barn-owl	Wild area near SPSC	1991-2013	Numerous	Irregular visual and hearing observations	Forest near SPSC and near Biglione creek, distance to SPSC from 7 m. to 300 m.
Crow, rook	Wild area near SPSC	1991-2013	Numerous	Irregular visual and hearing observations	Forest near SPSC and near Biglione creek, distance to SPSC from 7 m. to 300 m.
Magpie	Wild area near SPSC	1998-2006	Numerous	2 time a day for 1/2 h every time, for 10 months a year; visual and hearing observations	Forest near SPSC and near Biglione creek, distance to SPSC from 7 m. to 300 m.
Magpie	Wild area near SPSC	2007-2013	Numerous	2 time a day for 1/2 h every time, for 12 months a year; visual and hearing observations	Forest near SPSC and near Biglione creek, distance to SPSC from 7 m. to 300 m.
Buzzard	Wild area near SPSC	1999-2006	2	2 time a day for 1/2 h every time, for 10 months a year, visual and hearing observations	Forest near SPSC and near Biglione creek, distance to SPSC from 7 m. to 300 m.
Buzzard	Wild area near SPSC	2007-2013	2	2 time a day for 1/2 h every time, for 12 months a year, visual and hearing observations	Forest near SPSC and near Biglione creek, distance to SPSC from 7 m. to 300 m.
Viper	Garden of SPSC	1998-2006	2	Irregular visual observations	SPSC, garden near SPSC
Salamanders, toads	Garden of SPSC	1991-2013	4	Irregular visual observations	SPSC, Garden near SPSC
Hedgehog	Garden of SPSC	1995-2013	2	Irregular hearing observations	Garden and forest near SPSC, distance to SPSC from 7 m. to 300 m.

Continued

Fox	Wild area near SPSC	1991-2013	2	Irregular visual and hearing observations	Garden and forest near SPSC, distance to SPSC from 7 m. to 70 m.
Wolf	Wild area near SPSC	1991	1	Irregular visual and hearing observations	Garden and forest near SPSC, distance to SPSC from 7 m. to 70 m.
Squirrel	Garden of SPSC	1991-2013	4	Irregular visual and hearing observations	Garden and forest near SPSC, distance to SPSC from 7 m. to 70 m.
Cow, sheep, goat, cock, chicken	Farms near SPSC	1991-2013	Numerous	Irregular hearing observations	Farms near SPSC, with farms distance to SPSC from 300 m. to 1500 m.
Donkey	Farms near SPSC	1999-2013	2	Irregular hearing observations	Farms near SPSC, first farm is 300 m. from SPSC, second farm is 500 m. from SPSC
Limacidae, earth-worm	Farms near SPSC	1991-2013	Numerous	Irregular observations	Garden and SPSC basement

Table 2. Instruments in SPSC and nearby area.

Physical parameter	Instrumentation	Measurement unit and sensitivity	Monitoring modality	Place of monitoring	Period of monitoring
Magnetic induction	1 TreField EM Meter	0.1 - 100 μT in logarithmic scale	2 time/day for 1/2 h every time	On gneiss in SPSC and nearby area	1999-2013
Magnetic declination δ	4 compasses Virginia 6036VA	sensitivity of ±0.5˚	2 time/day for 1/2 h every time	2 on wood, 2 on iron surfaces in basement	1998-2013
β, γ particles	1 Geiger Ю нчмер SKM 05	Scale 0.1 - 99.9 μS/h; alarm at 0.5 μS/h; data every second	2 time/day for 1/2 h every time	SPSC/garden, on big rock crack	2003-2013
$Radon^{222}$ α particles	1 Radon-meter detector (Geoex, model 1027)	Measurements in pC/l	Continuous: PC connection	basement, at 0.30 m from the floor, on gneiss	2011-2013
Temperature	1 analogical thermometer	Degrees Celsius (±0.1˚C)	2 time/day at the same hours	In cellar and in Biglione creek	1999-2013
Temperature	1 thermometer TM-917 DICOM	from −100˚C to + 132˚C (±0.1˚C), every 0.4 sec.	Continuous: PC connection	In cellar, at a depth of 2 meters in the soil;	2013
Temperature, pressure/humidity	PCE-FWS 20	Digital measurements: Celsius degrees, hPa, %	2 time/day at the same hours	On the roof of the house	2013
Water pH	Litmus papers	----------	1 time/week	SPSC/garden/Biglione	2012-13
Infra-sounds	Infrasonic 200, Aetech,	5 samples/second	Continuous: PC connection	SPSC, at 1.20 m from the floor and 5 cm distance to a wall of the basement.	2013
EM signals: ELF, VLF and LF	CIEN electrodes	4 Hz - 50 kHz	Continuous: PC connection	SPSC garden	2012-2013

The anomalous animal behaviours were observed with the following modalities:

1) particular vocal language in a tripartite sequence (in 3.1, 3.2, 3.3);

2) non-vocal anomalous behaviour different from the usual pattern (in 3.4);

3) problems to health and safety (in 3.5).

3.1. Particular Vocal Language in a Tripartite Sequence: Animal Alarms with Shrill and High Sounds

The acoustic perception of vocal alarms can concern a large area, it gives concise information and it is easier to note. The animal vocal alarm is a particular vocal language, which seems aimed at its own species. It is an individual answer to a danger or a co-ordinate answer of the leading animal to the same danger. It can be supposed that the vocal animal alarm is a “thought answer”, which expresses oneself as a dialogue with other animals or with humans. A few hours and sometimes days before seismic events, animal agitation is now well known in scientific literature [13,14]. It was supposed that this behaviour is possibly due to ultra-sounds emitted by rocks [14], electric and magnetic variation [14], or presence of

dangerous gases [5,8,14]. The emission of ultra-sounds before rock fractures was demonstrated with the experimental work on local characteristic “Luserna stone” [15, 16].

