Contents lists available at ScienceDirect





Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Radiofrequency radiation injures trees around mobile phone base stations



Cornelia Waldmann-Selsam^a, Alfonso Balmori-de la Puente^b, Helmut Breunig^c, Alfonso Balmori^{d,*}

^a Karl-May-Str. 48, 96049 Bamberg, Germany

^b C/Navarra, 1 5°B, 47007 Valladolid, Spain

^c Baumhofstr. 39, 37520 Osterode, Germany

^d Consejería de Medio Ambiente, Junta de Castilla y León, C/Rigoberto Cortejoso, 14 47071 Valladolid, Spain

HIGHLIGHTS

GRAPHICAL ABSTRACT

 High frequency nonionizing radiation is becoming increasingly common.

• This study found a high level of damage to trees in the vicinity of phone masts.

 Deployment has been continued without consideration of environmental impact.

Bernartzky (1986), revisited:



ARTICLE INFO

Article history: Received 6 June 2016 Received in revised form 19 July 2016 Accepted 6 August 2016 Available online 24 August 2016

Editor: D. Barcelo

Keywords: Electromagnetic radiation Effects on trees Phone masts Radiofrequencies

ABSTRACT

In the last two decades, the deployment of phone masts around the world has taken place and, for many years, there has been a discussion in the scientific community about the possible environmental impact from mobile phone base stations. Trees have several advantages over animals as experimental subjects and the aim of this study was to verify whether there is a connection between unusual (generally unilateral) tree damage and radiofrequency exposure. To achieve this, a detailed long-term (2006–2015) field monitoring study was performed in the cities of Bamberg and Hallstadt (Germany). During monitoring, observations and photographic recordings of unusual or unexplainable tree damage were taken, alongside the measurement of electromagnetic radiation. In 2015 measurements of RF-EMF (Radiofrequency Electromagnetic Fields) were carried out. A polygon spanning both cities was chosen as the study site, where 144 measurements of the radiofrequency of electromagnetic fields were taken at a height of 1.5 m in streets and parks at different locations. By interpolation of the 144 measurement points, we were able to compile an electromagnetic map of the power flux density in Bamberg and Hallstadt. We selected 60 damaged trees, in addition to 30 randomly selected trees and 30 trees in low radiation areas (n = 120) in this polygon. The measurements of all trees revealed significant differences between the damaged side facing a phone mast and the opposite side, as well as differences between the exposed side of damaged trees and all other groups of trees in both sides. Thus, we found that side differences in measured values of power flux density corresponded to side differences in damage. The 30 selected trees in low radiation areas (no visual

* Corresponding author.

E-mail addresses: balmaral@jcyl.es, abalmori@ono.com (A. Balmori).

contact to any phone mast and power flux density under 50 $\mu W/m^2$) showed no damage. Statistical analysis demonstrated that electromagnetic radiation from mobile phone masts is harmful for trees. These results are consistent with the fact that damage afflicted on trees by mobile phone towers usually start on one side, extending to the whole tree over time.

© 2016 Elsevier B.V. All rights reserved.

1. Introduction

For many years, there has been a discussion in the scientific community about whether artificial radiofrequency radiation has harmful effects on living organisms and, more specifically, on the environmental impact from mobile phone base stations (Panagopoulos et al., 2016). Trees have several advantages over animals as experimental subjects: they are continuously exposed to radiation in a constant orientation in the electromagnetic field due to their inability to move (Vian et al., 2016). Additionally, it is possible to easily document changes over time, such as disturbed growth, dying branches, and premature colour change of leaves. Moreover, the damage to trees is objective and cannot be attributed to psychological or psychosomatic factors.

Plants are specialized in the interception of electromagnetic radiation (light) but radiofrequency radiation impact on plants, which is becoming common in the environment because of the exponential use of mobile phone technology, has received little attention and his physiological effect has long been considered negligible.

Since the mid-twentieth century, several researchers have investigated the effects of electromagnetic radiation on plants, both in the laboratory (Kiepenheuer et al., 1949; Brauer, 1950; Harte, 1950, 1972; Jerman et al., 1998; Lerchl et al., 2000; Sandu et al., 2005; Roux et al., 2006, 2008; Sharma et al., 2009; Tkalec et al., 2005, 2009; Beaubois et al., 2007; Kundu and IEEE, 2013; Pesnya and Romanovsky, 2013; Cammaerts and Johansson, 2015; Grémiaux et al., 2016; Vian et al., 2016), and in nature (field observations) (Bernatzky, 1986; Volkrodt, 1987, 1991; Selga and Selga, 1996; Balodis et al., 1996; Haggerty, 2010). Both kinds of study have frequently found pernicious effects.

Around the world, phone masts have been deployed in the last two decades everywhere. Preliminary published studies have indicated deleterious effects of radiofrequency radiation on trees (Balmori, 2004; Van't Wout, 2006; Schorpp, 2011; Waldmann-Selsam, 2007; Waldmann-Selsam and Eger, 2013), cautioning that research on this topic is extremely urgent (Balmori, 2015). However, these early warnings have had no success and deployment has been continued without consideration of environmental impact.

In a review of the effects of environmental microwaves on plants (Jayasanka and Asaeda, 2013), it was indicated that effects depend on the plant family and the growth stage, as well as the exposure duration, frequency, and power density. This review concluded that most studies that address the effects of microwaves on animals and plants have documented effects and responses at exposures below limits specified in the electromagnetic radiation exposure guidelines and it is therefore necessary to rethink these guidelines (Jayasanka and Asaeda, 2013).

Since 2005, on the occasion of medical examinations of sick residents living near mobile phone base stations, changes in nearby trees (crown, leaves, trunk, branches, growth...) were observed at the same time as clinical symptoms in humans occurred. Since 2006 tree damages in the radiation field of mobile phone base stations were documented (http://kompetenzinitiative.net/KIT/KIT/baeume-in-bamberg/). In the radio shadow of buildings or that one of other trees, the trees stayed healthy.

Additionally, unilateral crown damage, beginning on the side facing an antenna, pointed to a possible link between RF-EMF (Radiofrequency Electromagnetic Fields) and tree damage. We carried out measurements on both sides of unilaterally damaged trees. Most of the trees had been exposed to RF-EMF for at least five years. Each time we found considerable differences between the measured values on the damaged and on the healthy side.

The aim of the present study was to verify whether there is a connection between unusual (generally unilateral) tree damage and radiofrequency exposure.

2. Materials and methods

The official information of 65 mobile phone sites in the neighbouring cities Bamberg and Hallstadt was extracted from the EMF database (EMF-Datenbank) of the German Federal Network Agency (Bundesnetzagentur, in March 2011 and October 2015). Each site certificate ("Standortbescheinigung") provides information on the mounting height of antennas, the number and main beam direction of the sector antennas, the number of omnidirectional antennas (ND), the number of other transmitters, as well as the horizontal and vertical safety distances. The current specifications of the transmission facilities are available at: http://emf3.bundesnetzagentur.de/karte/Default.aspx

On most of the 65 mobile phone sites several sector antennas emitting RF-EMF with differences in frequency, modulation and other physical characteristics are installed (GSM 900, GSM 1800, UMTS, LTE (4th generation), TETRA). In 2011 there was a total of 483 sector antennas, in 2015 a total of 779 sector antennas.

Numerical code, address and UTM 32N coordinates for the 65 Mobile phone (base stations) sites in Bamberg and Hallstadt are shown in Table 1.

Between 2006 and 2015 there was observation and documentation of tree damages. There were some preliminary measurements on both sides of unilaterally damaged trees and approximately 700 trees in Bamberg and Hallstadt were visited. The condition of numerous trees has been documented in photographs. The photographs record the state of trees showing damage patterns not attributable to diseases, pests, drought or other environmental factors in order to monitor damage and growth over several years (in 2006, Olympus FE-100 was used; since 2007, Panasonic DMC-FZ50 was used).

In 2015 we selected a polygonal study site, with an approximate area of 30 km², which includes partial municipalities of Bamberg and Hall-stadt (70 km²). The study area with the location of the phone masts in the layer of natural areas and municipalities is shown in Fig. 1. In this area, different measurements (see below) were done both for having a radiation map and for knowing which are the incident power densities beside different trees. In spite of the fact that measurements are changing continuously, they do not show significant differences between times (own data, see below).

In this polygon, we performed 144 measurements of the radiofrequency electromagnetic fields at a height of 1.5 m at different points in the city. These measurements were taken in streets and parks and allowed the preparation of an electromagnetic map of Bamberg and Hallstadt with their interpolation. The measurements were carried out with an EMF-broadband analyzer HF 59B (27–3300 MHz) and the horizontal-isotrope broadband antenna UBB27_G3, (Gigahertz Solutions). Measurements of the sum peak values of power flux density were in μ W/m², which can be converted in V/m.

In general, a sector antenna covers an angle of 120° and the radiation of the sector antennas is distributed in main and secondary beams, bundled vertically and horizontally. The high-frequency emissions are reflected/diffracted and/or absorbed by buildings and trees. Therefore,

Official information of the 65 mobile phone base stations in Bamberg and Hallstadt.

