

Online Supplement to “Bacteria in the global atmosphere — Part I: Review and synthesis of literature data for different ecosystems”

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Descriptions of the state of bacterial cells

Table S1: Descriptions of the state of bacterial cells

Term	Definition ¹	Comments
Total bacteria	All non-lysed bacterial cells, including viable and non-viable cells.	The use of the term “bacteria” is not specified by most authors. We take it to include all prokaryotes (organisms without a cell nucleus), i.e. both <i>Bacteria</i> and <i>Archaea</i> , since the studies reviewed here do not explicitly distinguish these two domains.
Viable (living) bacteria	“A cell capable of dividing and forming at least one live daughter cell when it is placed in a favorable environment”.	Defining viability is difficult, mostly because there is no method to determine definitively whether an intact, dormant cell, under the right conditions, could be “resuscitated” and become metabolically and reproductively active.
Metabolically active bacteria	Bacteria actively engaging in detectable metabolic processes.	The presence of metabolically active cells can be tested by indirect measurements, e.g., of enzyme activity, photosynthesis, respiration and energy charge. Metabolic activity is often equated with viability (Colwell, 2000).
Dormant bacteria	Cells which have entered a “rest period” or “reversible interruption of phenotypic development” (Sussman and Halvorson, 1966).	Dormant bacteria do not metabolize, or else exist in a vegetative state and metabolize at very slow rates. Dormancy is a survival strategy used by bacteria when environmental conditions are unfavorable, for instance in response to low nutrient availability or danger of desiccation. It may involve the formation of a spore or cyst, but non-sporulating bacteria can also enter into dormant states. They do not reproduce while in the dormant state; however, they may be “resuscitated” and return to a metabolically active, reproductive state.
Culturable bacteria	Bacteria capable of growth and multiplication under a particular set of environmental conditions.	In environmental samples, only a small fraction of viable bacteria are culturable, and the size of this fraction depends on the particular experimental technique used. Many investigators refer to the culturable bacteria count as “viable” bacteria, which is misleading. We use the term “culturable” bacteria to emphasize this important distinction. Note also that we use the term “culturable” to mean “culturable by a particular method”, which is how it is usually used in observational studies. This is different from the usage in the term “viable but nonculturable”, in which “culturable” bacteria are implicitly defined as cells which can be cultured by at least one available method.
Viable but non-culturable (VBNC) bacteria	“Bacterial cells with detectable metabolic function, but not culturable by available methods” (Colwell, 2000)	The vast majority of bacteria in environmental samples are VBNC (Amann et al., 1995). These cells are very much alive — pathogenic bacteria in the viable but nonculturable stage are capable of causing disease (Colwell, 2000). The use of the terms “dormant” and VBNC in the literature is inconsistent. While dormant cells are VBNC, we do not equate the two terms. Many bacterial species have never been successfully cultured, even when metabolically active (Amann et al., 1995), and these species can also be termed VBNC.
Dead bacteria	Cells which are no longer capable of metabolic activity or reproduction, i.e., lysed cells and other cells incapable of being resuscitated.	It has been difficult to distinguish truly “dead” bacteria from those in a dormant phase. Unlike multicellular organisms, bacteria do not undergo a natural senescence and death sequence. A large number of methods have been proposed for distinguishing living bacteria from dead cells (Roszak and Colwell, 1987).

Flux measurements

Table S2: Fluxes of culturable, filtered bacteria to the atmosphere ($\text{m}^{-2} \text{s}^{-1}$)

Source	Season	Flux ($\text{m}^{-2} \text{s}^{-1}$)	Assessment ^d	Reference
High desert chaparral, Oregon, USA	summer	4.7 ^b	+	Lighthart and Shaffer (1994)
Snap beans	summer	499	+	Lindemann et al. (1982)
Alfalfa	summer	543	+	Lindemann et al. (1982)
Wheat	summer	57	+	Lindemann et al. (1982)
Dry cropland soil	summer-autumn	43 ± 9	+	Lindemann and Uppner (1985)
Wet cropland soil	summer-autumn	155 ± 57	+	Lindemann and Uppner (1985)
Nanjing, 30 m above ground	unknown	-5 - 45	-	Chen et al. (2001) ^c
Nanjing, 50 m above ground	unknown	-25 - 35	-	Chen et al. (2001)
Baling	summer	$3.3 \times 10^6 - 1.9 \times 10^7$	-	Lighthart (1984)
Harvesting	summer	$1.5 \times 10^8 - 10^9$	-	Lighthart (1984)

^aSee key in Table §3.

