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Supplementary information for

Costs of dust collection by *Trichodesmium*: Effect on buoyancy and toxic metal release

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Introduction:

This supplementary material provides readers with details regarding sedimentation experiments, toxicity assays and SEM-EDX analysis for examining the removal of toxic particles. **Sedimentation experiments** - experimental procedures (Fig. S1 and S2), raw data files (Table S1 and S2), modeling of colony sinking velocity (Text S1 and S2, Table S3, S4 and S5) and dust loss analysis (Text S3 and Fig. S3). **Toxicity assays** - experimental procedures (Text S4 and Fig. S4), colony mortality (incubated with $CuSO_4$; Fig. S5) and calculation of metal release (Table S6 and Fig. S6). Effective dust concentrations calculated for *in situ* colonies (Fig. S7) and colonies from incubations (Fig. S8). **SEM-EDX analysis** - experimental procedures (Fig. S9) and elemental maps (Fig. S10, S11, S12 and S13).

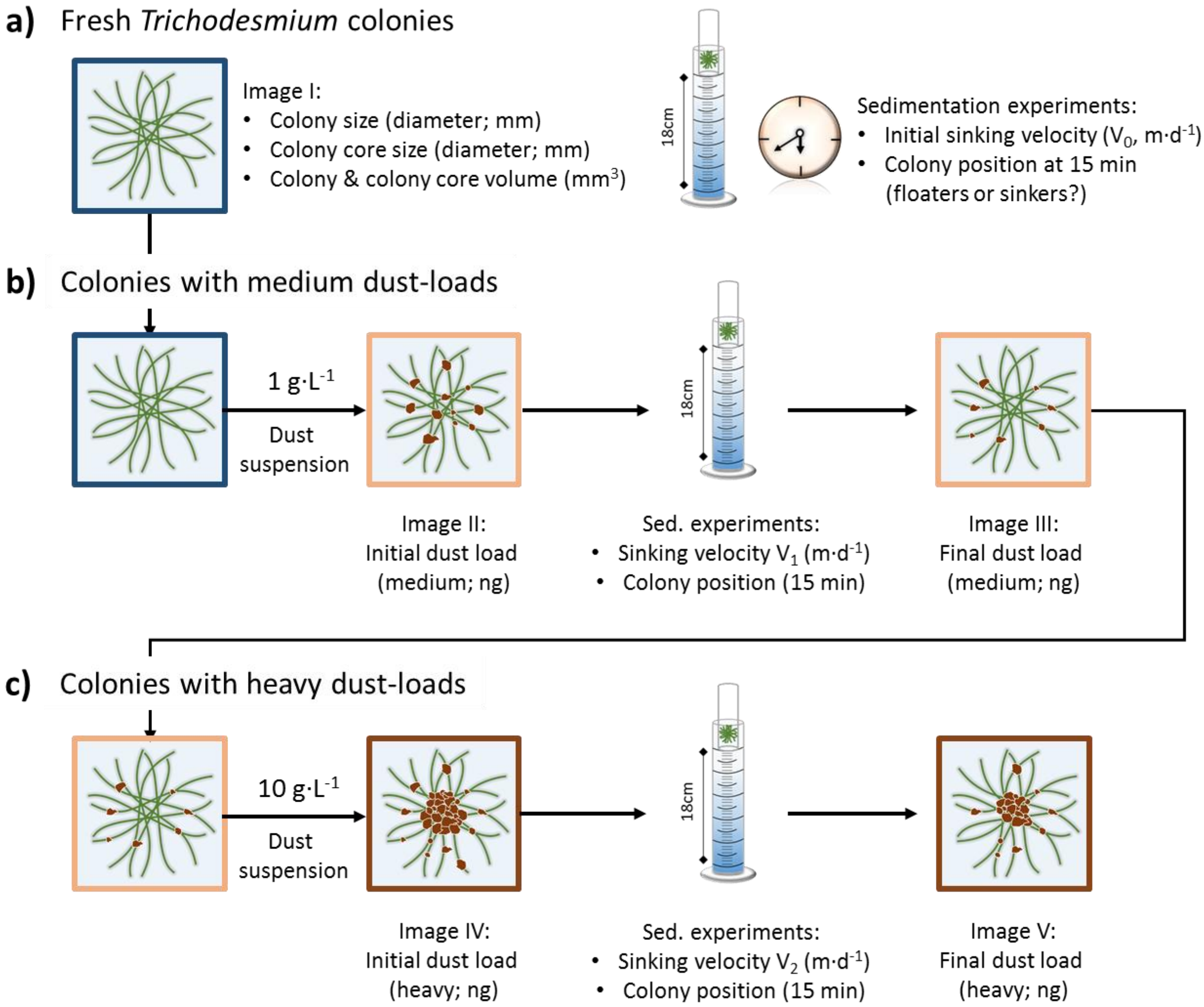


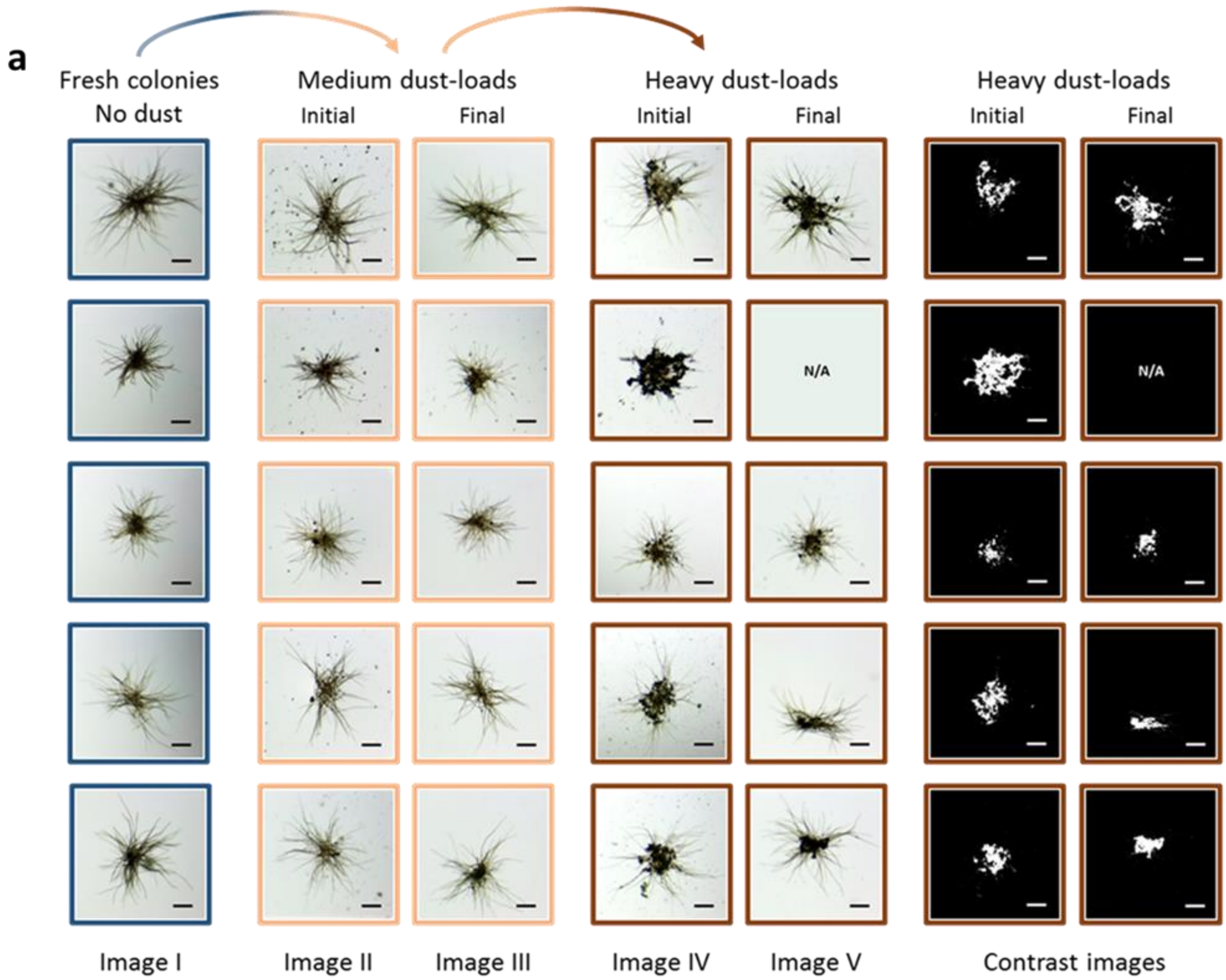
Figure S1. A schematic diagram of the experimental design for measuring the sinking velocity of a *Trichodesmium* colony at different dust loads.

The sinking velocity of *Trichodesmium* was measured on 5 individual days in the 2020 autumn season using 25 single colonies: without any dust particles (a) and with two manipulated dust-loads (medium and heavy, b and c).

(a) Freshly-collected colonies were first imaged under a stereoscope to determine their basic parameters (Image I). Each colony was then placed into a sedimentation chamber containing 100 mL fresh seawater using a 20 µL pipette equipped with cut tips to minimize the initial force added to the colony sinking velocity. Upon careful injection, a timer was started to measure the sinking time while the colony position (before reaching the bottom) was tracked and recorded by