The first Author has individuated a particular tripartite sequence in the vocal alarms of domestic animals and birds: phase A, lasting up to 2 hours, with shrills and high sounds, from 30 minutes until 10 hours before the earthquake, then, when cries stop simultaneously, phase B follows, with a strange and worrisome silence; finally phase C, with animal cries normally 20 - 40 seconds before the earthquakes, a few times 5 - 10 seconds before, generally stopping few seconds before the shock. Phase C is corroborated by the observations of other researchers in case of other earthquakes [5,17-19]. The vocal animal alarms beginning up to 10 hours before local earthquakes, sometimes before distant earthquakes if the future magnitude is great, are contemporaneous to observations of drastic reduction of variations in intensity and declination of the magnetic field and of radioactivity values observed in SPSC [10]. **Figures 1(a)** and **(b)** resume an interesting relation between seismic epicentre distances to SPSC, magnitude and percentage of unusual animal behaviours, in relation to domestic animal cries and to bird songs, noted before the same seismic event. Unusual animal behaviours were taken into account only for those species whose normal behaviour is known.

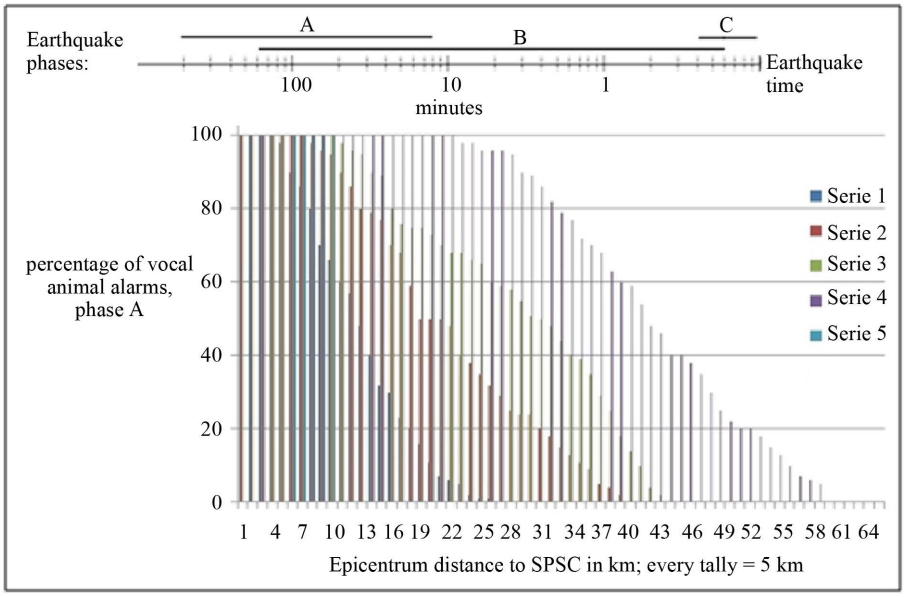
During phase A, dogs, cattle, sheep, equines, bats, birds cry all together simultaneously, for a long time and sometime up to half an hour, with agitation, emitting shrills, howls or high sounds. Then, they stop their laments all together, with a stupefying synchrony [8,17]. This silence may last 3 - 5 hours before the local first seismic shock and it is strange and worrisome, like the quiet that precedes the storm. It is interesting to observe that dogs living in farms, as opposed to dogs that live in urban areas, at first ululate. These howls are similar to those they emit when they hear ambulances or church bells. Then, dog howls modulate into barking, at the same time, with short and repeated sounds. This barking is composed by two articulations with an ascendant order of frequencies for all dogs, but dogs of small size repeat the same vocalization more frequently in a minute, the two articulations forming a dissonant interval occur. In case of ambulances or church bells, only dogs cry, not other animals, and they stop their cries when ambulances or bells stop their sound: so dogs do not bark after (it is possible to know the journey of the ambulance by the howls of the different dogs along the way). In case of seismic precursors, the barks after the howls are very prolonged and contemporaneous.

Cocks also shrill, but with a vocalization composed by three sounds, on the same intonation, the last of them prolonged. This short scheme of three sounds is also repeated three times in sequences separated by short pauses, repeated many times with agitation. This agitation is similar to the same shown when there is a fox, a stone marten or a hawk. In these latter cases the tripartite phrase is interrupted by other phrases modulated differently with melodic variations on the last sound: in this case, cocks shrill on different moments according to their proximity to the “danger” and not all together and at the same time, as in case of a seismic event. Also magpies and crows chatter with agitation, but with cries similar to the bipartite sounds of dogs. This behaviour shows a tonal language for all these animal species and it is important for us to distinguish the musical sequence. **Figure 1(a)** shows the percentage of animal cries before seismic events on the y axis and the distance of hypocentre to SPSC on the x axis. The colours are related to the magnitude of the earthquake. Animal vocal alarms lasted from half an hour to one hour and half, if the magnitude of following seismic event was greater than 4.