Code number	Adress in Bamberg and Hallstadt	Х	Y	Code number	Adress in Bamberg and Hallstadt	Х	Y
1	Altenburg	634268	5527019	34	Ludwigstr. 25 (Post)	636318	5529177
2	Am Borstig 2	636070	5531636	35	Luitpoldstr. 51	636241	5529232
3	Am Hirschknock	637511	5532267	36	Mainstraße, Ladekai 2	633924	5530319
4	An der Breitenau 2	637253	5530650	37	Mainstraße, Ladekai 3	633816	5530130
5	(An der Breitenau, P&R) ca.	637259	5526912	38	Margaretendamm 28	635341	5529331
6	(Artur-Landgraf-Straße)	635183	5526912	39	Memmelsdorfer Straße (Post) ca.	637769	5531392
7	Breitäckerstr. 9	632965	5529621	40	Memmelsdorfer Str. 208a	637568	5531191
8	Coburger Str. 6a	635877	5529951	41	Memmelsdorfer Str. 208a	634861	5528541
9	Coburger Str. 35	635252	5530468	42	Mußstr. 1	634949	5528827
10	Erlichstr. 47/51	637291	5527903	43	Pödeldorfer Str. 144	637828	5529305
11	Franz-Ludwig-Str. 7	635843	5528490	44	Rheinstr. 16 ca.	632910	5530367
12	Geisfelder Str. 30	637689	5528020	45	Robert-Bosch-Str. 40	637767	5528292
13	Grüner Markt 1	635624	5528370	46	Schildstr. 81	637049	5529049
14	Grüner Markt 23	635640	5528565	47	Schranne 3	635511	5528166
15	Gutenbergstr. 20	638448	5527180	48	Schützenstr. 23	636197	5527961
16	Hainstr. 4	635945	5528229	49	Schwarzenbergstr. 50	636762	5528732
17	Hainstr. 39	636341	5527550	50	Siemensstr. 37-43	638091	5528505
18	Hauptsmoorstr. 26a	638223	5530558	51	Theresienstr. 32	637487	5527866
19	Hauptsmoorwald, Pödeldorfer Straße	639683	5529635	52	Unterer Kaulberg 4	635350	5528084
20	Hauptsmoorwald, Geisfelder Straße	639890	5528022	53	Von-Ketteler-Str. 2	637905	5527553
21	Heiliggrabstr. 15	636054	5529240	54	Wilhelmsplatz 3	636316	5528259
22	Heinrichsdamm 1	635849	5528723	55	Zollnerstr. 181	637772	5530133
23	Heinrichsdamm 33a, P&R	636748	5527529	56	Heganger 18	634327	5530982
24	Hohenlohestr. 7	634794	5526480	57	Biegenhofstr. 13	633963	5531045
25	Kantstr. 33	637161	5530333	58	Seebachstr. 1	634399	5531764
26	Katzenberg	635374	5528266	59	Landsknechtstr.	634800	5531918
27	Kirschäckerstr. 37	636649	5530756	60	Lichtenfelser Str.	634864	5532621
28	(Kloster-Langheim-Str. 8)	637190	5529182	61	Michelinstr. 130 ca.	635629	5532106
29	Kronacher Str. 50	636722	5531496	62	Margaretendamm	634991	5529497
30	Lagerhausstr. 4-6	634850	5529871	63	Mainstr. 36a/Kiliansplatz	634326	5532386
31	Lagerhausstr. 19	634304	5530136	64	Bamberger Straße	635964	5526050
32	(Laurenziplatz 20)	635207	5527404	65	Würzburger Str. 76	635359	5526709
33	Ludwigstr. 2	635207	5529103				

due to existing obstacles there is an inhomogeneous radiofrequency field distribution. Buildings and vegetation (trees and foliage) can shield and reduce radiation and thus affect the quality of signal propagation (e.g. Meng and Lee, 2010). Living material is not a perfect dielectric object and interferes with high frequency electromagnetic fields in a way that depends upon several parameters, including the general shape, conductivity, and density of the tissue, and the frequency and amplitude of the electromagnetic radiation (Vian et al., 2016).

In the polygon mentioned before we selected 60 trees showing unilateral damage. The selection was limited by the fact that we were able to measure with the telescopic rod only up to a height of 6 m. Many trees (*Tilia, Betula, Quercus, Populus, Picea*) showing damage above the



Fig. 1. The study area with the location of the phone masts in the layer of natural areas, buildings, and municipalities.

height of 6 m could not be included. The measurements at the trees were done between April and October 2015. *Acer platanoides, Carpinus betulus, Tilia* sp., *Taxus baccata* and *Thuja occidentalis* are widely spread in Bamberg and Hallstadt and can be reached for measurements. Therefore they are the most represented species.

The selected 60 trees from the study polygon show damage patterns that are not usually attributable to harmful organisms, such as diseases (fungi, bacteria, viruses) and pests (insects, nematodes) or other environmental factors (water stress, heat, drought, frost, sun, compaction of the soil, air and soil pollutants).

The main features of damage from this source are:

- Trees are mainly affected on one side (showing side differences and unilateral damage) and can appear in any orientation. The damage only originates on one side.
- Damage appears without external indications that the tree is infested with insects, nematodes, fungi, bacteria or viruses.

- Damage appears on trees, which have previously grown well. Damage appears on once healthy trees within one or two years after Antennas were put into operation.
- Damage increases from the outside to the inner part of the crown over time.
- Trees of different species in the same location also show damage.
- Damage appears in favourable (gardens, parks) as well as in unfavourable locations.
- Trees in the same location, but that are shielded by buildings or other trees, are healthy.

For these damaged trees, we used 13 damage codes that may be recognised with the naked eye (for explanations, see Table 2). In order to explain each type of damage visually, a photograph was added for each damage code.

Table 2

Tree damage codes.



144 selected points in Bamberg and Hallstadt with their measurements and UTM coordinates.

Number	Streets and parks in Bamberg and Hallstadt	Measurement µW/m²	Х	Y	Number	Streets and parks in Bamberg and Hallstadt	Measurement µW/m²	Х	Y
1	Wassermannpark	2300	637395	5530345	73	Ludwigstraße/Zollnerstraße	50	636228	5529444
2	Memmelsdorfer Str. 209	1830	637581	5531113	74	Landratsamt, Ludwigstraße, Einfahrt	670	636422	5529044
3	Holunderweg	10	638125	5530967	75	Wilhelmsplatz, Mitte	460	636250	5528263
4	Hauptsmoorstraße/Seehofstraße	3600	638039	5530857	76	Amalienstr. 16	16570	636303	5528086
5	Greifffenbergstr. 79	4210	638349	5530855	77	Otttostr. 7a	120	636133	5527878
6	Heimfriedweg 16	870	638393	5530621	78	Schönbornstr 3	3640	636251	5527696
7	AWO Innenhof Parknlatz	3920	638223	5530584	79	Hainspielplatz	1530	636229	5527403
8	Ferdinand-Tietz-Str 40	2600	637883	5530616	80	P&R Heinrichsdamm Parknlatz bei	3400	636706	5527667
0	Ferdinand Hetz Str. 10	2000	037003	5550010	00	Kirschen	5100	050700	3327007
9	Ferdinand-Tietz-Str. 38	80	637889	5530601	81	P&R Heinrichsdamm, südöstlich des Senders, Eichen	1690	636755	5527504
10	Petrinistr. 20	1340	637797	5530514	82	Luisenhain, Höhe Wasserwerk	260	636895	5526482
11	Petrinistr. 32	4700	637891	5530449	83	Kapellenstraße	2120	637050	5528148
12	Zollnerstraße 181	9300	637773	5530102	84	Geisfelder Str. 9, Gärtnerei	740	637410	5528164
13	Wassermannstr. 14	540	637424	5530125	85	Gereuthstr. 8	30	637621	5527424
14	Feldkirchenstraße/Kantstraße	2620	636803	5530069	86	Distelweg, Innenhof	15	637881	5527160
15	Breslaustr. 20	3890	637392	5530431	87	Am Sendelbach BSC 1920	30	637331	5526877
16	Berliner Ring	16920	637188	5530786	88	Am Sendelbach, Kleingartenanlage	10	637542	5526222
17	Rodezstr. 3	3780	637044	5530765	89	Robert-Bosch-Straße	2060	637504	5528200
18	Am Spinnsever 3	880	637545	5530764	90	Ludwigstraße/Memmelsdorfer Straße	1000	635974	5529708
19	Kirschäckerstr. 24	4290	636655	5530857	91	Coburger Straße, Neubau	3460	635867	5529878
						Studentenwohnheim			
20	Kammermeisterweg	810	636283	5530282	92	Coburger Straße, junge Platane	3400	635835	5529941
21	Eichendorff-Gymnasium, Hof	6340	637194	5529084	93	Gundelsheimer Str. 2	9000	635783	5529680
22	Starkenfeldstraße/Pfarrfeldstraße	3660	637092	5529138	94	Hallstadter Straße	12	635232	5530212
22	Parkplatz auf der Westseite der	9020	636921	5528970	95	Gerberstraße/Benzstraße	1280	635108	5530546
23	Polizei	5020	050521	5520570	55	Gerberstruse/ benzstruse	1200	055100	5556510
24	Starkenfeldstraße, Höhe Polizei	1120	636975	5529061	96	Coburger Straße, Einfahrt Fitnesszentrum	2000	635326	5530508
25	Starkenfeldstr 2	860	637527	5529216	97	Kleintierzuchtanlage	890	635380	5530622
26	Pödeldorfer Str. Haltestelle	2180	636965	5529217	98	Margaretendamm Fingang ehemaliges	1300	635455	5529178
20	Kindergarten St. Heinrich Eingang	6450	637712	5520364	90	Hallenbad	1800	635200	5520365
27	Rindergarten St. Heimitin, Eingang	1620	627654	5520422	39 100	Margartandamm 29 nabo Sondoanlago	5560	625002	5520407
20	Wörthstraße	1020	037034	5529455	100	Margartendamm 58, nane sendeamage	5500	000000	5529497
29	Podeldorfer Str. 142, Nordseite	30	637840	5529437	101	Hafenstraße/Regnitzstraße	/610	634/19	5529740
30	Podeldorfer Str. 142, Súdseite	17060	637824	5529410	102	Lagerhausstraße	210	634556	5530102
31	Berliner Ring, Hohe Podeldorfer Str. 144	4480	637900	5529380	103	Hafenstr. 28, Bayerischer Hafen	3200	634192	5530370
32	Schwimmbad Bambados, Vorgarten mit Bambus	1620	638074	5529315	104	Laubanger 29	160	634202	5530561
33	Schwimmbad Bambados, Parkplatz, Feldahorn	2540	638202	5529346	105	Heganger	1400	634341	5530812
34	Carl-Meinelt-Str.	5360	638043	5529094	106	Emil-Kemmer-Str. 2	5000	633822	5530863
35	Volkspark, FC Eintracht, Ostseite	120	638343	5529065	107	Emil-Kemmer-Str. 14	2500	634342	5531099
36	Michelsberger Garten, Teil Streuobst	5450	634831	5528673	108	Dr. Robert-Pfleger-Straße 60	90	634448	5530978
37	Michelsberger Garten, Terrassengarten, bei Eibe	2500	634988	5528508	109	Friedhof Gaustadt, Haupteingang	13100	632981	5529677
38	Michelsberger Garten, Südostecke, bei Holunder	910	635036	5528455	110	Friedhof Gaustadt, Ahornpaar	1400	632929	5529728
39	Michelsberg, Aussichtsterrasse, oberhalb Weinberg	1260	634924	5528463	111	Herzog-Max-Str. 21	1600	636245	5528071
40	Michelsberg, Aussichtsterrasse, Aussichtspunkt	780	634911	5528537	112	Gaustadter Hauptstr. 116	10	634042	5529457
41	Michelsberg, Nordostecke, bei	390	634874	5528565	113	Landesgartenschaugelände, Hafenerlehnispfad	2000	633789	5529894
42	Storchsgasse/Michelsherg	200	634725	5528415	114	Landesgartenschau junge Baumgruppe	1270	633949	5529718
43	St Cetreu-Kirche Südseite	55	634518	5528405	115	Würzburger Str	340	635283	5527151
44	Villa Remeis, Garten	390	634295	5528203	116	Würzburger Straßo/Arthur Landgraf Straßo	1380	635355	5526862
45	Villa Remeis, Treppe	300	634400	5528237	117	Straße/Arthur-Landgraf-Straße Hohe-Kreuz-Straße/Würzburger Straße Haltestelle	590	635383	5526733
46	Majenbrunnen 2	3920	634744	5528838	118	Hohe-Kreuz-Straße	10950	635460	5526729
47	Am Leinritt	2140	635071	5528617	119	Am Hahnenweg 6	3420	635332	5526729
48	Abtsherg 27	130	634576	5528025	120	Am	640	625207	5526725
UF	10:00:16 27	130	054520	5520555	120	Hahnenweg/Viktor-von-Scheffel-Straße	010	055507	5520/10
49	Welcome Hotel Carten	3200	634789	5520012	121	Am Hahnenweg 28 a	145	635029	5526654
50	Mußstraße eingang Kindorgarten	1670	634864	552012	121	Schlüsselherger Straße	200	62/712	5526524
50	Mußetraße/Schlüsseletraße	710	63/2/6	5520011	122	Schlüsselberger Str./Haltastalla	460	63/17/0	5526570
50	Nobingerbof	2040	625000	5525054	124	Hezilostr., Parkdeck	70	624004	5520543
52 52	Nebiligerilloi	∠040 100	625120	5528901	124	Rezhostr, 15 Gieldeingweg, ivree Heistustes to 1	70	624512	5520505
23 E 4	Giai-Staullenberg-Platz	100	625120	5529009	120	Suckiellisweg, julige Hainbuchennecke	10	624700	5520054
54 55		10	0351/6	5529056	120	RUISIEIIISWEG, ODERES ENDE	300	034/08	5526789
22	Pieuierstraise/ weiße	1100	035222	0028820	127	GLOISE WIESE	1000	034874	3320810

