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

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November 3, 2009

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 *Bacteria* and *Archaea*, 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 dessication. 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 inconsistant. 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 (m^{-2} s^{-1}

Source	Season	Flux (m^{-2} s^{-1})	Assessment[a]	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 Upper (1985)
Wet cropland soil	summer-autumn	155 ± 57	+	Lindemann and Upper (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	3.3×10^{6} – 1.9×10^{7}	-	Lighthart (1984)
Harvesting	summer	1.5×10^{8} – 10^{9}	-	Lighthart (1984)

[a]See key in Table §3.
[b]Noon maximum emission flux
[c]Lacks 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})	Assess-ment [c]	Reference
Natural							
Vegetation							
Forest, Oregon	summer	I,c	522		410 – 665 [d]	*	Shaffer and Lighthart (1997)
Forest, Germany	autumn, winter, spring	I,c	50			+	Rüden et al. (1978) [e]
Highdesertchaparral, Oregon	summer	I,c			2 – 283	+	Lighthart and Shaffer (1994)
Tropicalgrassland, Australia	autumn	I,c	83		13 – 263	+	Tilley et al. (2001)
Tropicalgrassland, Australia	spring	I,c	146		44 – 457	+	Tilley et al. (2001)
Mountains(out − of − cloud)	spring	F,c	8			+	Bauer et al. (2002)
Mountains(out − of − cloud)	spring	I,m	**12000 [total]**			*	Bauer et al. (2002)
Mountains(interstital)	spring	I,m	**11000 [total]**			*	Bauer et al. (2002)
Marine − influenced							
PorquerollesIsland, France	full year	I,c	42	70		+	di Giorgio et al. (1996)
Coastal, Oregon	autumn	I,c	103		116 – 91 [d]	*	Shaffer and Lighthart (1997)
Coastal, Sweden	winter	I,c	99	10	2 – 3400	+	Bovallius et al. (1978b)
Coastal, Argentina	winter	I,c	1611 [f]	1.3 [f]		+	Negrin et al. (2007)
Coastal, Argentina	spring	I,c	957 [f]	1.1 [f]		+	Negrin et al. (2007)

[a] **Methods**: I: impaction, F: filtration, c: culture, m: microscopy

[b] **Values**: 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]".

[c] **Assessment 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 tempeerature, 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.

[d] 95% confidence bounds.

[e] Does not describe culture medium.

[f] Geometric 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})	Assess-ment [c]	Reference
Coastal, Argentina	autumn	I,c	672[f]	2.2[f]		+	Negrin et al. (2007)
Seaside university campus	spring	I,c	58		27 – 102	+	Tilley et al. (2001)
Remote coastal	winter	F,m	**2894 [total]**	**1672**		*	Harrison et al. (2005)
Remote coastal	spring	F,m	**5318 [total]**	**2517**		*	Harrison et al. (2005)
Remote coastal	summer	F,m	**8338 [total]**	**3342**		*	Harrison et al. (2005)
Remote coastal	autumn	F,m	**13921 [total]**	**15509**		*	Harrison et al. (2005)
Anthropogenic							
Agriculture							
Snap beans	summer	I,c	2240	725		+	Lindemann et al. (1982)
Alfalfa	autumn	I,c	2690	167		+	Lindemann et al. (1982)
Wheat	summer	I,c	506	243		+	Lindemann et al. (1982)
Corn	summer	I,c	141	85		+	Lindemann et al. (1982)
Mature ryegrass field	summer	I,c	109		127 – 92[d]	*	Shaffer and Lighthart (1997)
Swathed ryegrass field	summer	I,c	279		353 – 219[d]	*	Shaffer and Lighthart (1997)
Harvested ryegrass field	autumn	I,c	143		171 – 120[d]	*	Shaffer and Lighthart (1997)
Ryegrass field, Oregon	summer	F,m	**84798 [total]**[g]	**165184**	**2654 – 109287**	*	Tong and Lighthart (1999)
Dry cropland soil	summer-autumn	I,c,g	738	198		+	Lindemann and Upper (1985)
Wet cropland soil	summer-autumn	I,c,g	1546	439		+	Lindemann and Upper (1985)
Bare cropland soil	autumn	F,m	**58912 [total]**	**90429**	**1811 – 295576**	*	Tong and Lighthart (1999)
Dairy farm	winter	I,c	16	3	11 – 22	+	Mouli et al. (2005)
Rural downwind, England	winter	F,m	**4244 [total]**	**3416**		*	Harrison et al. (2005)
Rural downwind, England	spring	F,m	**10802 [total]**	**5434**		*	Harrison et al. (2005)
Rural downwind, England	summer	F,m	**14800 [total]**	**7522**		*	Harrison et al. (2005)
Rural downwind, England	autumn	F,m	**5989 [total]**	**2539**		*	Harrison et al. (2005)
Rural upwind, England	winter	F,m	**10127 [total]**	**5285**		*	Harrison et al. (2005)
Rural upwind, England	spring	F,m	**16341 [total]**	**10177**		*	Harrison et al. (2005)
Rural upwind, England	summer	F,m	**14134 [total]**	**11457**		*	Harrison et al. (2005)
Rural upwind, England	autumn	F,m	**8196 [total]**	**6362**		*	Harrison et al. (2005)
Rural	winter	I,c	2781[f]	1.8[f]		+	Negrin et al. (2007)
Rural	spring	I,c	2987[f]	1.7[f]		+	Negrin et al. (2007)
Rural	autumn	I,c	1031[f]	1.4[f]		+	Negrin et al. (2007)
Rural	winter	I,c	2463[f]	1.5[f]		+	Negrin et al. (2007)
Urban and suburban							