a researcher. The sinking velocity of a colony was calculated as the distance it travelled divided by time. Measurements of sinking velocity usually lasted less than 5 min, after which colonies were left in the same chamber and their positions at 15 min were observed. Some colonies remained at the bottom while others left the bottom and were relocated at different depth. We refer to these observations as indicators of the colony buoyancy and define those at the bottom as “sinkers” and the others as “floaters”.

(b) After measuring the initial sinking velocity (V_0), the colony was transferred with a long serological pipette into an eppendorf containing 1 $g \cdot L^{-1}$ dust suspension and mixed gently for loading dust particles (medium dust loads). Sinking velocity (V_1) measurements (and floatation status at 15 min) were performed using the same manner as described in (a). Stereoscopic images were taken prior to (Image II) and after experiments (Image III), for calculating initial and final dust loads via image analysis.

(c) Subsequently, the same colony was transferred into 10 $g \cdot L^{-1}$ dust suspension and mixed gently for measuring the sinking velocity (V_2) at heavy dust loads. Measurements of sinking velocity (V_2), determination of floatation status, as well as stereoscopic images (Image III and IV) were achieved in the same manner as described in (b).



b

Sample	Image I (no dust)				Image II & III (medium)		Image IV & V (heavy)	
	Diameter (mm)		Volume (mm^3)		Dust loads (ng)			
	Colony	Colony core	Colony	Colony core	Initial	Final	Initial	Final
Colony 1	1.2	0.2	0.852	0.007	111	74	1400	1973
Colony 2	0.8	0.2	0.247	0.006	410	120	3475	N/A
Colony 3	0.8	0.2	0.232	0.006	214	109	597	697
Colony 4	1.0	0.3	0.592	0.009	140	49	1538	723
Colony 5	1.0	0.2	0.502	0.006	96	33	1224	1036

Figure S2. An example of image analysis – estimation of dust loads on five Red Sea colonies from sedimentation experiments conducted on October 18th, 2020.