Table 3 (continued)

Number	Streets and parks in Bamberg and Hallstadt	$\begin{array}{l} Measurement \\ \mu W/m^2 \end{array}$	Х	Y	Number	Streets and parks in Bamberg and Hallstadt	Measurement µW/m²	Х	Y
56	Weidendamm/Don-Bosco-Straße	1860	635166	5529195	128	Suidgerstraße	195	634508	5526409
57	Katzenberg/Karolinenstraße	1720	635316	5528239	129	Waizendorfer Straße	280	635317	5525864
58	Vorderer Bach	450	635305	5528141	130	Waizendorfer Straße, Einfahrt Gärtnerei	210	635326	5525582
59	Obere Brücke	8000	635565	5528289	131	Klinikum, Nähe Spielplatz	175	635732	5525672
60	Judenstraße	6	635479	5528040	132	Klinikum Weiher	100	635759	5525520
61	Tourist Information	4920	635674	5528172	133	Buger Straße/Bamberger Straße	2730	635829	5526082
62	Universität, Am Kranen 14, Innenhof	10	635501	5528535	134	Dunantstraße	470	635848	5526176
63	Fleischstraße	10	635703	5528683	135	Buger Straße/Paradiesweg	90	635743	5526286
64	ZOB	600	635882	5528541	136	Buger Straße/Abzweigung Münchner	470	635528	5526499
						Ring			
65	Schönleinsplatz, Ostseite	900	636004	5528300	137	Hallstadt, Markplatz, bei Linde	2000	634582	5532426
66	Friedrichstraße, Parkplatz	165	635984	5528360	138	Hallstadt, Markplatz 21, Innenhof	8	634632	5532488
67	Franz-Ludwig-Straße/Luisenstraße	1720	636158	5528410	139	Hallstadt, Lichtenfelser Str. 12	4000	634659	5532474
68	Franz-Ludwig-Str, Strassenbauamt	90	636246	5528408	140	Hallstadt, Lichtenfelser Str. 8	9000	634720	5532516
69	Heiliggrabstraße, Nähe Sender	4740	636072	5529245	141	Hallstadt, Am	200	634743	5532784
						Gründleinsbach/Kemmerner Weg			
70	Heiliggrabstr. 29, Landesjustizkasse	20	636063	5529399	142	Hallstadt,	2200	634232	5532237
						Valentinstraße/Seebachstraße			
71	Heiliggrabstr. 57, Aussichtspunkt Schiefer Turm	4500	635797	5529410	143	Hallstadt, Johannisstr. 6	5000	634805	5532078
72	Bahnhof, ParkplatzWestseite	1600	636300	5529374	144	Hallstadt, Bamberger Straße/Michael-Bienlein-Straße	1860	634805	5531969
						Straise/initiaer-bieillelli-Straise			

For each selected tree, the types of damage and the Universal Transversal Mercator (UTM) coordinates were recorded. In addition, two measurements were recorded: on the side showing damage and on the side without damage, generally corresponding to opposite sides of each tree. On both sides, the measurements were carried out at a variable height of 1–6 m (depending on the height of the tree), using a telescopic rod, a ladder, and the broadband radiofrequency meter.

Most measurements were done in the afternoon or in the evening on different days between April and October 2015. But the measurements on the two sides of each single tree were done one after another immediately on the same day and at the same time. The measurements took about 5 min on each side. When we stood on the ground or on a ladder we measured the peak values. When we used the telescopic rod we measured the peak hold values. Using the telescopic rod and measuring peak hold values it took longer, because the measurements had to be repeated often in cases where RF-EMF emitting cars or passengers disturbed the results. At each single tree the two measurements were done in the height where the damage had appeared. Because the height of the 120 trees differed, it was necessary to do the measurements at different heights.

In theory, although measurements are changing continuously there is no evidence about significant changes in power densities of electromagnetic radiation produced by phone masts over time. One study carried over one year in the city of Madrid showed no changes in terms of radiation intensity between the three rounds of measurements



Fig. 2. Location of the 144 measurements points in Bamberg and Hallstadt in the study area.



Fig. 3. Map showing the 60 damaged trees and phone masts (both with code numbers) over the interpolation electromagnetic map of the 144 measurement points.

performed in about 200 sampling points (own data). Repeatability analysis checked this. Despite the fact that the increase in sector antennas (observed between 2011 and 2015) would have probably increased the radiation in the environment of the study area, measurements used in this study were mostly done in 2015.

In an attempt to link the electromagnetic radiation measured at every tree to specific phone masts, the distances to the three nearest antennas that could be mainly responsible for the radiation measurements at each tree were calculated in meters with Geographical Information System (GIS) programs, following the general approach criteria of proximity. However, it must be taken into account that buildings and vegetation diminish radiation intensity and, in many cases, the nearest phone mast or masts may be obscured by obstacles. In other cases, the phone mast is in direct line of sight from the tree and the radiation can reach the tree directly.

Additionally, 30 random points were generated inside the polygonal study area and outside a layer of buildings, downloaded from: http://www.mapcruzin.com/free-germany-arcgis-maps-shapefiles. htm using a Random Points tool of QGIS 2.6.0-Brighton (QGIS Development Team, 2014) allowing create random points inside a specific layer. Therefore the points were randomly situated in specific places in the study area outside buildings but not frequently concur with the location of trees. That is why measurements were taken from the nearest tree for each random point, generating a random tree group. Measurements and damage characteristics were scored in the same way as with 60 damaged trees explained above, measuring the maximum value of radiation corresponding to opposite sides of each tree.

In areas of the city with low measurements of electromagnetic radiation (no visual contact to any phone mast and power flux density $<50 \,\mu$ W/m²), we scored another 30 trees in the same way as with 60 damaged trees and 30 random points. The UTM coordinates and the three nearest phone masts of each tree in these last two groups (random and low radiation trees) were also recorded.

To generate electromagnetic maps, we used ArcGis 9.3 (ESRI, 2008) and QGIS 2.6.0-Brighton (QGIS Development Team, 2014). To check possible differences between groups of data and taking into account that there were two measures made in each tree, repeated measures analysis of variance were applied, considering a repeated measures factor (within-subjects) and another between-subjects. The post hoc

Bonferroni test was used in all cases to elucidate significant differences. Statistics were performed using STATISTICA 7 program (StatSoft, Inc, 2004).

3. Results

The results of radiation measurements obtained at 144 points in Bamberg and Hallstadt at a height of 1.5 m were between 6 μ W/m² (0.047 V/m) and 17,060 μ W/m² (2.53 V/m) (for measurements and UTM coordinates, see Table 3). The measured values are far below the current limit values (41 V/m for GSM system and 61 V/m for UMTS; ICNIRP, 1998).

The locations of these points in the study area are shown in Fig. 2. By interpolation of the 144 measurements points (Table 3), we prepared a map of the power flux density in Bamberg and Hallstadt (Fig. 3). This map is theoretical and approximate, since many factors affect the true electromagnetic values. However, the map is useful to provide approximate differences in exposure (electromagnetic pollution) throughout the city.

The 60 selected trees showing damage patterns not attributable to diseases, pests or other environmental factors are presented in Table 4. In this Table, we added the tree code number, the scientific name, the UTM coordinates, the measurements (power flux density) on both sides of each tree, and the distances (meters) and code numbers to the three nearest antennas for each tree, which may be mainly responsible for the electromagnetic radiation measured. We also included the orientation of the tree damage and the number of main (nearest) phone mast(s) in direct line of sight, whose lobe of radiation most directly affected each tree. Finally, we included the codes of damage observed in the 60 trees.

From all 60 selected trees, one or more phone mast(s) could be seen, with no obstacles between the phone mast and damaged tree. In many cases, one of the three closest antennas caused the main radiation on the tree surface. In ten trees (codes: 4, 7, 9, 10, 15, 26, 27, 31, 35, and 50), another antenna in direct line of sight caused the measured radiofrequency exposure. This was determined using topography and existing buildings (Table 4 and Fig. 3).

The 60 damaged trees (with their code number) and the phone masts are overlaid on the electromagnetic map prepared by interpolation of the 144 measurements points (Fig. 3). The likely antenna or

antennas causing radiation damage to each tree are also shown (Fig. 3). The measurements at all selected trees revealed significant differences between the damaged side facing a phone mast and the intact (or less

damaged) opposite side. On the side facing a phone mast, the measured values were 80–13,000 μ W/m² (0.173–2.213 V/m). On the opposite side the values were 8–720 μ W/m² (0.054–0.52 V/m).

Table 4

60 selected trees showing damage patterns not attributable to diseases, drought or other environmental factors.