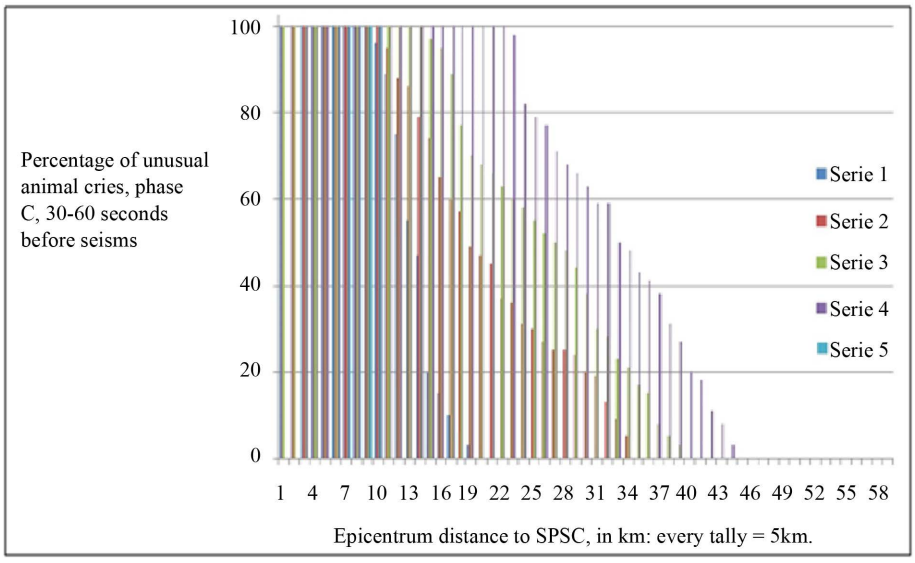
3.2. Instrumental Observations Associated to Strange Animal Behaviours

During phase A, little variations of the magnetic intensity and drastic reductions in variations of the magnetic angle declination were recorded. Magnetic anomalies started with great variations, a few days or some weeks before the earthquake but the sudden commencement did not coincide with the beginning of phase A. After the simultaneous vocal stop, the worrisome silence follows, the phase B. During phase B, a stop in the magnetic and electric variations and a stop of radon emission were always noted. The continuous monitoring of infra-sounds operating in SPSC shows the background noise to be comprised in the values 0.1 - 3 Hz, with several factor having an influence on it, like the Biglione creek nearby, whose flow variations can increase it up to 7 Hz. During phase A, we were not able to record in SPSC any difference in the background noise that can be related to a seismic event. Then, 30 - 40 seconds before the seismic shock (phase C) infra-sounds of 3.5 - 5 Hz were recorded, lasting a few seconds, with a particular progressive “crescendo” and then a progressive “decrescendo” of intensity. The Data-logger elaboration of the data recorded by the Infrasonic 200 shows for this “crescendo and diminuendo” a “Moorish arch” shape for the graphic representation of frequencies.

Usually, territorial competitions, sexual calls, dangers by intruders are expressed by domestic animals and birds with vocalizations not at the same time; these shrills are more varied as succession of frequencies, with longer phrases between pauses. Ache and loneliness (for dogs, cats, cattle and equines) give long vocalizations on two or three descendent frequencies, repeated more and more with reducing intensity. These are the differences be-



(a)



(b)

Figure 1. (a) percentage of unusual animal cries, phase A in relation to epicentre distance to SPSC and to magnitude; (b) percentage of unusual animal cries, phase C in relation to epicentre distance to SPSC and in relation to magnitude; series 1: 0 < M ≤ 1; series 2: 1 < M ≤ 2; series 3: 2 < M ≤ 3; series 4: 3 < M ≤ 4; series 5: 4 < M ≤ 5.

tween anomalous animal sounds during pre-seismic phases and normal animal sounds.

3.3. Statistical Behaviour of Dogs and Cats

A statistical study of unusual animal behaviours before earthquakes in Western Piedmont has been completed only for dogs and cats at this initial stage of study. Early warning signs as dog cries and cats hiding themselves were considered before 39 earthquakes around SPSC. The earthquakes were chosen according to their magnitudes and distances, approximately satisfying the Dobrovolsky condition [20], where the Dobrovolsky radius is

$$RD = 10^{0.43M} \quad (1)$$

considering seismic event distances RE = 1.5 RD [21] from SPSC. Table 3 resumes the principal observations, consisting of a total of 55 early warning signs, with 39 examples of dog cries and 16 examples of cats hiding themselves. These warnings occurred during phase A, therefore considering a shorter time span compared to observations of all different animals in all the phases, as calculated in past works. Therefore, frequency distribu-

Table 3. List of earthquakes near SPSC that can be linked with dog cries and cat hiding; Time (hh.mm.ss) is considered in LT; Depth is the depth of the earthquake hypocentre; Distance is the distance between the epicentre and the animal observation location; Dog and Cat columns represent observation times (in h) before the first shock.