(a) The size of colony and colony core was obtained from Image I using DinoCapture 2.0 software. To determine medium dust-loads (Image II and III), individual dust-covered area was measured using polygon tools and was summed to obtain the total dust-covered area (μm^2). To determine heavy dust-loads (Image IV and V), since dust particles were clustered in the colony core, total dust-covered area was obtained through pixel counting using contrast mode in ImageJ software. Total dust volume (μm^3) was subsequently derived by multiplying dust-covered area (μm^2) with an assumed constant thickness of 10 µm for the dust layer. Similar analysis was also conducted on natural dust loads of Red Sea (Eilat, this study) and Atlantic colonies (as reported by Held et al., 2022). All scale bars shown in the graph are 200 µm.

(b) A summary table of basic colony parameters and calculated medium and heavy dust loads for the colonies shown in panel a. The volume of colony and colony core was determined using the equation for calculating the sphere volume ($V=4/3 \cdot \pi \cdot r^3$). Dust loads were derived by multiplying total dust volume (μm^3) with a dust density of 2.5 $g \cdot cm^{-3}$. N/A means not available due to the colony loss during transfer.

Table S1. Image analysis of *in situ* dust loads for Red Sea and Atlantic *Trichodesmium* colonies; related to Fig. 1 in the main text.

Colony #	Collection date	Colony radius (mm)	Colony volume (µL)	Number of particles	Particle diameter (µm)	Total dust Volume (µm³)	Calculated dust weight[a] (ng)
1	10-Oct-18	0.644	1.1	1	N/A	7.4E+03	18
2	11-Oct-18	1.282	8.8	1	68	3.6E+04	91
3	15-Oct-18	0.814	2.3	7	10-26	3.9E+04	97
4	18-Oct-18	0.731	1.6	2	8-18	3.0E+03	8
5	18-Oct-18	0.464	0.4	4	18-20	1.1E+04	29
6	18-Oct-18	0.501	0.5	4	16-30	1.7E+04	42
7	28-Oct-18	0.760	1.8	3	12	5.9E+04	148
8	29-Oct-18	0.587	0.8	2	18-22	6.3E+03	16
9	29-Oct-18	0.477	0.5	1	40	1.3E+04	31
10	31-Oct-18	0.927	3.3	5	30-38	6.7E+04	167
11	1-Nov-18	0.689	1.4	1	16	2.0E+03	5
12	1-Nov-18	0.606	0.9	2	30-48	2.5E+04	63
13	1-Nov-18	0.557	0.7	2	16	4.4E+04	111
14	1-Nov-18	0.479	0.5	1	N/A	3.3E+03	8
15	6-Nov-18	0.469	0.4	2	10-16	2.8E+03	7
16	6-Nov-18	0.442	0.4	1	30	7.1E+03	18
17	7-Nov-18	0.560	0.7	2	20	9.4E+03	23
18	15-Nov-18	0.602	0.9	1	16	2.0E+03	5
19	7-May-19	0.887	2.9	2	12-18	3.7E+03	9
20	15-May-19	0.937	3.4	1	48	1.8E+04	45
21	15-May-19	0.572	0.8	1	18	2.5E+03	6
22	22-May-19	0.454	0.4	1	12	1.1E+03	3
23	22-May-19	0.658	1.2	1	N/A	2.1E+04	53
24	22-May-19	0.479	0.5	2	12-26	6.4E+03	16
Min.		0.442	0.4	1	8	1.1E+03	3
Max.		1.282	8.8	7	68	6.7E+04	167
Median.		0.595	0.9	2	18	8.4E+03	21
Held et al. (2021)	Fig. 1c	0.776	2.0	-	-	5.4E+06	13461
Held et al. (2021)	Fig. 1d	0.763	1.9	-	-	6.0E+06	14999
Held et al. (2021)	Fig. 1e	0.792	2.1	-	-	4.0E+06	9954
Held et al. (2021)	Fig. 1f	0.776	2.0	-	-	1.8E+06	4486

a. Dust weight (ng) was derived by multiplying the volume of dust particles (µm³) with a dust density of 2.5 g·cm⁻³.
b. N/A means not available because the particle diameter was too small to be measured.

Table S2. Data pairs of colony dust load and sinking velocity during sedimentation experiments (n=75). The data for six representative colonies (colored red) analyzed on October 18th and October 20th 2020 was plotted in Fig. 2 in the main text.

Data pairs	Exp. date	Colony ID	Colony radius	Treatments	Dust weight (ng)		Sinking velocity	Floatation status at 15 min
			mm		Initial	Final	m·d^{-1}	
1	18-Oct-20	A	0.588	No dust	-	-	64	Floater
2				Medium	111	74	119	Sinker
3				Heavy	1400	1973	141	Sinker
4		B	0.389	No dust	-	-	64	Sinker
5				Medium	410	120	53	Floater
6				Heavy	3475	Colony lost	351	Sinker
7		C	0.381	No dust	-	-	38	Floater
8				Medium	214	109	47	Sinker
9				Heavy	597	697	75	Sinker
10		D	0.521	No dust	-	-	58	Floater
11				Medium	140	49	34	Sinker
12				Heavy	1538	723	38	Sinker
13		E	0.493	No dust	-	-	45	Floater
14				Medium	96	33	45	Sinker
15				Heavy	1224	1036	131	Sinker
16	20-Oct-20	F	0.502	No dust	-	-	22	Floater
17				Medium	649	512	198	Sinker
18				Heavy	4065	2752	479	Sinker
19		G	0.504	No dust	-	-	26	Floater
20				Medium	168	51	41	Floater
21				Heavy	4419	2221	211	Sinker
22		H	0.454	No dust	-	-	32	Floater
23				Medium	114	38	66	Sinker
24				Heavy	3045	133	83	Sinker
25		I	0.433	No dust	-	-	37	Floater
26				Medium	1405	648	114	Sinker
27				Heavy	2721	1345	161	Sinker
28		J	0.532	No dust	-	-	21	Floater
29				Medium	1053	559	142	Sinker
30				Heavy	1910	2747	277	Sinker
31	21-Oct-20	K	0.376	No dust	-	-	42	Floater
32				Medium	16	20	144	Floater
33				Heavy	2442	39	220	Sinker
34		L	0.410	No dust	-	-	33	Floater
35				Medium	69	2	234	Sinker
36				Heavy	2997	40	251	Sinker