														Effect codes												
														1	2	3	4	5	6	7	8	9	10	11	12	13
N°	Scientific name	×	X	Side antenna measurement $\mu W/m^2$	Opposite side measurement µW/m ²	Number of Phone Mast 1	Distance a 1	Number of Phone Mast 2	Distance a 2	Number of Phone Mast 3	Distance a 3	Direction of damage	Number of main phone mast(s) causing the radiation	Damage only on one side	Sparse leaves or needles (crown transparency)	Brown leaves (start at leaf margins)	Colour change of leaves prematurely	leaves fall prematurely	Dead branches (Peak branches dried).	Tip of the main guide dried	Irregular growth	Not grow in eight	Color change of needles	Dead parts were trimmed down	damage on different sides	no damage
1	Acer platanoides	636298	5529366	970	130	35	145,6	34	190,1	21	274,6	S, SW	35,34,21	+	+	+		+	+	+		+				
2	Acer platanoides	638211	5530518	680	80	18	41,76	55	583,9	40	930,8	N	18	+	+	+		+	+			+		+		
3	Acer platanoides	637868	5529371	2100	290	43	77,18	28	703,9	55	768	s	43	+	+	+		+	+	+		+				
4	Acer platanoides	635316	5528245	2300	130	26	61,68	52	164,6	47	210,4	E, S	26,52,47, 14	+	+	+		+	+	+		+		+		
5	Acer platanoides	636677	5527688	3600	290	23	174,1	17	363,2	48	552,2	S	23	+	+	+		+	+	+		+		+		
6	Acer platanoides	637536	5528219	700	140	45	242,3	12	251	51	356,4	E	45	+	+	+		+	+	+						
7	Acer platanoides	635339	5526919	270	30	6	156,2	65	211	32	502,6	w	1	+		+		+	+	+		+		+		
8	Acer platanoides	635876	5528029	80	10	16	211,6	48	328,1	47	389,9	w	47	+	+	+		+								
9	Acer platanoides	634819	5526187	160	20	24	294,1	65	751,1	6	811,2	N	24, 1		+	+		+	+					+		
10	Acer platanoides	634638	5526163	180	55	24	353,3	65	904,4	6	926,3	N	24, 1		+	+		+	+							
11	Acer platanoides	635022	5526270	95	20	24	310	65	553,4	6	661,9	NW	24	+	+			+								
12	Acer platanoides	634854	5532596	11800	400	60	26,93	63	568,2	59	680,1	N	60	+	+	+		+	+	+		+				
13	Acer platanoides	634455	5532438	9900	620	63	139,1	60	448,1	59	624	w	63	+			+							+		
14	Acer platanoides	634890	5532028	3380	500	59	142,1	58	557,5	60	593,6	SW	59	+	+	+		+	+	+		+		+		
15	Acer platanoides	634815	5532307	1050	50	60	317,8	59	389,3	63	495,3	SW	58	+	+	+		+	+	+		+		+		
16	Carpinus betulus	638001	5530928	1210	120	18	431,5	40	506,6	39	518,8	s	18	+	+	+		+	+							
17	Carpinus betulus	637996	5530945	2520	150	18	448,7	40	493,7	39	501,3	s	18	+	+	+		+	+							
18	Carpinus betulus	637987	5530959	890	90	18	465,3	40	478,9	39	484,8	S	18	+	+	+		+								
19	Carpinus betulus	637984	5530970	670	10	40	471,1	39	473,6	18	476,3	S	18	+	+	+		+								
20	Carpinus betulus	636619	5528966	1000	200	33	169,6	49	274,2	34	367,6	SE	49		+	+		+	+			+		+		
21	Carpinus betulus	636068	5529245	430	20	21	14,87	35	173,5	34	259,1	w	21	+	+	+		+				+		+		
22	Carpinus betulus	637138	5530413	4340	110	25	83,24	4	263,4	5	450,6	NE	4	+	+	+		+	+	+		+				
23	Carpinus betulus	637664	5530231	990	60	55	145,8	25	513,2	4	586,9	Е	55	+	+	+		+	+							
24	Carpinus betulus	633137	5529754	2700	50	7	217,4	44	653,7	37	776,2	E	37	+	+	+		+	+							
25	Tilia sp.	636098	5528729	870	150	22	249,1	11	349,5	14	486,5	w	22	+	+	+		+	+							
26	Tilia sp.	636261	5528398	410	20	54	149,5	16	358,4	11	428	w	14	+		+		+								
27	Tilia sp.	636030	5528283	680	160	16	100,7	11	279	54	287	s	48	+	+		+	+	+					+		
28	Tilia sp.	634972	5528626	660	170	41	139,8	42	202,3	26	539,6	SW	41	+	+	+		+	+	+		+		+		
29	Tilia sp.	636283	5529365	2450	160	35	139,5	34	191,2	21	260,9	SW	35, 34, 21	+		+		+				+		+		
30	Tilia sp.	634573	5532422	3800	420	63	249,6	60	352,5	59	552,8	NE	60	+	+	+		+	+					+		
31	Tilia sp.	635319	5526914	380	120	6	136	65	208,9	32	502,6	w	1	+	+		+	+	+	+						
32	Quercus robur	638598	5526911	860	130	15	308	53	944,7	12	1434	NW	15		+			+	+							
33	Quercus rubra	637501	5529207	1340	120	28	312	43	341,4	46	478,8	E	43	+	+			+	+							
34	Quercus rubra	637107	5528961	1650	250	46	105,4	28	236,1	49	414,1	SW	49	+	+				+							
35	Aesculus hippocastanum	636092	5528434	400	20	16	252,3	11	255,2	54	284,3	w	14	+	+	+		+	+	+		+				
36	Robinia pseudoacacia	638653	5526920	1300	40	15	331,1	53	979,9	12	1463	NW	15	+			+		+	+		+				

Table 4 (continued)

37	Robinia pseudoacacia	638619	5526874	660	240	15	350,5	53	985,3	12	1476	NW	15	+			+		+					+	
38	Sorbus occuparia	634587	5526564	84	8	24	223,4	1	555,7	6	690,2	N	1	+	+	+		+	+	+		+			
39	Acer negundo	637722	5529366	3060	310	43	122,3	28	562,9	46	743,9	SE	43	+	+			+	+			+		+	
40	Acer saccharinum	637852	5527078	840	180	53	477,9	15	604,7	51	868,4	E	15	+	+			+							
41	Juglans regia	634841	5528669	4500	590	41	129,6	42	191,4	26	668,2	N, E	42	+	+			+	+	+	+	+			
42	Taxus baccata	635767	5528046	300	70	16	255,3	47	282,7	13	354,2	NW	47	+	+				+				+	+	
43	Taxus baccata	635491	5526727	8970	190	65	133,2	6	359,3	32	734,2	w	65	+	+				+				+	+	
44	Taxus baccata	634997	5528506	2500	240	41	140,4	42	324,6	26	446,9	N,E,W	41,42		+				+				+	+	
45	Taxus baccata	635272	5527980	2700	70	52	130	47	302,8	26	303,6	NE	52	+	+				+				+	+	
46	Taxus baccata	637586	5529231	1520	190	43	253,1	28	399	46	567	E	43	+	+								+	+	
47	Thuja occidentalis	632975	5529719	910	30	7	98,51	44	651,3	37	936,1	s	7	+	+				+				+		
48	Thuja occidentalis	636128	5527881	120	10	48	105,6	16	393,2	17	393,6	s	17	+	+				+				+		
49	Thuja occidentalis	634900	5532611	13000	520	60	37,36	63	616,5	59	700,2	NW	60	+	+				+				+		
50	Thuja occidentalis	634387	5528232	290	50	41	565,8	42	818,5	52	974,3	s	1	+	+				+	+			+		
51	Picea pungens	638525	5526863	770	90	15	326,2	53	927,6	12	1427	NE	15	+	+				+				+		
52	Picea pungens	634328	5531086	3080	310	56	104	57	367,3	58	681,7	w	57		+				+			+	+		
53	Picea pungens	633280	5529546	1350	200	7	323,8	37	792,7	44	900,5	w	7	+	+				+		+		+		
54	Pinus sylvestris	638542	5526861	790	50	15	332,6	53	940,5	12	1439	NE	15		+				+		+	+	+		
55	Pinus sylvestris	634461	5532462	5300	130	63	154,9	60	433,2	59	641	SW	63	+	+								+		
56	Pseudotsuga menziesii	638560	5526844	1720	60	15	354,2	53	965,2	12	1463	NE	15	+	+				+	+		+	+		
57	Juniperus communis	634664	5526141	160	20	24	363,1	65	897,6	6	929,4	N	24	+	+				+				+		
58	Corylus avellana 'Contorta	634355	5532399	420	80	63	31,78	60	555,3	58	636,5	w	63	+	+	+		+	+						
59	Corylus avellana	637720	5529249	3880	720	43	121,7	28	534,2	46	700,2	N	43	+	+	+		+						+	
60	Symphoricarpos albus	636002	5528299	1200	320	16	90,27	11	248,5	54	316,5	E	54	+	+			+	+					+	

In the five most represented species $(n \ge 4)$ among the 60 affected trees, most trees showed damage only on one side: unilateral damage (Damage code 1, Tables 2 and 4). By species and percentages: Acer platanoides (86%), Carpinus betulus (88%), Tilia sp. (100%), Taxus baccata (80%) and Thuja occidentalis (100%). On the seven trees not given code 1, the damage spread over the whole tree, but trees still showed side differences. Most of these trees were characterized with sparse leaves or needles (crown transparency) (Damage code 2, Tables 2 and 4). By species and percentages: Acer platanoides (86%), Carpinus betulus (100%), Taxus baccata (100%) and Thuja occidentalis (100%). In many of the trees with the one-sided damage, the leaves turned prematurely yellow or brown in June - this always began at the leaf margins (Damage code 3, Tables 2 and 4). The species with higher percentages were: Acer platanoides (86%) and Carpinus betulus (100%). In many trees leaves fall prematurely: Acer platanoides (93%), Carpinus betulus (100%) and Tilia sp. (100%) (Damage code 5, Tables 2 and 4). Many trees of the species Acer platanoides (80%), Taxus baccata (80%) and Thuja occidentalis (100%) had dead branches (Peak branches dried) (Damage code 6, Tables 2 and 4). All the trees of the species *Taxus baccata* (100%) and Thuja occidentalis (100%) exhibited color change of the needles (Damage code 10, Tables 2 and 4). Finally, in all trees of the species Taxus baccata, dead parts were trimmed (Damage code 11, Tables 2 and 4). Some trees stopped growing in height while, in others, the main guide died (see Tables 2 and 4).

The 30 randomly selected trees are presented in Table 5 with the tree code number, the scientific name, the UTM coordinates, the measurements (power flux density) on both sides of each tree, the distance (meters) to the three nearest antennas, their code number and the damage codes. Trees in these locations may be in areas with either high or low radiation. Seventeen trees in this group were situated in places with low radiation and showed no signs of damage. The measurements were 8–50 μ W/m² (0.054–0.137 V/m) and showed no

difference between the two opposite sides. Thirteen trees stood in the radiation field of one or more phone mast. Six of these had damage only on the side facing a phone mast, and five had damages on other sides. The measurements on the exposed sides were $40-4600 \ \mu\text{W/m}^2$ (0.122–1.316 V/m).