^bNoon maximum emission flux

^cLacks description of nutrient agar, measurement dates. Values estimated from digitized plot.

Concentration measurements

Table S3: Observed concentrations of bacterial aerosol: colony forming units or total number.

Source	Season	Method ^a	Concentration ^b (m ⁻³)	Standard error ^b (m ⁻³)	Min – Max ^b (m ⁻³)	Assessment ^c	Reference
Natural							
<i>Vegetation</i>							
<i>Forest, Oregon</i>	summer	I,c	522		410 – 665 ^d	*	Shaffer and Lighthart (1997)
<i>Forest, Germany</i>	autumn, winter, spring	I,c	50			+	Rüden et al. (1978) ^e
<i>Highdesertchaparral, Oregon</i>	summer	I,c			2 – 283	+	Lighthart and Shaffer (1994)
<i>Tropicalgrassland, Australia</i>	autumn	I,c	83		13 – 263	+	Tilley et al. (2001)
<i>Tropicalgrassland, Australia</i>	spring	I,c	146		44 – 457	+	Tilley et al. (2001)
<i>Mountains(out – of – cloud)</i>	spring	F,c	8			+	Bauer et al. (2002)
<i>Mountains(out – of – cloud)</i>	spring	I,m	12000 [total]			*	Bauer et al. (2002)
<i>Mountains(interstitial)</i>	spring	I,m	11000 [total]			*	Bauer et al. (2002)
<i>Marine – influenced</i>							
<i>PorquerollesIsland, France</i>	full year	I,c	42	70		+	di Giorgio et al. (1996)
<i>Coastal, Oregon</i>	autumn	I,c	103		116 – 91 ^d	*	Shaffer and Lighthart (1997)
<i>Coastal, Sweden</i>	winter	I,c	99	10	2 – 3400	+	Bovallius et al. (1978b)
<i>Coastal, Argentina</i>	winter	I,c	1611 ^f	1.3 ^f		+	Negrin et al. (2007)
<i>Coastal, Argentina</i>	spring	I,c	957 ^f	1.1 ^f		+	Negrin et al. (2007)

^aMethods: I: impactation, F: filtration, c: culture, m: microscopy

^bValues: Standard error, minimum and maximum values are given for concentration where available. Measurements of culturable bacteria are expressed as the concentration of colony forming units (CFU). Where total (as opposed to culturable) bacteria were measured, the entry is in bold font and labelled “[total]”.

^cAssessment key: *: Exemplary experimental method and description, +: Acceptable experimental method and description, -: Experiment is inadequately described or method contains serious flaws (however, values are included in table for completeness). To be rated “acceptable”, the measurement study must include: 1) Site description, 2) meteorological description of the study period, and 3) use of the aerosol sampling instrumentation. If culture methods were used, detailed information is needed, including at least: 1) Composition of nutrient agar, 2) incubation temperature, and 3) incubation time. Studies rated “exemplary” were distinguished by especially thoughtful experimental design and careful documentation. Features of “exemplary” articles included: 1) Counting of total (as opposed to culturable) population, 2) vertical profiles, 3) systematic sampling at various times of day and seasons, 4) estimates of the surface flux based on accepted micrometeorological methods, 5) statistically robust indicators of the middle and the spread in concentration distribution, 6) isokinetic aerosol sampling, 7) multi-variable statistical analysis of correlations with meteorological variables and with total particulate matter, 8) mention of the anti-contamination measures taken (e.g. sterilization, use of sterile blanks), 9) correlations with air pollution, meteorological variables, or other particle concentrations, 10) identification of species / genus via genetic analysis, 11) Gram staining and other standard microbiological analysis techniques, and 12) if culture methods were used, use of multiple culture media, incubation times or incubation temperatures, with an intercomparison of methods.