	Date [mm/gg/aa]	**Time** [hh,mmss]	**Depth** [km]	**Distance** [km]	**Magnitude** [M_w]	**Dogs** [h]	**Cats** [h]
1	08/21/00	17.14'	7,4	91,7	4,6	7	7
2	07/18/01	22.47'	15	91,7	4,2	6,5	5,83
3	09/26/05	04.20'.38"	29	30,4	2,3	3	3,12
4	10/31/06	20.11'.08"	9,9	18,4	2,3	3,5	3,5
5	08/29/08	15.24'.23"	13	28,3	2,1	5,83	5,83
6	10/10/08	13.55'.39"	9,1	39,2	2,2	5	-
7	10/24/08	04.06'	10	97,5	4,1	7	7
8	03/19/09	12.39'.50"	43,3	51,7	4,1	8	-
9	03/23/09	20.01'.09"	10	36,4	2	6	-
10	04/19/09	13.39'	40	65	3,9	8	8
11	05/14/10	07.55'	9	35	2	5,33	-
12	09/29/10	03.46'.42"	10	62	3,3	7,67	-
13	11/11/10	18.24'.18"	13,5	14	2,1	8	-
14	11/11/10	21.57'.30"	13,2	24	2,2	2	-
15	11/14/10	20,31'58"	12,5	27,9	2,2	7,67	-
16	12/18/10	21,53'	18	18	2,3	10	8,67
17	12/22/10	11,02'	24	6	2,6	8	6,67
18	04/19/11	21,04'41"	18,5	45	2,7	5,5	5,5
19	07/23/11	16,56'53"	20	25,3	2,2	4,5	4,5
20	07/25/11	12,31'20"	25	17,2	4,3	8	6,67
21	01/26/12	3,23'52"	10,2	23,3	2	5,33	-
22	02/02/12	18,22'39"	10,2	32	3,9	8,78	-
23	02/05/12	7,26'14"	8,5	51,6	2,1	8	-
24	02/05/12	16,42'	8,4	31	2,1	7	-
25	02/26/12	22,37'55"	6,9	49,4	4,4	8,75	-
26	02/26/12	23,39'34"	6	48,9	3,3	9,78	-
27	02/27/12	16,31'20"	7,4	51,8	3,5	5,83	-
28	02/29/12	5,44'09"	11,8	16,5	2,7	8,03	-
29	09/29/12	21,06'32"	10	39,4	2	4,67	-
30	10/03/12	9,20'43"	10,02	43	3,9	8,08	8,08
31	10/04/12	17,27'47"	16,1	39	2,3	6,33	6,33
32	10/05/12	15,09'01"	11,7	38	2,4	6	-
33	12/31/12	12,48'06"	18,1	39,5	2,7	6	-
34	04/07/13	3,13'11"	10	54	3,3	8	6,67
35	04/13/13	17,30'38"	10,1	35	2,3	7	-
36	04/13/13	19,15'37"	10	39	2,1	7	-
37	04/17/13	13,37'39"	14,1	28,2	2,1	7,23	-
38	05/05/13	5,33'35"	9,7	40	2	6,33	-
39	05/06/13	9,5455"	9,4	30	2,1	8,72	8,72

tion, as shown in **Figure 2(a)**, was calculated relative to simple time t, as already shown in Rikitake [22]: its shape is well described by a Weibull distribution [23]. Following Rikitake [22], a function R(t) = 1 – F(t) was defined, where F(t) is the cumulative probability, **Figure 2(b)**, of an earthquake occurring during a period from 0 to t. A plot of Ln (Ln (1/R(t))) versus Ln (t) is shown in **Figure 2(c)**. The straight-line fitting in the figure, neglecting the lower values of Ln (t) for which a different distribution is probably valid [22], confirms that the recorded data can be roughly governed by a Weibull distribution with coefficients k = 7.58 10^{-6} and m = 5.636. Mean and standard deviation can be calculated through the Gamma function [23]

$$E = \left[k/(m+1)\right]^{-1/(m+1)} \Gamma\left[(m+2)/(m+1)\right] \quad (2)$$

and

$$\sigma = E\left\{\Gamma\left[(m+3)/(m+1)\right]/\Gamma^2\left[(m+2)/(m+1)\right]-1\right\}^{1/2} \quad (3)$$

respectively with E = 7.3 hours and σ = 1.3 hours, anticipating of some hours the general animal precursors [22], but according to previous results for dogs and cats [24].

Data from the phase C were excluded as they were considered to reveal dog and cat agitation at the time of P-wave arrival. Taking into account earthquake data, short timed warnings from dogs and cats resulted independent from the earthquake magnitude, according to other studies [13], even if small earthquakes can alarm dogs and cats later than in the case of greater earthquakes. Such small earthquakes have generally greater depths than other small earthquakes which usually alarm dogs and cats according to average values. Finally, great earthquakes influence dog and cat behaviour for any depths with more or less the same mean warning time. The warning time distributions were also plotted in separate charts for dogs (**Figure 3**) and cats (**Figure 4**). The straight line shown in **Figure 3(c)** confirms that the recorded data for dogs (**Figure 3(a)**) can also be governed by a Weibull distribution with coefficients k = 7.73 10^{-6} and m = 5.590, which corresponds to $E(t)$ = 7.4 hours and σ = 1.3 hours. And, the straight line shown in **Figure 4(c)** confirms that the recorded data for cats (**Figure 4(a)**) can also be governed by a Weibull distribution with coefficients k = 5.60 10^{-5} and m = 4.723, which corresponds to E = 6.9 hours and σ = 1.4 hours. **Figures 3(b)** and **4(b)** are the cumulative probabilities.