The 30 trees selected in areas with low radiation (radio shadow of hills, buildings or trees) are presented in Table 6 with the tree code number, scientific name, UTM coordinates, measurements (power flux density) on both sides of each tree, distance (meters) to the three nearest antennas, their code number and the damage codes. All trees selected in low radiation areas showed no damage (code 13). The power flux density values measured were $3-40 \ \mu W/m^2$ (0.033–0.122 V/m) and no significant differences were found between the two opposite sides.

The trees in random points and the trees in areas of low radiation are represented In Fig. 4 over the electromagnetic map prepared by interpolation of the 144 measurements points.

We performed a Repeated Measures ANOVA analysis in order to include the measurements of the exposed and shielded side of each tree (R1 = within subjects factor) in the three groups of trees (damaged, random, and low radiation), and to avoid pseudoreplication. The comparisons of all factor levels revealed significant differences, including the interaction between factors. A post hoc Bonferroni comparisons test, recommended for different sized groups of samples, revealed significant differences between measurements from the exposed side of damaged trees and all other groups (Table 7). Fig. 5 shows the measurements (mean and standard error) in all groups.

In the "Random points" group of trees, we performed another Repeated Measures ANOVA (R1 = within subjects factor) for trees damaged and undamaged within this group (Table 8). The results showed significant differences in both factors, including the interaction, which means that depending on the group of tree (damaged or undamaged),

Results of the tree measurements at the 30 random points.

																	Effe	ct cod	es					
												1	2	3	4	5	6	7	8	9	10	11	12	13
N°	Scientific name	×	*	Side antenna measurement µW/m²	Opposite side measurement $\mu W/m^2$	Number of Phone Mast 1	Distance a 1	Number of Phone Mast 2	Distance a 2	Number of Phone Mast 3	Distance a 3	Damage only on one side	Sparse leaves or needles (crown transparency)	Brown leaves (start at leaf margins)	Colour change of leaves prematurely	leaves fall prematurely	Dead branches (Peak branches dried).	Tip of the main guide dried	Irregular growth	Not grow in eight	Color change of needles	Dead parts were trimmed down	damage on different sides	no damage
1	Salix viminalis	634095	5532455	10	10	63	241,1	58	754,9	60	786,7													+
2	Thuja occidentalis	634760	5532680	500	120	60	119,6	63	524,2	59	763		+				+	+			+		+	——
3	Abies alba	634030	5530490	2200	900	36	201,2	37	418,8	31	447,7		+				+			+	+		+	
4	Acer campestre	634545	5530739	890	320	56	326,5	31	649,4	57	657,5	+	+				+							
5	Acer platanoides	634557	5530005	4600	1100	31	284,9	30	322,2	62	668,1	+	+	+		+						+		
6	Picea abies	635311	5530644	1900	210	9	185,6	8	894,8	30	900									+	+			
7	Thuja occidentalis	635635	5529879	10	10	8	252,5	38	621,9	9	702,6													+
8	Acer platanoides	635693	5529848	2600	310	8	210,9	38	625,5	21	707,1	+	+			+	+					+		
9	Cornus sanguinea	636415	5530248	40	30	27	559,3	8	614,5	25	750,8													+
10	Acer pseudoplatanus	637525	5530896	50	50	5	270,5	40	298,1	4	366,7													+
11	Syringa	638111	5531436	10	10	39	344,8	40	595,7	18	885,1													+
12	Acer platanoides 'Globorum'	637928	5530541	30	30	18	295,5	55	436,8	4	683,7													+
13	Acer platanoides	637159	5529361	20	15	28	181,7	46	330,8	43	671,3													+
14	Quercus rubra	638342	5528994	1480	570	50	549,7	43	600,8	45	907,4		+			+	+					+	+	
15	Thuja occidentalis	638359	5528569	25	20	50	275,5	45	653,6	12	866,2											<u> </u>		+
10	Titla sp	637412	552/922	460	320	51	93,6	10	122,5	12	293,8											+		
1/	Quercus robur	637363	552/80/	45	33	52	120	51	137,3	12	389,4													+
10		637804	5527028	4400	120	55	125,8	15	590,4	12	408,5		+				+		+				+	
20	Acer pseudopiatanas	627220	552/155	100	120	22	965 1	52	970.9	51	849,1 000.7	+	+			+	+	+				+		
20		637329	5520888	190	30	23	202,1	10	511.2	51	570.5	+										+		
21	Quercus robur	627215	552/425	40	20	25	1267	10	1200	51	378,5										+			+
22	Salix matsudana 'Tortuosa'	625402	5525412	15	13	64	040.0	23	1220	65	1421	Ŧ									-			+
23	Populus tramula	635410	5525828	15	12	64	596.8	65	8825	24	807													+
25	Salix matsudana 'Tortuosa'	634981	5526161	41	23	24	369.8	65	665.7	6	7777													+
25	Brunue en	634901	5526050	28	23	24	431.4	65	845.7	6	031.0													+
20	Picea nungens	634791	5526809	470	340	24	329	6	405 3	1	563.6		+				+		+				+	
28	Cornus sanguinea	635164	5527863	15	15	52	288 9	26	454.4	47	460 7		· ·										·	+
29	Cornus sanguinea	634905	5528779	20	20	47	65 12	41	242	26	695.1													+
30	Acer negundo	634202	5529092	8	8	42	792.6	41	859	62	886.9													+
	0										,5													

significant or non-significant respectively differences between the measurements of the two sides are seen (Fig. 6). A post hoc Bonferroni comparisons test showed significant differences between the measurements from the exposed side of damaged trees and all other groups in the random points group (Table 8).

Of the 120 trees, those with lower mean distance to the three closest antennas have usually higher values of radiation (Fig. 7). However, screening is common in cities due to a large amount of buildings, thus some trees that are close to antennas show lower radiation values than expected. This means that radiation measurements at points close to antennas are variable (high and low) while trees farther from antennas always have low values.

A dossier with documentation gathered over the years and the examples of tree damages is presented in: http://kompetenzinitiative. net/KIT/KIT/baeume-in-bamberg/

4. Discussion

In the present study it was useful, that tree damages in the vicinity of phone masts in Bamberg and Hallstadt had been documented starting 2006. We found a high level of damage to trees in the vicinity of phone masts. The damage encountered in these trees is not attributable to harmful organisms, such as diseases, pests or other environmental factors. These would impact upon the entire tree, whereas damage to trees in the present study was only found on parts of the tree and only on one side (unilateral). Therefore, these factors cannot explain the damage documented here. Generally in all trees of this study, damage is higher in areas of high radiation and occurs on the side where the nearest phone mast is located (Table 4 and Fig. 3). Moreover, areas with more antennas have more levels of radiation and damaged trees are found most often in these high electromagnetic polluted areas. These results showed that side differences in damage corresponded to side differences in measured values of power flux density. This paper look at the effects on trees, but also provides information on how electromagnetic radiation is distributed in a city (interpolation map and Fig. 7).

In this study deciduous and coniferous trees were examined under the real radiofrequency field conditions around phone masts in Bamberg and Hallstadt. From most phone masts a broad band of frequencies with different modulations and pulse frequencies and fluctuating power densities is emitted (GSM 900, GSM 1800, UMTS, LTE, TETRA). Different signals may have different effects due to their physical parameters (Belyaev, 2010; IARC, 2013). We do not discriminate between these different signals and cannot answer the question which part of the

Results of the tree measurements in the 30 points with low radiation.

			Effect codes																					
												1	2	3	4	5	6	7	8	9	10	11	12	13
Nº	Scientific name	×	٨	Side antenna measurement $\mu W/m^2$	Opposite side measurement $\mu W/m^2$	Number of Phone Mast 1	Distance a 1	Number of Phone Mast 2	Distance a 2	Number of Phone Mast 3	Distance a 3	Damage only on one side	Sparse leaves or needles (crown transparency)	Brown leaves (start at leaf margins)	Colour change of leaves prematurely	leaves fall prematurely	Dead branches (Peak branches dried).	Tip of the main guide dried	Irregular growth	Not grow in eight	Color change of needles	Dead parts were trimmed down	damage on different sides	no damage
1	Acer platanoides	636741	5529855	26	20	25	636,3	33	784,1	35	798,8													+
2	Carpinus betulus	634853	5529041	10	8	42	234,5	62	476,4	41	500,1													+
3	Carpinus betulus	638311	5528439	12	10	50	229,7	45	563,5	12	750													+
4	Carpinus betulus	636753	5529880	8	8	25	609,6	33	811,5	28	823,5													+
5	Carpinus betulus	637817	5527130	15	12	53	432,1	15	633	51	806,6													+
6	Carpinus betulus	634931	5526731	15	15	24	286	6	310,3	65	428,6													+
7	Tilia sp.	636500	5529673	8	8	35	511,4	34	528,3	33	570,3													+
8	Tilia sp.	636824	5529794	17	9	25	635,7	28	713,1	33	755,3													+
9	Quercus robur	636455	5526130	9	8	64	497,5	65	1240	17	1425													+
10	Quercus robur 'Fastigiata'	636178	5528932	10	10	34	282,2	35	306,5	21	332													+
11	Aesculus hippocastanum	636828	5529780	10	10	25	645,5	28	699	33	744,2													+
12	Aesculus carnea	636463	5529709	12	12	35	526,1	34	551,4	33	608,6													+
13	Robinia pseudoacacia	635507	5528534	15	15	14	136,6	13	201,5	26	299,2													+
14	Robinia pseudoacacia	634720	5532783	8	8	60	216,7	63	559,3	59	868,7													+
15	Acer campestre	635697	5528689	40	30	14	136,5	22	155,8	11	246,8													+
16	Acer campestre	636486	5526116	6	6	64	526,2	65	1273	23	1437													+
17	Juglans regia	635744	5528667	20	15	22	119	14	145,7	11	202,8													+
18	Platanus hispanica	635496	5528529	17	15	14	148,4	13	204,1	26	289,9													+
19	Prunus avium	637958	5530874	10	8	18	412,4	40	502,6	39	551,4													+
20	Prunus sp.	636079	5528463	10	10	11	237,5	16	269,7	54	312,7													+
21	Taxus baccata	638407	5528502	5	5	50	316	45	673,6	12	864,8													+
22	Taxus baccata	638222	5531032	10	10	18	474	39	578,6	40	673,1													+
23	Thuja occidentalis	636518	5529853	9	9	8	648,4	35	680	34	705													+
24	Thuja occidentalis	635318	5528784	20	15	42	371,5	14	389,4	13	514,8													+
25	Picea pungens	636512	5529735	17	17	35	571,4	34	590,8	33	632													+
26	Juniperus communis	636549	5529756	8	8	35	607,8	34	623,4	33	653,7													+
27	Cornus sanguinea	638167	5529098	8	6	43	397,2	50	597,9	45	899,8													+
28	Sambucus nigra	635529	5525601	5	5	64	625,2	65	1121	24	1146													+
29	Corylus avellana	636422	5526181	5	3	64	476,4	65	1187	17	1371													+
30	Corylus avellana	636625	5529834	6	6	35	714	34	725,2	25	732,3													+

radiation has caused the damage. Nevertheless broad bands of frequencies, modulation, pulse frequencies, interferences and other physical characteristics may play an important role, since in some cases, damage already appears at low intensities. This can be a shortcoming of the study.