37		M	0.499	No dust	-	-	50	Sinker
38				Medium	166	43	158	Sinker
39				Heavy	2621	56	180	Sinker
40		N	0.482	No dust	-	-	38	Floater
41				Medium	132	101	221	Floater
42				Heavy	4024	3128	351	Sinker
43		O	0.566	No dust	-	-	50	Floater
44				Medium	68	58	243	Sinker
45				Heavy	1872	1290	129	Sinker
46	22-Oct-20	P	0.399	No dust	-	-	37	Floater
47				Medium	53	7	216	Floater
48				Heavy	951	31	102	Sinker
49		Q	0.420	No dust	-	-	20	Floater
50				Medium	85	37	237	Floater
51				Heavy	2343	759	144	Sinker
52		R	0.393	No dust	-	-	36	Floater
53				Medium	38	74	65	Floater
54				Heavy	1021	1403	65	Sinker
55		S	0.373	No dust	-	-	25	Floater
56				Medium	50	5	198	Sinker
57				Heavy	497	61	65	Sinker
58		T	0.435	No dust	-	-	14	Floater
59				Medium	99	62	144	Sinker
60				Heavy	2561	1628	186	Sinker
61	26-Oct-20	U	0.543	No dust	-	-	53	Sinker
62				Medium	114	48	211	Sinker
63				Heavy	1089	84	16	Floater
64		V	0.445	No dust	-	-	37	Floater
65				Medium	82	18	138	Sinker
66				Heavy	2075	1155	23	Sinker
67		W	0.457	No dust	-	-	0	Floater
68				Medium	61	9	122	Floater
69				Heavy	334	174	52	Floater
70		X	0.399	No dust	-	-	36	Floater
71				Medium	55	5	113	Floater
72				Heavy	1508	765	59	Sinker
73		Y	0.689	No dust	-	-	11	Floater
74				Medium	153	210	156	Sinker
75				Heavy	409	675	23	Floater

Supplementary text S1. Modeling the sinking velocity of natural *Trichodesmium* colonies loaded with dust particles.

The sinking velocity of a *Trichodesmium* colony can be calculated according to Stoke's Law (Kromkamp & Walsby, 1990; White et al., 2006), using the following equation:

$$v = \frac{2gr^2(\rho_c - \rho_w)A}{9\phi\eta} \quad (eq.1)$$

Where: ***v*** **–** colony sinking velocity ($m\cdot s^{-1}$); ***g*** **–** gravitational acceleration ($m\cdot s^{-2}$); ***r*** **–** colony radius (m); ρ_C and ρ_W **–** colony and seawater density, respectively ($kg\cdot m^{-3}$); ***A*** **–** cell volume to colony volume ratio; ***Φ*** **–** coefficient of form resistance; ***η*** **–** molecular viscosity of the medium ($kg\cdot m^{-1}\cdot s^{-1}$). ***A*** is the ratio of cell volume to colony volume, since most of space within colony sphere is occupied by seawater. For instance, ***A*** was assigned a value of 0.05 in the study by White et al. (2006), indicating that the colony sphere consists of 5% cell volume and 95% seawater volume.

We considered the significant change of ρ_C and ***A*** for *Trichodesmium* colonies after interacting with dust particles. Assuming that dust volume did not exceed the colony volume, new ρ_C and ***A*** can be derived as follows:

$$\rho' = \rho_{colony+dust} = \frac{m_{cell} + m_{dust}}{V_{cell} + V_{dust}} \quad (eq.2)$$

$$A' = \frac{V_{cell} + V_{dust}}{V_{colony}} \quad (eq.3)$$

$$V_{colony} = \frac{4}{3}\pi r^3 \quad (eq.4)$$

Where in eq.2: ***ρ'*** **–** the new density of a colony with dust ($kg\cdot m^{-3}$); m_{cell} and m_{dust} **–** cell and dust mass, respectively (kg); V_{cell} and V_{dust} **–** cell and dust volume, respectively (m^3). Where in eq.3: ***A'*** **–** cell and dust volume to colony volume ratio; V_{cell}, V_{dust} and V_{colony} are cell, dust and colony volume, respectively (m^3). Where in eq.4: V_{colony} **–** colony volume (m^3); ***r*** **–** colony radius (m). Substituting equation 2, 3 and 4 into equation 1 and performing integration, the sinking velocity of a colony with dust particles (***v'***) is derived as follows:

$$v' = v_{colony+dust} = \frac{g}{6\pi r\phi\eta}[m_{dust} - \rho_w V_{dust} + m_{cell} - \rho_w V_{cell}] \quad (eq.5)$$

Since:

$$V_{dust} = \frac{m_{dust}}{\rho_{dust}} \quad (eq.6); \quad V_{cell} = \frac{m_{cell}}{\rho_{cell}} \quad (eq.7)$$

Where: ρ_{dust} and ρ_{cell} **–** *Trichodesmium* dust density and cell density, respectively ($kg\cdot m^{-3}$). Substituting equation 6 and 7 into equation 5 derives equation 8:

$$v' = m_{dust} \cdot \frac{g\left(1 - \frac{\rho_W}{\rho_{dust}}\right)}{6\pi r\phi\eta} + m_{cell} \cdot \frac{g\left(1 - \frac{\rho_W}{\rho_{cell}}\right)}{6\pi r\phi\eta} \quad (eq. 8)$$