Even if a warning time difference of half an hour in dogs and cats is within the margin of error, it could reflect differences in some kind of perception between them: cats have the better sense of hearing, while dogs have the better sense of smell. Cats can detect higher frequencies of sound than many other mammals including dogs. The upper range of hearing in cats is about 60 to 65 kHz, which allows them to hear both their kittens and the ultrasonic calls of rodents. Smell is the most developed sense in dogs and overcomes the sense of smell of cats, as the formers have more than 10 times (up to 300 millions) the number of odour sensitive cells of the latters. Being so, dogs are able to sense gases coming from the ground before cats and begin to cry, but they are not able to escape from SPSC because of their size. When cats smell the same gases, they are able to escape or hide. In order to be confirmed, such hypotheses need the mentioned gases to be identified and measured and to verify that such gases produce the observed behaviours in dog and cats. At the moment, only Radon measurements are active in SPSC, confirming an increase of Radon concentrations many hours before an earthquake and a sudden decreasing a few hours before the shock. It is well known that Radon comes out of the ground driven by other gases [25], sustaining the hypotheses above. A further confirmation should come from ultrasound measurements, now still absent in SPSC.

3.4. Non-Vocal Anomalous Behaviours Different from the Usual Pattern

The most evident non-vocal animal behaviour is the advanced awakening from hibernation, possibly due to an increase in temperature, to magnetic variations or to emissions of dangerous gas. During winter, the precursor increase in soil and water temperature is a better forewarning as it is easier to notice. A rise in temperature up to 5˚C - 6˚C above the mean seasonal values at SPSC was often recorded before seismic events. This could explain the premature awakening of animals in hibernation (bats, insects, amphibious and reptiles) and premature larvae development. This unusual animal behaviour is a short term precursor, usually 12 - 15 hours before. Damages to people and animal health were observed at SPSC, in connection with measured high radon values. A rapid evolution of pathologies, especially dermatological effects, was reported at SPSC when the radioactive emission was much higher than the local average values.

Unusual Flight Behaviour with Magnetic Sudden Variations: it is very important to individuate the right moment of the sudden magnetic commencement because it is the moment of unusual flight behaviour observations. SPSC observations confirm that when geomagnetic perturbation is not due to sun activity, but it is due to the variation of the magnetic permeability of rocks under stress, we can observe unusual flight of some birds and a few problems of balance for dogs, cats and also human subjects. The sudden beginning can be followed for up to

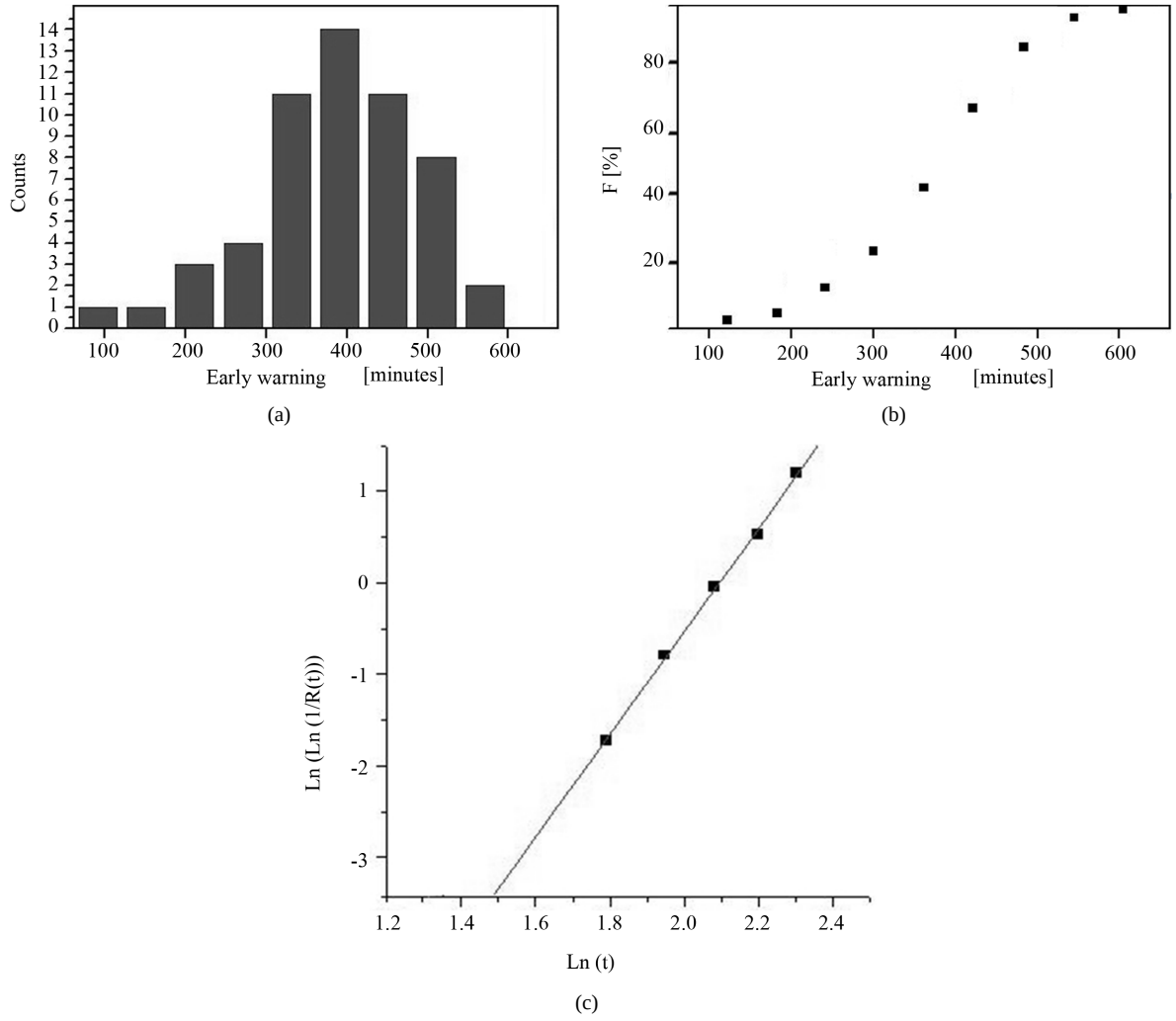


Figure 2. (a) statistical distribution of phase A of dogs and cats behaviour from Table 1; (b) cumulative probability; (c) Weibull coefficients fitting.