The aim of the present study was to find out whether there is a causal relationship between the unilateral tree damages, which had been observed since 2006, and the RF-EMF emitted from phone masts and a preliminary observation to find out whether various species react differently to RF exposure.

The selection of the 60 unilaterally damaged trees was limited by the fact that we could do measurements only up to a height of 6 m. Trees with damages above the height of 6 m could not be included.

Many factors can affect the health of trees: Air and soil pollutants, heat, frost, drought, as well as composition, compaction and sealing of the soil, road salts, root injury due to construction work, diseases and pests. Most of these factors do not affect a tree only on one side over a period of >5 years. Industrial air pollutants could eventually cause unilateral damage in direction to an industrial emitter. But the observed unilateral damages appeared in all directions and were not oriented to the incineration plant or other industrial plants. Root injury due to construction work can produce damage on one side of a tree, but 24 of the

60 selected trees were situated in gardens, parks or on the cemetery where they could not be affected by construction damages.

From the damaged side there was always visual contact to one or more phone mast (s). In each case measurements of the power flux density on the damaged side which was facing a phone mast and on the opposite side without (or with less) damage were carried out and the difference between the measured values on both sides was significant (Fig. 5), as well as between the exposed side of damaged trees and all other groups. In all 60 trees the gradient of damage corresponded to a gradient of measured values. The attenuation of the RF-EMF within the treetop offers an explanation: a part of the RF-EMF is absorbed by leaves or needles and another part is reflected, scattered and diffracted.

In the randomely selected group of 30 trees, 17 trees were situated on places with low radiation. These 17 trees showed no damages, the measured values were below 50 μ W/m² (0.137 V/m) and there was no difference between opposite sides as in the low radiation group. On the other hand, 13 trees grew in the radiation field of one or more phone mast (s). These trees showed unilateral damage or damage on different sides. The measured values at damaged trees showed differences between both sides as in the previous group above.

In the group of 30 trees in areas with low radiation (radio shadow of hills, buildings or trees and without visual contact to phone masts)



Fig. 4. Map showing the 30 trees at random points and the 30 trees in areas of low radiation (both with code numbers) over the interpolation electromagnetic map of the 144 measurement points. Phone masts (with code numbers) are also represented.

there were no unilateral damages. The measured values were below $50 \ \mu W/m^2$ (0.137 V/m) and there was no difference between opposite sides. These results in the three groups point to a connection between unilateral tree damage and RF exposure.

In the electromagnetic field of all mobile phone base stations visited numerous tree damages were observed. The damage occurred in temporal relation with the putting into operation of new mobile phone base stations. Woody plants of all species are affected (deciduous and coniferous trees as well as shrubs).

In the five most represented species ($n \ge 4$) among the 60 damaged trees (*Acer platanoides, Carpinus betulus, Tilia* sp., *Taxus baccata* and *Thuja occidentalis*), most trees showed damage only on one side (Damage code 1, Tables 2 and 4). Most of these trees were characterized with sparse leaves or needles (crown transparency) (Damage code 2, Tables 2 and 4). In many of the trees with the one-sided damage, the leaves turned prematurely yellow or brown in June – this always began at

the leaf margins (Damage code 3, Tables 2 and 4). In many trees leaves fall prematurely (Damage code 5, Tables 2 and 4) or had dead branches (Peak branches dried) (Damage code 6, Tables 2 and 4). Some trees stopped growing in height while, in others, the main guide died (see Tables 2 and 4).

The differences in susceptibility of different species could be related to radiofrequency energy absorption properties of the trees (e.g., dielectric property). Perhaps this study cannot answer questions about these differences, however it is quite possible that differences are related to the electrical conductivity, related also with the density of the wood (species of fast or slow growth) and particularly with the percentage of water in the tissues. Poplars and aspen that grow near rivers and water bodies in Spain seem to be particularly sensitive to the effects of radiation. But the waves reflection in the water could also influence.

The results presented here lead us to conclude that damage found in the selected trees is caused by electromagnetic radiation from phone

Table 7

Repeated measures ANOVA analysis and Bonferroni post hoc comparisons (p < 0.01 values with *) in the three types of trees (damaged, random, and low radiation). Measurement Side 1/2 correspond to the maximum/minumum value of radiation respectively for the opposite sides of each tree.

-		66	Deers of		MC	Г		-
		33	Degr. of		IVIS	F		р
Intercept		62663309	1		62663309	25.814	60	0.000001*
Type of tr	ee	52931692	2		26465846	10.902	80	0.000046*
Error		284010086	117		2427437			
R1		33197069	1		33197069	18.286	694	0.000039*
R1*Type of	of tree	44608664	2		22304332	12.286	56	0.000014*
Error		212395158	117		1815343			
	Type of tree	R1	{1}	{2}	{3}	{4}	{5}	{6}
1	Damaged	Measurement		0.000000*	0.001829*	0.000001*	0.000000*	0.000000*
	Ũ	Side1						
2	Damaged	Measurement	0.000000*		1.000000	1.000000	1.000000	1.000000
		Side2						
3	Random	Measurement	0.001829*	1.000000		1.000000	1.000000	1.000000
		Side1						
4	Random	Measurement	0.000001*	1.000000	1.000000		1.000000	1.000000
		Side2						
5	Low	Measurement	0.000000*	1.000000	1.000000	1.000000		1.000000
	radiation	Side1						
6	Low	Measurement	0.000000*	1.000000	1.000000	1.000000	1.000000	
	radiation	Side2						



Fig. 5. Differences between measurements in both sides for the three different tree groups: damaged, random, and low radiation. Measurement Side 1/2 correspond to the maximum/minumum value of radiation respectively for the opposite sides of each tree. The bars represent means \pm standard errors. The central point represents the mean and the straight line \pm 0.95*SE.

masts, as we proposed in previous studies (Balmori, 2004; Waldmann-Selsam, 2007; Waldmann-Selsam and Eger, 2013; Balmori, 2014). Interested parties are able to locate the damaged trees found in this work in Bamberg and Hallstadt with their UTM coordinates. However, trees with code numbers 20, 38 and 48 (Table 4) have been cut down and removed.

Research on the effects of radiation from phone masts is advancing rapidly. In February 2011 the first symposium on the effects of electromagnetic radiation on trees took place in Baarn, Netherlands (Schorpp, 2011 - http://www.boomaantastingen.nl/), where similar effects and results to those found in the current paper were presented.

Although there are some related experiments that show no effect of long-term exposure (3,5 years), 2450-MHz (continous wave) and power flux densities from 0.007 to 300 W/m² on crown transparency, height growth and photosynthesis of young spruce and beech trees (Schmutz et al., 1996), this result may not be transferred to modulated 2450-MHz or to other pulsed and modulated frequencies. In addiction, an increasing number of studies have highlighted biological responses and modifications at the molecular and whole plant level after exposure to high frequency electromagnetic fields (Vian et al., 2016). Plants can perceive and respond to various kinds of electromagnetic radiation over a wide range of frequencies. Moreover, a low electric field intensity (5 V/m) was sufficient to evoke morphological responses (Grémiaux et al., 2016). Electromagnetic radiation impacts at physiological and



Fig. 6. Differences between measurements in both sides for the damaged and undamaged trees within the random trees group. Measurement side 1/2 correspond to the maximum/ minumum value of radiation respectively for the opposite sides of each tree. The bars represent means \pm standard errors. The central point represents the mean and the straight line \pm 0.95*SE.

ecological levels (Cammaerts and Johansson, 2015), and evokes a multitude of responses in plants. The effects of high frequency electromagnetic fields can also take place at the subcellular level: it can alter the activity of several enzymes, including those of reactive oxygen species (ROS) metabolism, a well-known marker of plant responses to various kinds of environmental factors; it evokes the expression of specific genes previously implicated in plant responses to wounding (gene expression modifications), and modifies the growth of the whole plants (Vian et al., 2016). It could be hypothesized that membrane potential variations in response to electromagnetic radiation exposure may initiate electrical waves of depolarization (AP and/or VP) that could initiate immediate or delayed growth responses (Grémiaux et al., 2016). It has been proposed that electromagnetic fields act similarly in plants and in animals, with the probable activation of calcium channels via their voltage sensor (Pall, 2016).

Electromagnetic radiation (1800 MHz) interferes with carbohydrate metabolism and inhibits the growth of *Zea mays* (Kumar et al., 2015). Furthermore, cell phone electromagnetic radiation inhibits root growth of the mung bean (*Vigna radiata*) by inducing ROS-generated oxidative stress despite increased activities of antioxidant enzymes (Sharma et al., 2009). Germination rate and embryonic stem length of *Triticum aestivum* was also affected by cell phone radiation (Hussein and El-Maghraby, 2014). After soybeans were exposed to weak microwave radiation from the GSM 900 mobile phone and base station, growth of

Table 8

Repeated measures ANOVA analysis and Bonferroni post hoc comparisons (p < 0.01 values with *) in the random trees group. Measurement Side 1/2 correspond to the maximum/minumum value of radiation respectively for the opposite sides of each tree.