^d95% confidence bounds.

^eDoes not describe culture medium.

^fGeometric mean and geometric standard deviation are reported.

Source	Season	Method ^a	Concentration ^b (m ⁻³)	Standard error ^b (m ⁻³)	Min – Max ^b (m ⁻³)	Assessment ^c	Reference
<i>Coastal, Argentina Seasideuniversity campus</i>	autumn	I,c	672 ^f	2.2 ^f		+	Negrin et al. (2007)
	spring	I,c	58		27 – 102	+	Tilley et al. (2001)
	winter	F,m	2894 [total]	1672		*	Harrison et al. (2005)
	spring	F,m	5318 [total]	2517		*	Harrison et al. (2005)
	summer	F,m	8338 [total]	3342		*	Harrison et al. (2005)
<i>Remotecoastal</i>	autumn	F,m	13921 [total]	15509		*	Harrison et al. (2005)
Anthropogenic							
<i>Agriculture</i>							
<i>Snapbeans</i>	summer	I,c	2240	725		+	Lindemann et al. (1982)
<i>Alfalfa</i>	autumn	I,c	2690	167		+	Lindemann et al. (1982)
<i>Wheat</i>	summer	I,c	506	243		+	Lindemann et al. (1982)
<i>Corn</i>	summer	I,c	141	85		+	Lindemann et al. (1982)
<i>Matureyegrassfield</i>	summer	I,c	109		127 – 92 ^d	*	Shaffer and Lighthart (1997)
<i>Swathedyegrassfield</i>	summer	I,c	279		353 – 219 ^d	*	Shaffer and Lighthart (1997)
<i>Harvestedyegrassfield</i>	autumn	I,c	143		171 – 120 ^d	*	Shaffer and Lighthart (1997)
<i>Ryegrassfield, Oregon</i>	summer	F,m	84798 [total]^g	165184	2654 – 109287	*	Tong and Lighthart (1999)
<i>Drycroplandsoil</i>	summer- autumn	I,c,g	738	198		+	Lindemann and Upper (1985)
<i>Wetcroplandsoil</i>	summer- autumn	I,c,g	1546	439		+	Lindemann and Upper (1985)
Barocroplandsoil							
<i>Dairyfarm</i>	autumn	F,m	58912 [total]	90429	1811 – 295576	*	Tong and Lighthart (1999)
<i>Ruraldownwind, England</i>	winter	I,c	16	3	11 – 22	+	Mouli et al. (2005)
<i>Ruraldownwind, England</i>	winter	F,m	4244 [total]	3416		*	Harrison et al. (2005)
<i>Ruraldownwind, England</i>	spring	F,m	10802 [total]	5434		*	Harrison et al. (2005)
<i>Ruraldownwind, England</i>	summer	F,m	14800 [total]	7522		*	Harrison et al. (2005)
<i>Ruraldownwind, England</i>	autumn	F,m	5989 [total]	2539		*	Harrison et al. (2005)
<i>Ruralupwind, England</i>	winter	F,m	10127 [total]	5285		*	Harrison et al. (2005)
<i>Ruralupwind, England</i>	spring	F,m	16341 [total]	10177		*	Harrison et al. (2005)
<i>Ruralupwind, England</i>	summer	F,m	14134 [total]	11457		*	Harrison et al. (2005)
<i>Ruralupwind, England</i>	autumn	F,m	8196 [total]	6362		*	Harrison et al. (2005)
<i>Rural</i>	winter	I,c	2781 ^f	1.8 ^f		+	Negrin et al. (2007)
<i>Rural</i>	spring	I,c	2987 ^f	1.7 ^f		+	Negrin et al. (2007)
<i>Rural</i>	autumn	I,c	1031 ^f	1.4 ^f		+	Negrin et al. (2007)
<i>Rural</i>	winter	I,c	2463 ^f	1.5 ^f		+	Negrin et al. (2007)
<i>Urbanandsuburban</i>							

^gMean concentration over mature grass (one sampling day), swathed grass (two days) and dry grass (four days).