Where: ***v′*** **–** the sinking velocity of colony with dust particles ($m \cdot s^{-1}$); $\boldsymbol{m_{dust}}$ and $\boldsymbol{m_{cell}}$ **–** dust and cell mass, respectively (kg); ***g*** **–** gravitational acceleration ($m \cdot s^{-2}$); $\boldsymbol{\rho_W}$, $\boldsymbol{\rho_{dust}}$ and $\boldsymbol{\rho_{cell}}$ **–** seawater, dust and cell density, respectively ($kg \cdot m^{-3}$); ***r*** **–** colony radius (m); ***Φ*** **–** coefficient of form resistance; ***η*** **–** molecular viscosity of the medium ($kg \cdot m^{-1} \cdot s^{-1}$).

$$K = \frac{g\left(1 - \frac{\rho_W}{\rho_{dust}}\right)}{6\pi r\phi\eta} \quad (eq. 9); \quad v_0 = m_{cell} \cdot \frac{g\left(1 - \frac{\rho_W}{\rho_{cell}}\right)}{6\pi r\phi\eta} \quad (eq. 10)$$

Equation 8 predicts a linear increase of velocity (***v′***) with increasing dust weight ($\boldsymbol{m_{dust}}$). The slope (dust factor-K) is influenced by colony size (***r***), seawater ($\boldsymbol{\rho_W}$) and dust density ($\boldsymbol{\rho_{dust}}$). The intercept (sinking velocity when the colony is particle-free; herein defined as "***v0***") is influenced by cell mass ($\boldsymbol{m_{cell}}$), colony size (***r***), seawater ($\boldsymbol{\rho_W}$) and cell density ($\boldsymbol{\rho_{cell}}$). When dust load is zero, the intercept (***v0***) can be converted to equation 1 using equation 3. Calculations and simulations of dust factor (K) and sinking velocity of particle-free colonies (***v0***) are described in supplementary text S2.

Supplementary text S2. Calculations and simulations of dust factor (K) and sinking velocity of particle-free colonies (*v0*).

Using python (Version 3.10.9) with a *linspace* function, we first simulated the range of dust factors (K) derived from equation 8, using parameter values obtained from this study and literatures (see Table S3). During the simulation, seawater and dust density and colony radius (***ρ**water*, ***ρ**dust* and ***r***) were set to be variants, while the remaining parameters were fixed to literature values. The simulated dust factor (K) ranged from 2.2-7.4 x 10^5 m·s^{-1}·kg^{-1} (0.02-0.06 m·d^{-1}·ng^{-1}). All python codes related to the calculation of dust factor (K) can be found in Github (*https://github.com/Zhanzhu1110/Trichobuoyancy.git*), as well as in Zenodo (*https://zenodo.org/records/10290901*; DOI:10.5281/zenodo.10290901)(Wang et al., 2023).

Table S3. The equation and parameter values for calculating dust factor (K)

Dust factor (K)	Para-meters	Definitions	Parameter range	Units	Source
$\frac{g\left(1-\frac{\rho_w}{\rho_{dust}}\right)}{6\pi r\phi\eta}$	K	Dust factor	2.2 x 10^5 to 7.4 x 10^5	m·s^{-1}·kg^{-1}	Simulation results
	ρ_w	Seawater density	Variable[a]	kg·m^{-3}	Benaltabet et al. (2022)
	ρ_{dust}	Dust density	Variable[b]	kg·m^{-3}	McConnell et al. (2008); Schladitz et al. (2009)
	r	Colony radius	Variable[c]	m	This study (Table S2)
	g	Gravitational acceleration	9.81	m·s^{-2}	Wikipedia[d]
	Φ	Form resistance	1	-	White et al. (2006)
	η	Dynamic viscosity	9.60 x 10^{-4}	kg·m^{-1}·s^{-1}	White et al. (2006)

a. The range of seawater densities (ρ_W) is from 1026.5 to 1029 kg·m^{-3} (Rea Sea surface to ca. 700m).
b. The range of dust densities (ρ_{dust}) is from 2100 to 2600 kg·m^{-3}.
c. The range of colony radius (r) is from 0.442 to 1.282 mm (measured on Red Sea colonies, see Table S2).
d. *https://en.wikipedia.org/wiki/Gravity_of_Earth*

Simulation of sinking velocity of particle-free colonies (***v0***) requires the key parameter of cell mass (***m**cell*) or more specifically, the cell volume (***V**cell*; see Table S4 for ***V**cell* estimation). Using equation 7 and 10, the equation for calculating ***v0*** is derived as follows:

$$v_0 = \frac{g \cdot V_{cell} \cdot (\rho_{cell} - \rho_W)}{6\pi r\phi\eta} \quad (eq. 11)$$

Where: ***v0*** **–**the sinking velocity of particle-free colonies (m·s^{-1}); ***V**cell* **–** cell volume (m^3); ***ρ**cell* and ***ρ**W* **–** cell and seawater density, respectively (kg·m^{-3}); ***r*** **–** colony radius (m); ***Φ*** **–** coefficient of form resistance; ***η*** **–** molecular viscosity of the medium (kg·m^{-1}·s^{-1}). During the simulation, four parameters (***V**cell*, ***ρ**cell*, ***ρ**water* and

r) were set to be variants, while the rest parameters were fixed to literature values (see Table S5). Using python, we obtained the sinking velocity of particle-free colonies ranged between 9.9 x 10^{-7}- 1.1 x 10^{-4} m·s^{-1} (0 to 9 m·d^{-1}). All python codes related to the calculation of ***v0*** can be found in Github (https://github.com/Zhanzhu1110/Trichobuoyancy.git) and Zenodo (https://zenodo.org/records/10290901; DOI:10.5281/zenodo.10290901)(Wang et al., 2023).