	S	SS		Degr. of		MS		F		р
Intercept	1	7829607		1		17829607		16.60	985	0.000343*
13 code	1	6391606		1		16391606		15.27	023	0.000538*
Error	3	30056202		28		1073436				
R1	3	3701923		1		3701923		16.73	250	0.000329*
R1*13 code	3	3627579		1		3627579		16.39	647	0.000368*
Error	6	6194761		28		221241				
	13 code		R1		{1}		{2}		{3}	{4}
1	Undamaged		Measurement Side				1.000000		0.002129*	0.416303
	Ū.		1							
2	Undamaged		Measurement Side		1.000000				0.000034*	0.927155
			2							
3	Damaged		Measurement Side		0.002129*		0.000034*			0.000055*
			1							
4	Damaged		Measurement Side		0.416303		0.927155		0.000055*	
			2							



Fig. 7. Scatterplot showing the correlation between measurements from each of the 120 trees and the mean distance to the three nearest antennas. Dashed lines represent the 0.95 confidence interval.

epicotyl and hypocotyl was reduced, whereas the outgrowth of roots was stimulated. These findings indicate that the observed effects were significantly dependent on field strength as well as amplitude modulation of the applied field (Halgamuge et al., 2015). Phone mast radiation also affects common cress (*Lepidium sativum*) seed germination (Cammaerts and Johansson, 2015). In *Arabidopsis thaliana*, the long term exposure to non ionizing radiation causes a reduction in the number of chloroplasts as well as the decrease of stroma thylakoids and the photosynthetic pigments (Stefi et al., 2016). Finally, low-intensity exposure to radiofrequency fields can induce mitotic aberrations in root meristematic cells of *Allium cepa*; the observed effects were markedly dependent on the frequencies applied as well as on field strength and modulation (Tkalec et al., 2009).

In general, polarization from man-made electromagnetic radiation appears to have a greater bioactive effect than natural radiation, and significantly increases the probability for initiation of biological or health effects (Panagopoulos et al., 2015).

Tree damages as in Bamberg and Hallstadt were documented by the authors in several countries: Spain (Valladolid, Salamanca, Madrid, Palencia, León), Germany (Munich, Nürnberg, Erlangen, Bayreuth, Neuburg/Donau, Garmisch-Partenkirchen, Murnau, Stuttgart, Kassel, Fulda, Göttingen, biosphere reserve Rhön, Tegernsee Valley and in several small towns), Austria (Graz), Belgium (Brussels) and Luxemburg.

Each phone mast can harm many trees and each tree can be affected by several phone masts belonging to the same or different base stations. Damaged trees seem to exist around each antenna and the several million phone masts in the world could potentially be damaging the growth and health of millions of trees. This can occur not only in cities, but also in well-preserved forests, and in natural and national parks, where base stations are being installed without the necessary prior environmental impact studies, due to a lack of knowledge of the problem. For this reason, it is essential for an assessment on the environmental impact of any new base station prior to implementation.

Additionally, phone masts can cause a drop in timber productivity in plantations of pine, poplar, etc., as well as fruits, nuts, etc. Thus, the industry must be required to pay damages to plantation owners. Similarly, as trees are a common social good, the industry should compensate for damaged and dead trees around the world due to radiation. Further, the money spent by municipalities to repair or replace damaged trees should enter into the computation of costs/benefits of this technology. For installation of any new technology, the burden of proof should be to the industry that requires demonstration of safety prior to deployment.

Electromagnetic radiation from telecommunication antennas affected the abundance and composition of wild pollinators in natural habitats and these changes in the composition of pollinator communities associated with electromagnetic smog may have important ecological and economic impacts on the pollination service that could significantly affect the maintenance of wild plant diversity, crop production and human welfare (Lázaro et al., 2016).

Evidence for plant damage due to high frequency electromagnetic radiation was not taken into account in determining the current statutory regulations (the limit values). Once the problem becomes evident, the guidelines of radiation emitted by the antennas should be reviewed. Proper risk assessment of electromagnetic radiation should be undertaken to develop management strategies for reducing this pollution in the natural environment (Kumar et al., 2015).

Moreover, due to the lack of recognition, certain modern projects with interesting ideas for decreasing environmental pollution could have opposite effects than expected. For example, in the Netherlands, the TreeWiFi project (http://treewifi.org/), which aims to motivate people to use bikes and public transport in order to reduce the [NO2] pollution providing free WiFi when air quality improves, could be favoring electromagnetic pollution with even more harmful effects as it has been demonstrated in this manuscript (see also: http://www.greenpeace.org/canada/fr/Blog/le-wi-fi-tuerait-les-ar-bres/blog/33569/).

In addition, the number of sector antennas has increased in Bamberg and this increase appears to be accelerating: 483 sector antennas in 2011 and 779 sector antennas in 2015. Both radiation and damaged trees represent a loss of quality of life for citizens. This study began after finding that patients who claimed to be affected by phone masts, referred to as radiation, live in areas where affected trees and plants are located. Evidence of radiation damage was even found in potted plants inside patient homes (Waldmann-Selsam and Eger, 2013). Thus, this study is certainly complementary to the study by Eger and Jahn (2010) and other research that has shown effects on the health of people by phone masts located in their vicinity (Santini et al., 2002; Eger et al., 2004; Wolf and Wolf, 2004; Abdel-Rassoul et al., 2007; Khurana et al., 2010; Dode et al., 2011; Gómez-Perretta et al., 2013; Shahbazi-Gahrouei et al., 2014; Belyaev et al., 2015).

In the introduction to the International Seminar on "Effects of Electromagnetic Fields on the Living Environment" in 1999 in Ismaning, Germany, organized by WHO, ICNIRP and German Federal Office for Radiation Protection (BfS), M. Repacholi, head of the International EMF Project of the WHO, said: "By comparison, influences of these fields on plants, animals, birds and other living organisms have not been properly examined. Given that any adverse impacts on the environment will ultimately affect human life, it is difficult to understand why more work has not been done. There are many questions that need to be raised:" and "....it seems that research should focus on the long-term, lowlevel EMF exposure for which almost no information is available. Specific topics that need to be addressed include: ... EMF influences on agri-

cultural plants and trees" (Matthes et al., 2000).

5. Conclusions

In this study we found a high-level damage in trees within the vicinity of phone masts. Preliminary laboratory studies have indicated some deleterious effects of radiofrequency radiation. However, these early warnings have had no success and deployment has been continued without consideration of environmental impact.

We observed trees with unilateral damage in the radiation field of phone masts. We excluded the possibility that root injury due to construction work or air pollutants could have caused the unilateral damage. We found out that from the damaged side there was always visual contact to one or more phone mast (s).

Statistical analyses demonstrated that the electromagnetic radiation from cellphone towers is harmful to trees. Results show that the measurements in the most affected sides of damaged trees (i.e. those that withstand higher radiation levels) are different to all other groups. These results are consistent with the fact that damage inflicted on trees by cellphone towers usually start on one side, extending to the whole tree over time.

The occurrence of unilateral damage is the most important fact in our study and an important argument for a causal relationship with RF-EMF, as it supplies evidence for non-thermal RF-EMF effects. This constitutes a danger for trees worldwide. The further deployment of phone masts has to be stopped. Scientific research on trees under the real radiofrequency field conditions must continue.

Acknowledgements

The work presented here was carried out without any funding. Francisco Cabrero and José Ignacio Aguirre from the Department of Zoology, University Complutense of Madrid suggested the interpolation points on the map of radiation. This paper is dedicated in memoriam to the great Swedish researcher and courageous man, Örjan Hallberg. Authors have not a conflict of interest to declare.

References

- Abdel-Rassoul, G., El-Fateh, O.A., Salem, M.A., Michael, A., Farahat, F., El-Batanouny, M., Salem, E., 2007. Neurobehavioral effects among inhabitants around mobile phone base stations. Neurotoxicology 28, 434–440.
- Balmori, A., 2004. Pueden afectar las microondas pulsadas emitidas por las antenas de telefonía a los árboles y otros vegetales? Ecosistemas 13, 79–87.
- Balmori, A., 2014. Electrosmog and species conservation. Sci. Total Environ. 496, 314–316.Balmori, A., 2015. Anthropogenic radiofrequency electromagnetic fields as an emerging threat to wildlife orientation. Sci. Total Environ. 518, 58–60.
- Balodis, V.G., Brumelis, K., Kalviskis, O., Nikodemus, D., Tjarve, V.Z., 1996. Does the Skrunda Radio Location Station disminish the radial growth of pine trees? Sci. Total Environ. 180, 57–64.
- Beaubois, E., Girard, S., Lallechere, S., Davies, E., Paladian, F., Bonnet, P., Ledoit, G., Vian, A., 2007. Intercellular communication in plants: evidence for two rapidly transmitted systemic signals generated in response to electromagnetic field stimulation in tomato. Plant Cell Environ. 30, 834–844.
- Belyaev, I., 2010. Dependence of non-thermal biological effects of microwaves on physical and biological variables: implications for reproducibility and safety standards. In: Giuliani, L., Soffritti, M. (Eds.), European Journal of Oncology - Library Non-thermal effects and mechanisms of interaction between electromagnetic fields and living matterAn ICEMS Monograph vol. 5. RAMAZZINI INSTITUTE, Bologna, Italy (http:// www.icems.eu/papers.htm?f=/c/a/2009/12/15/MNHJ1B49KH.DTL).
- Belyaev, I., Dean, A., Eger, H., Hubmann, G., Jandrisovits, R., Johansson, O., Moshammer, H., Kern, M., Kundi, M., Lercher, P., Mosgoller, W., Moshammer, H., Muller, K., Oberfeld, G., Ohnsorge, P., Pelzmann, P., Scheingraber, C., Thill, R., 2015. EUROPAEM EMF Guideline 2015 for the prevention, diagnosis and treatment of EMF-related health problems and illnesses. Rev. Environ. Health 30, 337–371.
- Bernatzky, A., 1986. Elektromagnetischer Smog Feind des Lebens. Der Naturarzt 11, 22–25 (http://www.diewellenbrecher.de/pdf/bernatzky.pdf).
- Brauer, I., 1950. Experimentelle Untersuchungen über die Wirkung von Meterwellen verschiedener Feldstärke auf das Teilungswachstum der Pflanzen. Chromosoma 3, 483–509 (http://www.springerlink.com/content/kqn177g8g5114787/, letzter Zugriff: 30.5.2013).
- Cammaerts, M.C., Johansson, O., 2015. Effect of man-made electromagnetic fields on common Brassicaceae *Lepidium sativum* (cress d'Alinois) seed germination: a preliminary replication study. Fyton 84, 132–137.
- Dode, A.C., Leão, M.M., de AF Tejo, F., Gomes, A.C., Dode, D.C., Dode, M.C., Caiaffa, W.T., 2011. Mortality by neoplasia and cellular telephone base stations in the Belo Horizonte municipality, Minas Gerais state, Brazil. Sci. Total Environ. 409, 3649–3665.
- Eger, H., Uwe, K., Hagen, B., Lucas, P., Vogel, P., Voit, H., 2004. Einfluss der räumlichen Nähe von Mobilfunksendeanlagen auf die Krebsinzidenz. Umwelt Med. Ges. 17, 326–332.
- Eger, H., Jahn, M., 2010. Specific symptoms and radiation from mobile basis stations in Selbitz, Bavaria, Germany: evidence for a dose-effect relationship (original article in German). Umwelt Med. Ges. 23, 130–139.
- ESRI (Environmental Systems Research Institute), 2008. ArcMap 9.3 (Build 1770). ESRI® ArcGIS, 9, 1999–2008.
- Gómez-Perretta, C., Navarro, E.A., Segura, J., Portolés, M., 2013. Subjective symptoms related to GSM radiation from mobile phone base stations: a cross-sectional study. BMJ open 3 (12), e003836.
- Grémiaux, A., Girard, S., Guérin, V., Lothier, J., Baluška, F., Davies, E., Bonnet, P., Vian, A., 2016. Low-amplitude, high-frequency electromagnetic field exposure causes delayed and reduced growth in Rosa hybrid. J. Plant Physiol. 190, 44–53.
- Haggerty, K., 2010. Adverse influence of radio frequency background on trembling aspen seedlings: preliminary observations. Int. J. For. Res. 2010, 836278.
- Halgamuge, M.N., Yak, S.K., Eberhardt, J.L., 2015. Reduced growth of soybean seedlings after exposure to weak microwave radiation from GSM 900 mobile phone and base station. Bioelectromagnetics 36, 87–95.
- Harte, C., 1950. Mutationsauslösung durch Ultrakurzwellen. Chromosoma 3, 140-147.