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

[h] Mean and variation from Lighthart (1997)
[i] No aerosol sampling system used.
[j] Lacks description of measurement sites, composition of nutrient agar, incubation temperature and incubation time.
[k] Lacks 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})	Assess-ment [c]	Reference
TaichungCity		I,c				+	Wang et al. (2007)
Point sources							
Agriculturalactivities							
Baling	summer	I,c			$3.3 \times 10^6 - 1.9 \times 10^6$	-	Lighthart (1984)
Combining	summer	I,c			$1.5 \times 10^8 - 1.0 \times 10^9$	-	Lighthart (1984)
Sewageplants	unknown	I,c	850, 3700, 8500			-	Yousefi and Rama (1992) [l]
Hospital	unknown	I,c	950			-	Yousefi and Rama (1992) [l]
Oilrefinery	winter	I,c	1474^f	1.3^f		+	Negrin et al. (2007)
Oilrefinery	spring	I,c	1998^f	1.1^f		+	Negrin et al. (2007)
Oilrefinery	autumn	I,c	1260^f	1.5^f		+	Negrin et al. (2007)
Oilrefinery	winter	I,c	752^f	1.7^f		+	Negrin et al. (2007)
Dust events							
Israel, surfaceduststorm	January	I,c	995			+	Schlesinger et al. (2006)
Israel, clearday	January	I,c	108			+	Schlesinger et al. (2006)
Israel, duststorm	April	I,c	694			+	Schlesinger et al. (2006)
Israel, clearday	April	I,c	79			+	Schlesinger et al. (2006)
Carribean, dustevent		I,c			0 – 20	*	Prospero et al. (2005)
Carribean, background	full year	I,c	0			*	Prospero et al. (2005)
Mali, dustevent		F,c			720 – 15700	+	Kellogg et al. (2004)
Mali, background		F,c			200 – 1100	+	Kellogg et al. (2004)
Caribbean, dustevent		F,c			90 – 350		Griffin et al. (2001)
Caribbean, background		F,c	100			+	Griffin et al. (2001)
Carribean, dustevent		F,c			0 – 185	+	Griffin et al. (2003)
Carribean, background		F,c			0 – 66	+	Griffin et al. (2003)
Korea, dustevent		I,c			225 – 3425		Choi et al. (1997)
Korea, background		I,c			105 – 621		Choi et al. (1997)
Sweden, dustevent	winter	I,c	245			+	Bovallius et al. (1978a)
Sweden, background	full year	I,c	144			+	Bovallius et al. (1978a)
At altitude							
SanAntonio, Texas							
690*m, landairmass*	summer – winter	F,c	≈ 725			+	Fulton and Mitchell (1966)
690*m, seaairmass*	summer – winter	F,c	≈ 225			+	Fulton and Mitchell (1966)
690*m*	autumn	F,c			0 – 800	+	Fulton (1966a)
1600*m*	autumn	F,c			0 – 300	+	Fulton (1966a)

[l] Lacks 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})	Assess-ment [c]	Reference
$3127m$	autumn	F,c			0 – 200	+	Fulton (1966a)
$Ruralarea, Texas$							
$365m$	winter	F,c	151			+	Fulton (1966b)
$1280m$	winter	F,c	61			+	Fulton (1966b)
$2500m$	winter	F,c	38			+	Fulton (1966b)

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