Source	Season	Method ^a	Concentration ^b (m ⁻³)	Standard error ^b (m ⁻³)	Min – Max ^b (m ⁻³)	Assessment ^c	Reference
<i>Moscow</i>	full year	I,c	812		50 – 5730	+	Vlodavets and Mats (1958)
<i>Montreal, rooftop(120 m)</i>	full year	I,c	791	589	10 – 1940	+	Kelly and Pady (1954) ^h
<i>Citypark, Paris</i>	multi-year	I,c	290			-	Miquel (1883) in Gregory (1971) ⁱ
<i>Citypark, Sweden</i>	multi-year	I,c	763	160	100 – 2500	+	Bovallius et al. (1978b)
<i>Busystreet</i>	multi-year	I,c	7500			-	Miquel (1883) in Gregory (1971) ⁱ
<i>Citystreet</i>	multi-year	I,c	850	170	100 – 4000	+	Bovallius et al. (1978b)
<i>Universitycampus</i>	winter	I,c	3	1	1 – 5	+	Mouli et al. (2005)
<i>Suburban, Argentina</i>	winter	I,c	1925	1.2		+	Negrin et al. (2007)
<i>Suburban, Argentina</i>	spring	I,c	1643	1.1		+	Negrin et al. (2007)
<i>Suburban, Argentina</i>	autumn	I,c	581	1.9		+	Negrin et al. (2007)
<i>Urban(kerbside)</i>	winter	I,c	10	2	7 – 14	+	Mouli et al. (2005)
<i>Hospitalcampus</i>	winter	I,c	4	2	2 – 7	+	Mouli et al. (2005)
<i>Centralbusstation</i>	winter	I,c	15	1	13 – 17	+	Mouli et al. (2005)
<i>Industrialzone</i>	winter	I,c	19	5	13 – 29	+	Mouli et al. (2005)
<i>SaudiArabia</i>	full year	I,c			≈ 100–2000	-	Mahdy and El-Sehrawi (1997) ^j
<i>Beijing</i>							
<i>Researchcampus</i>	full year	I,c	2799	292	130 – 21928	+	Fang et al. (2007)
<i>Busyintersection</i>	full year	I,c	2401	187	106 – 22100	+	Fang et al. (2007)
<i>Botanicalgarden</i>	full year	I,c	1484	88	71 – 6463	+	Fang et al. (2007)
<i>Marsetilles</i>	full year	I,c	791	598		+	di Giorgio et al. (1996)
<i>Nanjing, 30m</i>	unknown	I,c	640	300	150 – 1066	-	Chen et al. (2001) ^k
<i>Nanjing, 50m</i>	unknown	I,c	490	150	270 – 720	-	Chen et al. (2001) ^k
<i>BuenosAires</i>	winter	I,c	644 ^f	1.4 ^f		+	Negrin et al. (2007)
<i>BuenosAires</i>	spring	I,c	1873 ^f	1.4 ^f		+	Negrin et al. (2007)
<i>BuenosAires</i>	autumn	I,c	1207 ^f	1.9 ^f		+	Negrin et al. (2007)
<i>BuenosAires</i>	winter	I,c	2131 ^f	1.6 ^f		+	Negrin et al. (2007)
<i>Urban(kerbside), Oregon</i>	autumn	I,c	609		688 – 539	*	Shaffer and Lighthart (1997)
<i>MexicoCity</i>	full year	I,c	151 (median)		26 – 2999	+	Rosas et al. (1994)
<i>UpperSilesia, Poland</i>	summer	I,c	664 (median)		77 – 4344	+	Pastuszka et al. (2000)
<i>UpperSilesia, Poland</i>	winter	I,c	78 (median)		13 – 406	+	Pastuszka et al. (2000)
<i>Birmingham, England</i>	winter	F,m	3286 [total]	2254		*	Harrison et al. (2005)
<i>Birmingham, England</i>	spring	F,m	17504 [total]	13769		*	Harrison et al. (2005)
<i>Birmingham, England</i>	summer	F,m	14584 [total]	5531		*	Harrison et al. (2005)
<i>Birmingham, England</i>	autumn	F,m	12481 [total]	6980		*	Harrison et al. (2005)

^aMean and variation from Lighthart (1997)

^bNo aerosol sampling system used.