a few days by a variation of the absolute value of declination δ and by a variation of the intensity of the geomagnetic field. In these occasions, the needles of the SPSC compasses have a dampened oscillating motion around a new local North-South axis. At the beginning of δ oscillation due to seismic activity, unusual flight behaviour was often noted. During this first moment it was noticed that domestic animals are nervous and insects and arachnids are more aggressive, until magnetic variations are great. A few days before Ferrara's area earthquake on May 20th and 29th 2012, M = 6.0 and 5.8 [26], and the L'Aquila earthquake on April 6th 2009, M = 6.3 [27], it was observed, in some areas of Piedmont, unusual flight behaviours in female blackbirds, male tits and bats. In the morning of May 18th 2012, 8:30 LT, instruments recorded in SPSC a declination variation δ of 7˚ towards East. In the following moments a female blackbirds listed and banged against a wall of SPSC. A high magnetic declination variation of 15˚ East was also observed two days before the L'Aquila earthquake. The geomagnetic situation the week before these earthquakes was quiet.

Animals Seek Safety: during phase C farm animals seek safety from cow-houses, barns, pens or from other buildings. Animal shrills and their agitation can alarm people, so this animal behaviour has often saved people [18,19] and indeed it occurred in two cases [3,4]. For example, before the earthquake of April 2nd 1808, at 17:43 LT, with magnitude M = 5.7 [3] and with epicentre in Luserna San Giovanni, a woman of San Germano and her sons were saved because of the cries of their cows, also other people inside buildings saved themselves, thanks to the agitation of their cows a few seconds before the seismic shock. But also during phase A anomalous behaviours can occur to seek safety. A local earthquake in Val Pellice, occurred on May 28th 2008, during a severe rainstorm, caused at the same time four landslides: two on Vandalino Mountain, one at Rorà and one at Vil-

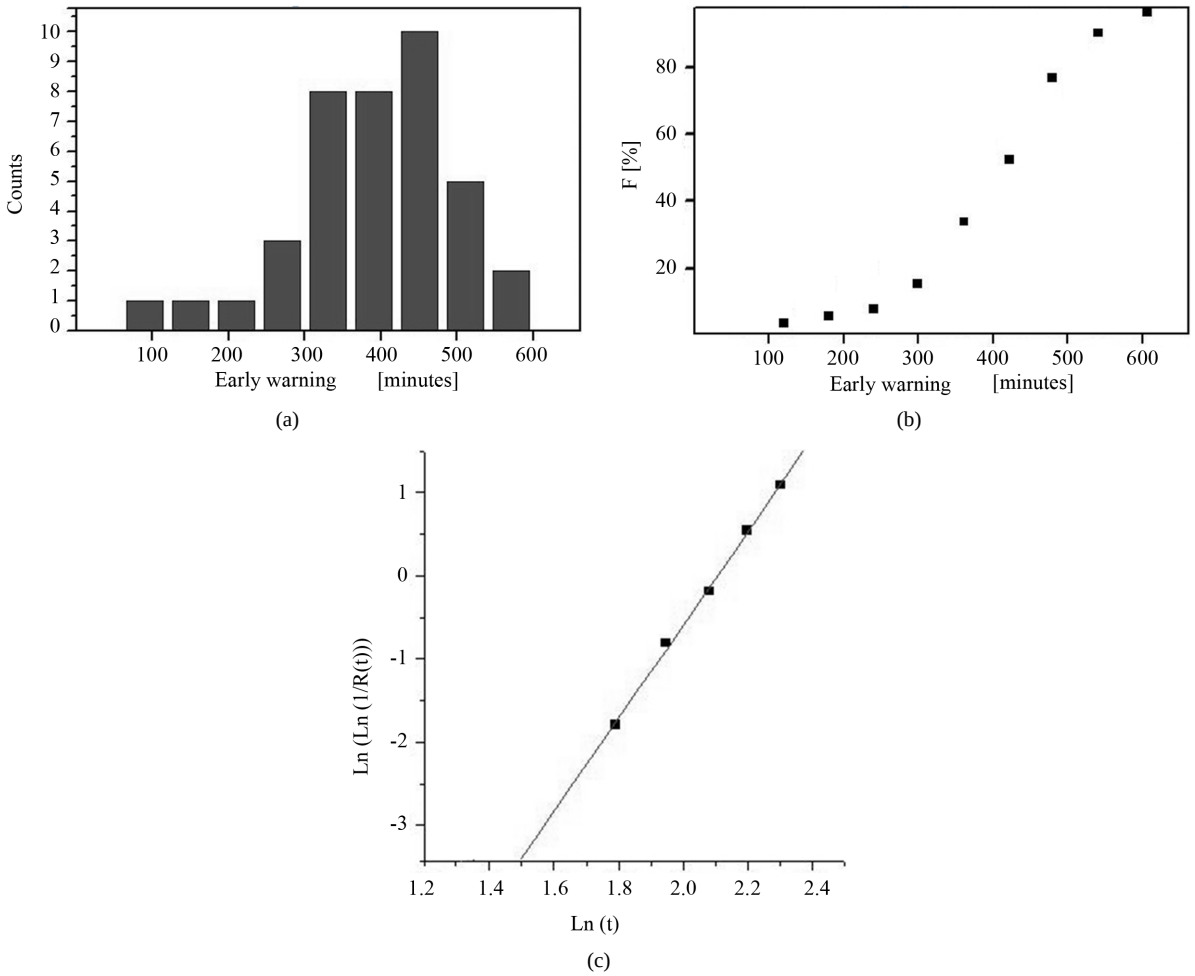


Figure 3. (a) statistical distribution of phase A of dogs behaviour from Table 1; (b) cumulative probability; (c) Weibull coefficients fitting.