- Harte, C., 1972. Auslösung von Chromosomenmutationen durch Meterwellen in Pollenmutterzellen von Oenothera. Chromosoma 36, 329–337 (http://www. springerlink.com/content/x32049jrnm4u7858/).
- Hussein, R.A., El-Maghraby, M.A., 2014. Effect of two brands of cell phone on germination rate and seedling of wheat (*Triticum aestivum*). J. Environ. Pollut. Human Health 2, 85–90.
- IARC, 2013. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Nonionizing Radiation, Part 2: Radiofrequency Electromagnetic Fields vol. 102. IARC Press, Lyon, France (http://monographs.iarc.fr/ENG/Monographs/vol102/mono102. pdf).
- I. C. N. I. R. P., 1998. Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz). Health Phys. 74 (4), 494–522.
- Jayasanka, S.M.D.H., Asaeda, T., 2013. The significance of microwaves in the environment and its effect on plants. Environ. Rev. 22, 220–228.
- Jerman, I., Berden, M., Ruzic, R., Skarja, M., 1998. Biological effects of TV set electromagnetic fields on the growth of spruce seedlings. Electromagn. Biol. Med. 17, 31–42.
- Kiepenheuer, K.O., Brauer, I., Harte, C., 1949. Über die Wirkung von Meterwellen auf das Teilungswachstum der Pflanzen. Naturwissenschaften 36, 27.
- Kundu, A., IEEE, 2013. Specific Absorption Rate evaluation in apple exposed to RF radiation from GSM mobile towers. IEEE Applied Electromagnetics Conference (AEMC). IEEE, pp. 1–2 (ISBN 978-1-4799-3266-5).
- Khurana, V.G., Hardell, L., Everaert, J., Bortkiewicz, A., Carlberg, M., Ahonen, M., 2010. Epidemiological evidence for a health risk from mobile phone base stations. Int. J. Occup. Environ. Health 16, 263–267.
- Kumar, A., Singh, H.P., Batish, D.R., Kaur, S., Kohli, R.K., 2015. EMF radiations (1800 MHz)inhibited early seedling growth of maize (*Zea mays*) involves alterations in starch and sucrose metabolism. Protoplasma 1–7.
- Lázaro, A., Chroni, A., Tscheulin, T., Devalez, J., Matsoukas, C., Petanidou, T., 2016. Electromagnetic radiation of mobile telecommunication antennas affects the abundance and composition of wild pollinators. J. Insect Conserv. 1–10 http://dx.doi.org/10.1007/ s10841-016-9868-8.
- Lerchl, D., Lerchl, A., Hantsch, P., et al., 2000. Studies on the effects of radio-frequency fields on conifers, Kurzmitteilung auf der Tagung der Bioelectromagnetics Society in München. http://www.boomaantastingen.nl/EMF_and_conifers%5B1%5D.pdf.
- Matthes, R., Bernhardt, J.H., Repacholi, M.H., 2000. Effects of electromagnetic fields on the living environment. Proceedings International Seminar on Effects of Electromagnetic Fields on the Living Environment – Ismaning, Germany, October 4 and 5, 1999, ICNIRP 10/2000.
- Meng, Y.S., Lee, Y.H., 2010. Investigations of foliage effect on modern wireless communication systems: a review. Prog. Electromagn. Res. 105, 313–332.
- Pall, M., 2016. Electromagnetic fields act similarly in plants as in animals: probable activation of calcium channels via their voltage sensor. Curr. Chem. Biol. (http:// benthamscience.com/journals/current-chemical-biology/article/141390/).
- Panagopoulos, D.J., Johansson, O., Carlo, G.L., 2015. Polarization: a key difference between man-made and natural electromagnetic fields, in regard to biological activity. Sci. Rep. 5, 14914. http://dx.doi.org/10.1038/srep14914.
- Panagopoulos, D.J., Cammaerts, M.C., Favre, D., Balmori, A., 2016. Comments on environmental impact of radiofrequency fields from mobile phone base stations. Crit. Rev. Environ. Sci. Technol. http://dx.doi.org/10.1080/10643389.2016.1182107.
- Pesnya, D.S., Romanovsky, A.V., 2013. Comparison of cytotoxic and genotoxic effects of plutonium-239 alpha particles and mobile phone GSM 900 radiation in the *Allium cepa* test. Mutat. Res. Genet. Toxicol. Environ. Mutagen. 750, 27–33.
- QGIS Development Team, 2014. Quantum GIS geographic information system version 2.6.0-Brighton [Internet]. http://qgis.osgeo.org.
- Roux, D., Vian, A., Girard, S., Bonnet, P., Paladian, F., Davies, E., Ledoigt, G., 2006. Electromagnetic fields (900 MHz) evoke consistent molecular responses in tomato plants. Physiol. Plant. 128, 283–288.
- Roux, D., Vian, A., Girard, S., Bonnet, P., Paladian, F., Davies, E., Ledoigt, G., 2008. High frequency (900 MHz) low amplitude (5 V m — 1) electromagnetic field: a genuine environmental stimulus that affects transcription, translation, calcium and energy charge in tomato. Planta 227, 883–891.
- Sandu, D.D., Goiceanu, C., Ispas, A., Creanga, I., Miclaus, S., Creanga, D.E., 2005. A preliminary study on ultra high frequency electromagnetic fields effect on black locust chlorophylls. Acta Biol. Hung, 56, 109–117.
- Santini, R., Santini, P., Danze, J.M., Le Ruz, P., Seigne, M., 2002. Study of the health of people living in the vicinity of mobile phone base stations: I. Influences of distance and sex. Pathol. Biol. 50, 369–373.
- Schmutz, P., Siegenthaler, J., Stäger, C., Tarjan, D., Bucher, J.B., 1996. Long-term exposure of young spruce and beech trees to 2450 MHz microwave radiation. Sci. Total Environ. 180. 43–48.
- Schorpp, V., 2011. Tree damage from chronic high frequency exposure. The effect of electromagnetic radiation on trees, First symposium February 18, 2011, Lecture, Baan, Netherlands (http://www.puls-schlag.org/download/Schorpp-2011-02-18,pdf).
- Selga, T., Selga, M., 1996. Response of *Pinus sylvestris* L. needles to electromagnetic fields. Cytological and ultrastructural aspects. Sci. Total Environ. 180, 65–73.
- Shahbazi-Gahrouei, D., Karbalae, M., Moradi, H.A., Baradaran-Ghahfarokhi, M., 2014. Health effects of living near mobile phone base transceiver station (BTS) antennae: a report from Isfahan, Iran. Electromagn. Biol. Med. 33, 206–210.
- Sharma, V.P., Singh, H.P., Kohli, R.K., Batish, D.R., 2009. Mobile phone radiation inhibits Vigna radiata (mung bean) root growth by inducing oxidative stress. Sci. Total Environ. 407, 5543–5547.
- StatSoft, Inc, 2004. STATISTICA (data analysis software system), version 7. www.statsoft. com.
- Stefi, A.L., Margaritis, L.H., Christodoulakis, N.S., 2016. The effect of the non ionizing radiation on cultivated plants of Arabidopsis thaliana (Col.). Flora 223, 114–120.

- Tkalec, M., Malarić, K., Pevalek-Kozlina, B., 2005. Influence of 400, 900, and 1900 MHz. electromagnetic fields on *Lemna minor* growth and peroxidase activity. Bioelectromagnetics 26, 185–193.
- Tkalec, M., Malarič, K., Pavlica, M., Pevalek-Kozlina, B., Vidaković-Cifrek, Ž., 2009. Effects of radiofrequency electromagnetic fields on seed germination and root meristematic cells of *Allium cepa* L. Mutat. Res. Genet. Toxicol. Environ. Mutagen. 672, 76–81.
- Van't Wout, N., 2006. Unkown tree damage. http://www.boomaantastingen.nl. Vian, A., Davies, E., Gendraud, M., Bonnet, P., 2016. Plant responses to high frequency elec-
- tromagnetic fields. Biomed. Res. Int. 2016, 1830262. http://dx.doi.org/10.1155/2016/ 1830262.
- Volkrodt, W., 1987. Wer ist am Waldsterben schuld? Mikrowellensmog der Funk- und Nachrichtensysteme. Raum Zeit 26, 53–62.
 Volkrodt, W., 1991. Droht den Mikrowellen ein ähnliches Fiasko wie der Atomenergie?
- Volkrodt, W., 1991. Droht den Mikrowellen ein ahnliches Fiasko wie der Atomenergie? Wetter-Boden-Mensch 4, 16–23.
- Waldmann-selsam, C., 2007. Mikrowellensyndrom ein neues Krankheitsbild, Vortrag, 6. Rheinland-Pfälzisch-Hessisches Mobilfunksymposium, 14.4.2007, BUND Rheinland-Pfalz, Mainz. http://www.bund-rlp.de/publikationen/ tagungsbaende/mobilfunksymposium/6_mobilfunksymposium/.
- ы киеппапа-rtaiz, Mainz. http://www.bund-rlp.de/publikationen/ tagungsbaende/mobilfunksymposium/6_mobilfunksymposium/. Waldmann-Selsam, C., Eger, H., 2013. Baumschäden im Umkreis von Mobilfunksendeanlagen. Umwelt Med. Ges. 26, 198–208 (http:// kompetenzinitiative.net/KIT/wp-content/uploads/2016/06/Tree-damages-inthe-vicinity-of-mobile-phone-base-stations.pdf).
- Wolf, R., Wolf, D., 2004. Increased incidence of cancer near a cell-phone transmitter station. Int. J. Cancer 1, 123–128.