Table S4. Estimation of total cell volume (*V_{cell}*) in single Red Sea *Trichodesmium* colonies

Trichodesmium	Single cell volume	Cell number	Total cell volume[a]	Source
	μm³	#	μm³	
Tuft colonies	-	-	3.9 x 10^5	Benavides et al. (2022) - SI
Puff colonies (Eilat)	83-209[b]	4708-11088	3.9 -23 x 10^5	Basu and Shaked (2018) - Table SI-B

a. Total cell volume (μm³) was derived by multiplying the single cell volume (μm³) with cell number (#).

b. Single cell volume (μm³) was derived by considering the cell as a cylinder ($V=\pi r^2*d$). Cell radius (r) and cell length (d) used here ranged between 2.4-2.9 μm and 4.8-8.2 μm, respectively (Basu & Shaked, 2018). Calculated single cell volume is similar to the results of *Trichodesmium* IMS101 culture, as reported by Ho (2013).

Table S5. Equation and parameter values for calculating sinking velocity of particle-free colonies (*v0*)

v0	Para-meters	Definitions	Parameter range	Units	Source
$\frac{g \cdot V_{cell} \cdot (\rho_{cell} - \rho_w)}{6\pi r \phi \eta}$	*v0*	Sinking velocity (particle-free)	9.9 x 10^{-7} to 1.1 x 10^{-4}	m·s^{-1}	Simulation results
	V_{cell}	Cell volume	Variable[a]	m^3	Table S4
	ρ_{cell}	Cell density	Variable[b]	kg·m^{-3}	White et al. (2006)
	ρ_w	Seawater density	Variable[c]	kg·m^{-3}	Benaltabet et al. (2022)
	r	Colony radius	Variable[d]	m	This study (Table S2)
	g	Gravitational acceleration	9.81	m·s^{-2}	Wikipedia[e]
	Φ	Form resistance	1	-	White et al. (2006)
	η	Dynamic viscosity	9.60 x 10^{-4}	kg·m^{-1}·s^{-1}	White et al. (2006)

a. The range of cell volume is from 3.9 -23 x 10^5 μm³ (see Table S4)

b. The range of a sinking cell density (ρ_{cell}) is from 1035 to 1065 kg·m^{-3}, as reported by White et al. (2006).

c. The range of seawater density (ρ_w) is from 1026.5 to 1029 kg·m^{-3} (sea surface to ca. 700m).

d. The range of colony radius (r) is from 0.442 to 1.282 mm (measured on Red Sea colonies, see Table S2).

e. *https://en.wikipedia.org/wiki/Gravity_of_Earth*

Table S6. Calculation of dust loss on *Trichodesmium* colonies during sedimentation experiments.

Data pairs	Exp. date	Colony ID	Colony radius	Colony volume	Dust load ng			Dust loss
			mm	mm^3; µL	Treatments	Initial	Final	ng
1	18-Oct-20	A	0.588	0.852	Medium	111	74	37
2					Heavy	1400	1973	No loss
3		B	0.389	0.247	Medium	410	120	290
4					Heavy	3475	Colony lost	Colony lost
5		C	0.381	0.232	Medium	214	109	105
6					Heavy	597	697	No loss
7		D	0.521	0.592	Medium	140	49	90
8					Heavy	1538	723	815
9		E	0.493	0.502	Medium	96	33	63
10					Heavy	1224	1036	188
11	20-Oct-20	F	0.502	0.530	Medium	649	512	137
12					Heavy	4065	2752	1313
13		G	0.504	0.536	Medium	168	51	117
14					Heavy	4419	2221	2198
15		H	0.454	0.392	Medium	114	38	75
16					Heavy	3045	133	2912
17		I	0.433	0.340	Medium	1405	648	757
18					Heavy	2721	1345	1376
19		J	0.532	0.631	Medium	1053	559	494
20					Heavy	1910	2747	No loss
21	21-Oct-20	K	0.376	0.223	Medium	16	20	No loss
22					Heavy	2442	39	2403
23		L	0.410	0.289	Medium	69	2	67
24					Heavy	2997	40	2957
25		M	0.499	0.520	Medium	166	43	123
26					Heavy	2621	56	2564
27		N	0.482	0.469	Medium	132	101	31
28					Heavy	4024	3128	896
29		O	0.566	0.760	Medium	68	58	10
30					Heavy	1872	1290	582

31	22-Oct-20	P	0.399	0.266	Medium	53	7	46
32					Heavy	951	31	920
33		Q	0.420	0.310	Medium	85	37	48
34					Heavy	2343	759	1584
35		R	0.393	0.254	Medium	38	74	No loss
36					Heavy	1021	1403	No loss
37		S	0.373	0.217	Medium	50	5	45
38					Heavy	497	61	435
39		T	0.435	0.345	Medium	99	62	36
40					Heavy	2561	1628	932
41	26-Oct-20	U	0.543	0.671	Medium	114	48	65
42					Heavy	1089	84	1005
43		V	0.445	0.369	Medium	82	18	64
44					Heavy	2075	1155	920
45		W	0.457	0.400	Medium	61	9	52
46					Heavy	334	174	161
47		X	0.399	0.266	Medium	55	5	50
48					Heavy	1508	765	744
49		Y	0.689	1.370	Medium	153	210	No loss
50					Heavy	409	675	No loss

Treatments	Dust loss (ng)	
Medium	Min	10
	Max	757
Heavy	Min	161
	Max	2957

Supplementary text S3. Selection criterion for data pairs presented in Fig. 3, related to the main text - Section 3.1.3.