lar Pellice, killing four people. Half an hour before the seismic event and landslides, a male goat saved all his female goats, guiding them away from their pen, which was subsequently destroyed. He returned with his herd the following day.

The Unusual Reptile, Limacidae Behaviour and pH Water: while the majority of animal species seeks safety outside, a few species, such as reptiles (vipers, snakes), generally seek safety going inside houses 3 - 5 hours before a local earthquake. They yearn for dry places; if you let them enter inside, without scaring them, you can observe they take shelter in wool blankets, the same behaviour was noted at SPSC in toads, frogs, stag beetles and even Limacidae. It is interesting to observe how some of these species are behaving strangely as they usually like humidity whereas wool is hydro-repellent. Two days before the seismic event of October 3rd 2012, epicentre in Sampeyre (16 km to SPSC) and M = 3.9, the Limacidae were moving in the fields standing on a fifth or their foot: they were probably escaping from the humid ground. The ground water pH was 10.5, so it is possible to suppose that the new chemical and physical properties of the soil water were the cause of this unusual behaviour.

3.5. Problems to Health and Safety

Damages to human and animal health were observed, in connection with measured high radon values, like rapid evolution of pathologies, especially dermatological effects and pneumonias by contact. High values of β and γ particles, up to 56.0 μS/h, were recorded two days before the two earthquakes of M = 4.6, 19:14 LT, and M = 4.8, 19:15 LT, both occurred on August 21st 2000, in the provinces of Asti and Alessandria. The radon meter measured more than 1517 Bq/m^3 in air (α particles) at the same time. The same day a viper and an unknown snake climbed at the first floor, by run-ladder. Three days after high radioactive emission, many insects and arachnids were founded dead in SPSC basement, in cellar and garden. Continuous α particles values in SPSC for the April-June 2012 period are reported in Figure 5. Coloured