^cLacks description of measurement sites, composition of nutrient agar, incubation temperature and incubation time.

^dLacks description of nutrient agar, measurement dates. Values estimated from digitized plot.

Source	Season	Method ^a	Concentration ^b (m ⁻³)	Standard error ^b (m ⁻³)	Min – Max ^b (m ⁻³)	Assessment ^c	Reference
<i>TaichungCity</i>							
Point sources							
<i>Agriculturalactivities</i>							
<i>Baling</i>	summer	I,c			$3.3 \times 10^6 - 1.9 \times 10^6$	-	Lighthart (1984)
<i>Combining</i>	summer	I,c			$1.5 \times 10^8 - 1.0 \times 10^9$	-	Lighthart (1984)
<i>Sewageplants</i>	unknown	I,c	850, 3700, 8500			-	Yousefi and Rama (1992) ^f
<i>Hospital</i>	unknown	I,c	950			-	Yousefi and Rama (1992) ^f
<i>Oilrefinery</i>	winter	I,c	1474 ^f	1.3 ^f		+	Negrin et al. (2007)
<i>Oilrefinery</i>	spring	I,c	1998 ^f	1.1 ^f		+	Negrin et al. (2007)
<i>Oilrefinery</i>	autumn	I,c	1260 ^f	1.5 ^f		+	Negrin et al. (2007)
<i>Oilrefinery</i>	winter	I,c	752 ^f	1.7 ^f		+	Negrin et al. (2007)
Dust events							
<i>Israel, sur faceduststorm</i>	January	I,c	995			+	Schlesinger et al. (2006)
<i>Israel, clear day</i>	January	I,c	108			+	Schlesinger et al. (2006)
<i>Israel, duststorm</i>	April	I,c	694			+	Schlesinger et al. (2006)
<i>Israel, clear day</i>	April	I,c	79			+	Schlesinger et al. (2006)
<i>Carribbean, dustevent</i>		I,c			0 – 20	*	Prospero et al. (2005)
<i>Carribbean, back ground</i>	full year	I,c	0			*	Prospero et al. (2005)
<i>Mali, dustevent</i>		F,c			720 – 15700	+	Kellogg et al. (2004)
<i>Mali, back ground</i>		F,c			200 – 1100	+	Kellogg et al. (2004)
<i>Carribbean, dustevent</i>		F,c			90 – 350	+	Griffin et al. (2001)
<i>Carribbean, back ground</i>		F,c	100			+	Griffin et al. (2001)
<i>Carribbean, dustevent</i>		F,c			0 – 185	+	Griffin et al. (2003)
<i>Carribbean, back ground</i>		F,c			0 – 66	+	Griffin et al. (2003)
<i>Korea, dustevent</i>		I,c			225 – 3425		Choi et al. (1997)
<i>Korea, back ground</i>	winter	I,c	245		105 – 621		Choi et al. (1997)
<i>Sweden, dustevent</i>	full year	I,c	144			+	Bovallius et al. (1978a)
<i>Sweden, back ground</i>		I,c				+	Bovallius et al. (1978a)
At altitude							
<i>San Antonio, Texas</i>							
<i>690m, landairmass</i>	summer	F,c	≈ 725			+	Fulton and Mitchell (1966)
	winter						
<i>690m, seaairmass</i>	summer	F,c	≈ 225			+	Fulton and Mitchell (1966)
	winter						
<i>690m</i>	autumn	F,c			0 – 800	+	Fulton (1966a)
<i>1600m</i>	autumn	F,c			0 – 300	+	Fulton (1966a)

^fLacks measurement dates and description of culture medium.

Source	Season	Method ^a	Concentration ^b (m ⁻³)	Standard error ^b (m ⁻³)	Min – Max ^b (m ⁻³)	Assessment ^c	Reference
3127m <i>Ruralarea, Texas</i>	autumn	F,c			0 – 200	+	Fulton (1966a)
365m	winter	F,c	151			+	Fulton (1966b)
1280m	winter	F,c	61			+	Fulton (1966b)
2500m	winter	F,c	38			+	Fulton (1966b)

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