To illustrate the effect of dust loss on colony sinking velocity, we selected 20 out of 50 total data pairs obtained from sedimentation experiments and showed seven representative data pairs in Fig. 3 and the rest in Fig. S3 (n=13). The selected data pairs/colonies meet the following requirements: 1) calculation of dust loss was found to be positive values (42 out of 50 total data pairs) and 2) measured sinking velocities of these colonies against their initial dust loads plotted below the prediction line established in Fig. 2b ($y = 0.06\ m\cdot d^{-1}\cdot ng^{-1}$ x dust weight (ng) + $53\ m\cdot d^{-1}$; 20 out of 42 data pairs).

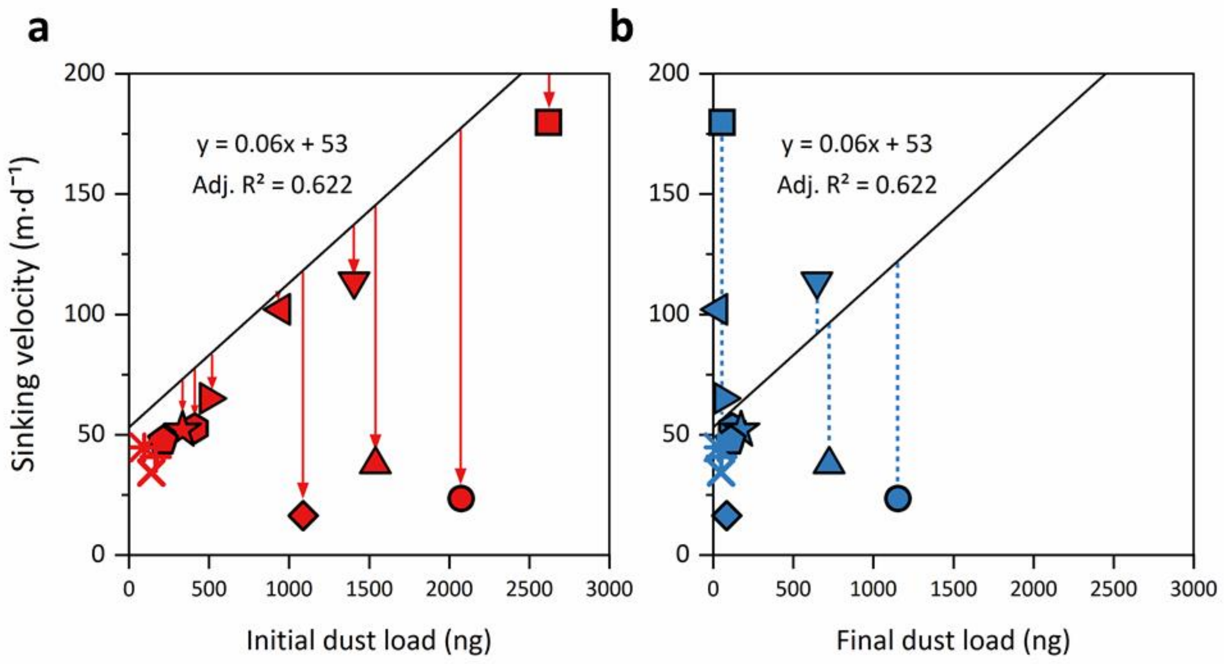


Figure S3. Effect of dust loss on colony sinking velocity. Measured sinking velocities of additional colonies (n=13, shown as different symbols) plotted against their initial (a) and final (b) dust loads, related to the main text – Fig.3. The equation (black line) is the linear relationship established in the main text - Fig. 2b. Arrows and dash lines indicate the mismatch of measured sinking velocities and expected velocities calculated from initial and final dust loads, respectively.

Supplementary text S4. Toxicity assays – incubation experiments on Red Sea *Trichodesmium* colonies with dust suspension, dust leachates and dissolved Cu ($CuSO_4$) and visual examinations of colony mortality during incubations.

To investigate the particle toxicity to *Trichodesmium*, we conducted incubations experiments on colonies with dust suspension and leachate for 24 hrs during the spring of 2022 (n=176; see main text – section 2.3). Simultaneously, similar incubation assays were conducted on Red Sea colonies with dissolved Cu ($CuSO_4$).

Primary $CuSO_4$ solutions were prepared daily in Milli-Q water (18.2 Ω) and diluted to final concentrations of 5, 10, 50, 200, 250, 500, 1000, and 3000 nM using filtered seawater (FSW). Two colonies per well were incubated in a 48-well plate containing 0.5 mL $CuSO_4$ solutions and were kept in a culture room (25 ^oC, ~80 µE $m^{-2} \cdot s^{-1}$, 10:14 h light-dark cycle) for up to 74 hrs. Visual examination of colony and filament shape, structure, and color was performed under a stereoscope (Fig. S4). Incubation of colonies without $CuSO_4$ addition served as control. Incubations with dissolved Cu were repeated thrice using freshly-collected Red Sea colonies (n=118).