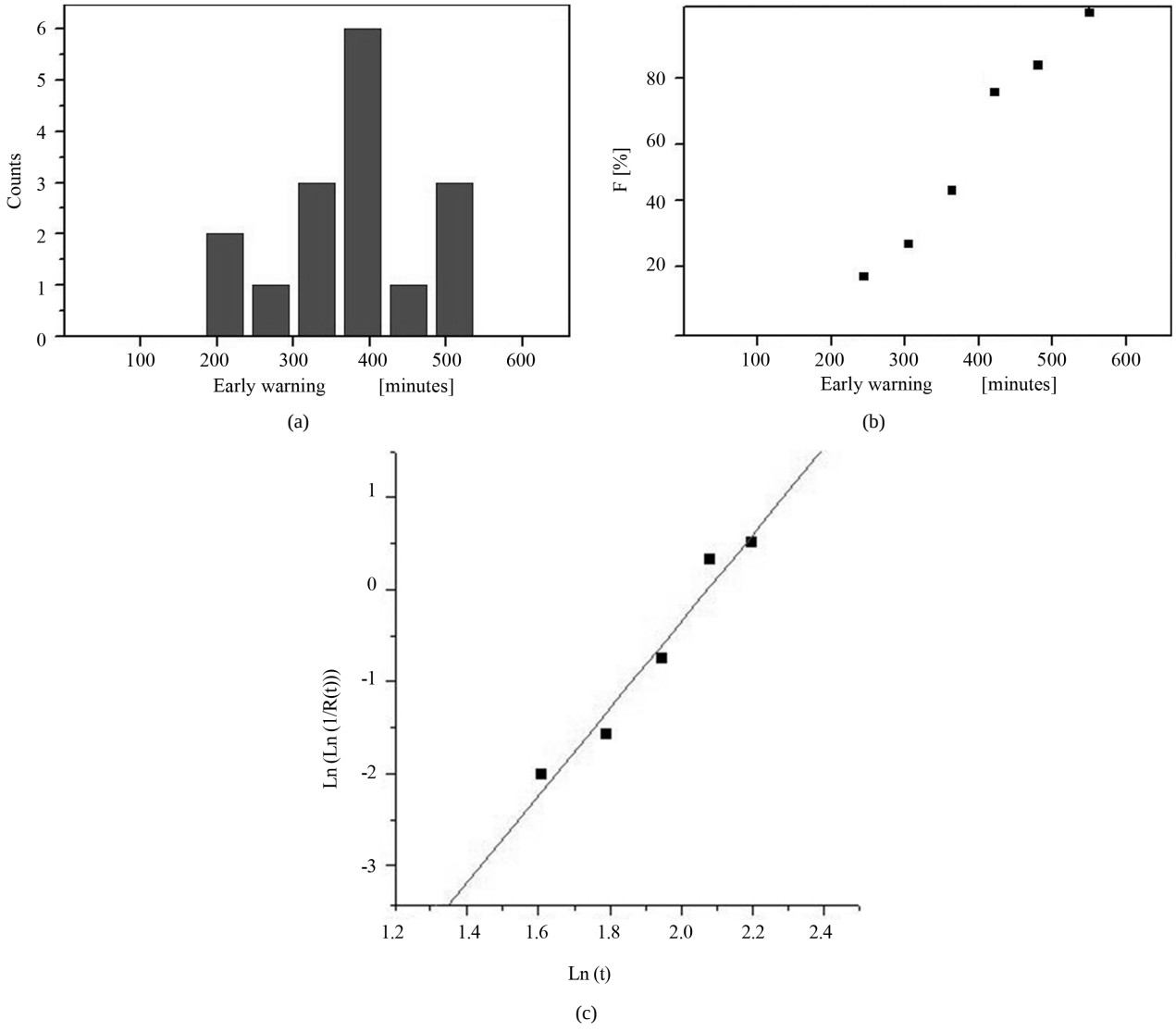


Figure 4. (a) Statistical distribution of phase A of cats' behaviour from Table 1; (b) cumulative probability; (c) Weibull coefficients fitting.

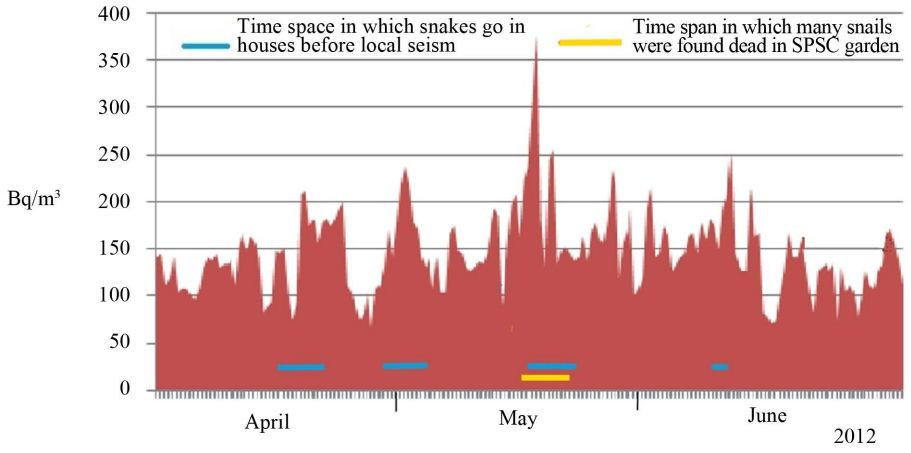


Figure 5. Radon monitoring during April-June 2012; coloured horizontal lines indicates anomalous behaviour of snails and snakes.

lines report dead snails in SPSC garden and snakes entering in SPSC before the earthquakes.

An increase in the water temperature of rivers and lakes and/or to the emission of warm and dangerous gas (radon, sulphurous gasses, hydrocyanic anhydrite, ozone, CO2…) can cause the death of fish. Three days before the two earthquakes of M = 4.6, 19:14 LT, and M = 4.8, 19:15 LT, both occurred the August 21st 2000, it was reported in Torre Pellice the death of all fishes of a little artificial lake fed by the Biglione creek, whose temperature increased by 6˚C, recorded in the night. Also some frogs and fresh water shrimps died near the Biglione.

4. Conclusions

The Valle Pellice is a moderate seismic area, however several phenomena regarding unusual animal behaviour can be observed. A moderate seismic activity can also generate unusual animal behaviours if the area magnifies magnetic, electric and radioactive variations, due to interesting geological structures, like an intrusive volcano with geothermal activity. When the rise in temperature, in radon concentration, or in magnetic declination is great, evident anomalous animal behaviours can be observed, which are reactions to save themselves or to reduce the damage to the health. The comparison "a posteriori" with local seismic activity can be resumed in the following points:

1) a particular tripartite sequence of animal vocal language was noted: phase A, lasting up to 2 hours, 0.5 - 10 hours before moderate and near seismic activity, phase B characterized by the absence of alarm calls and finally phase C immediately before (20 - 40 seconds) the seismic shock characterized by alarm signals;

2) increased emission of $Radon^{222}$ in the air above average values (α particles) many hours (sometimes days) before the seismic shock with its sudden decreasing a few hours before, and an increase of β and γ emission before the seismic shock;

3) variations in the pH values of water, on meadows and in rivers;

4) variations in the magnetic declination and magnetic intensity;

5) an increase of the temperature in the subsoil contemporaneously to increased radon emission.

Statistics of early strange behaviours in dogs and cats confirmed previous results obtained from other observations [24], and in this case it can be stated very precisely that the average warning time is about 7 hours. In contrast to results obtained in other studies [13], a little magnitude dependence of warning time occurs for small earthquake with great depth. Usually, dogs cry slightly earlier than cats are hiding. Even if this difference is within the margin of error, it could indicate the sense of smell as favourite in forecasting warnings for this area of NW Italy. These particularities are probably due also to the way of collecting information, which allows observations from restricted area to be correlated to small local seismic activity, contrarily to data relative to strong earthquakes from other regions of the world. The observations described, also for small earthquakes, regard areas near mines, close to Vandalino Mountain.

Acknowledgements

Tanks to Angelo Agostino, Alberto Carpinteri, Giulio Fanti, Giampaolo Giuliani, Francesco Lattarulo, Giovanni Martinelli, Lisa Pierotti, Riccardo Sandrone, Alessandro Vaio and Paolo Volpe.

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