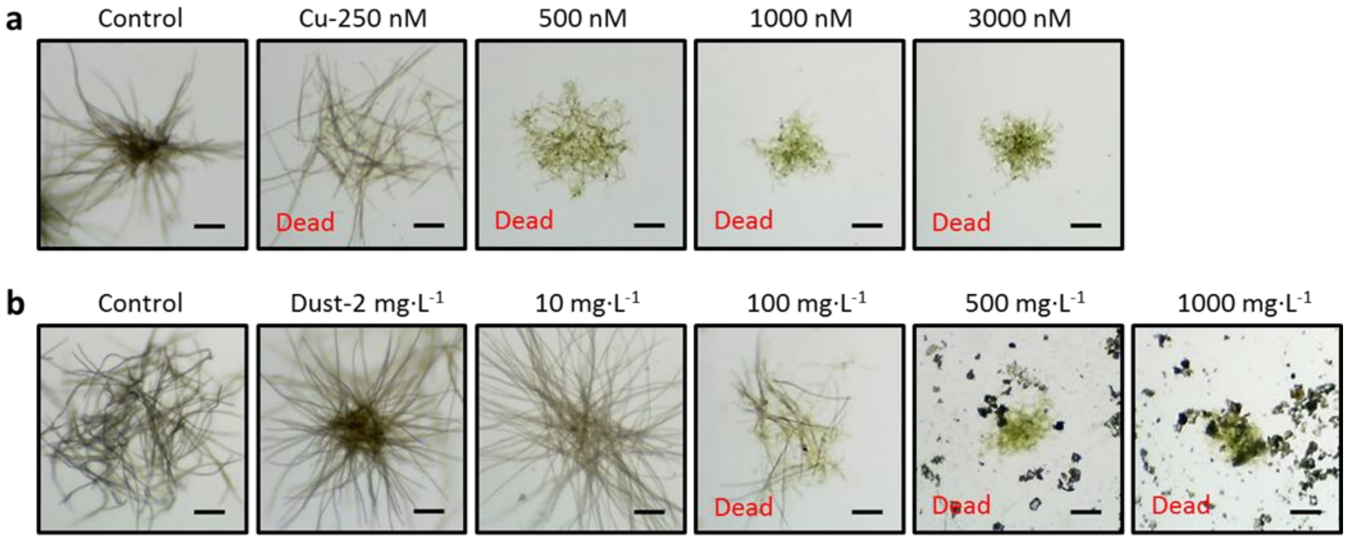


Figure S4. Stereoscopic observations of Red Sea *Trichodesmium* colonies when exposed to $CuSO_4$ (a) and dust suspensions (b) for 24 hrs. All scale bars are 200 µm. The mortality of *Trichodesmium* (%) was calculated by diving the number of dead colonies to the total number of colonies used in each treatment. Colonies identified as "dead" colonies were marked accordingly in the images.

Addition of 3000 nM $CuSO_4$ induced an acute toxicity to *Trichodesmium*, with 100% of colonies dead in 2hrs. Moreover, no colonies survived when incubating with >200 nM $CuSO_4$ for 24 hrs. Incubating with 5-50 nM Cu for 24 hrs yields 30-50% mortality of colonies (Fig. S5).

Applying Chlorophyll *a* (Chl *a*) content measured on Red Sea colonies (~5 ng Chl *a* $colony^{-1}$; unpublished data), we determined the lethal dose 100 (LD100) of Cu as 0.6 µg total Cu · (µg Chl *a*)$^{-1}$ (when total [Cu] = 200 nM). It is important to note that we reported the toxicity threshold of Cu with a unit of total Cu per biomass in this study, yet the toxicity does not depend on the total Cu added but rather on free (non-complexed) Cu concentrations (Paytan et al., 2009; Sunda & Huntsman, 1998). The toxicity threshold of Cu for

Trichodesmium was comparable to the Cu threshold for *Synechococcus* WH8102 (0.2 - 2 µg Cu · (µg Chl *a*)$^{-1}$), as reported by Paytan et al. (2009).

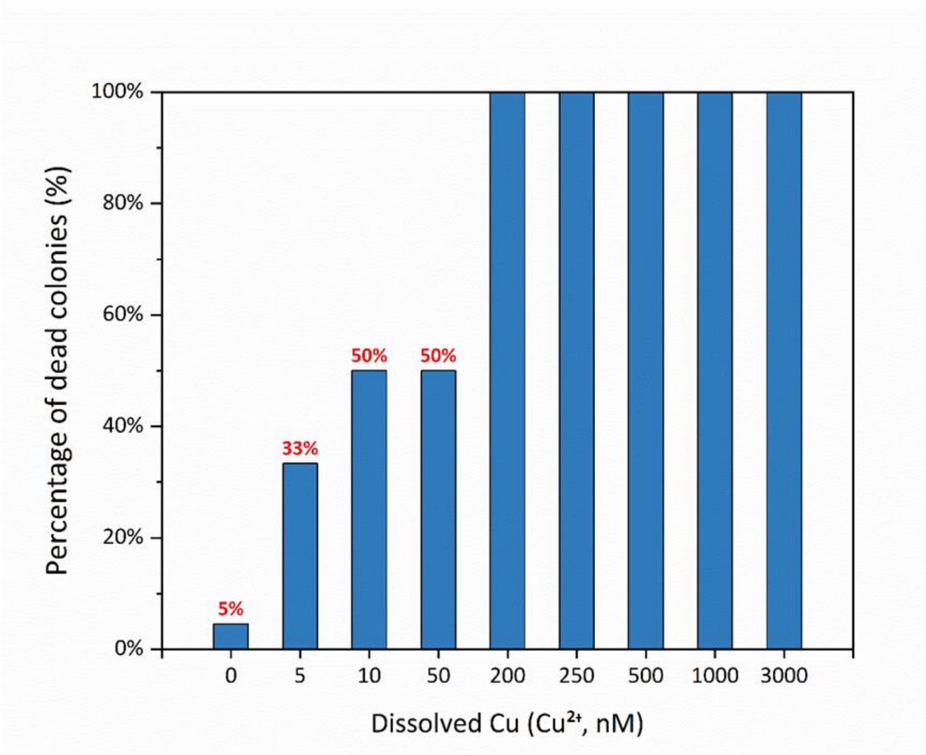
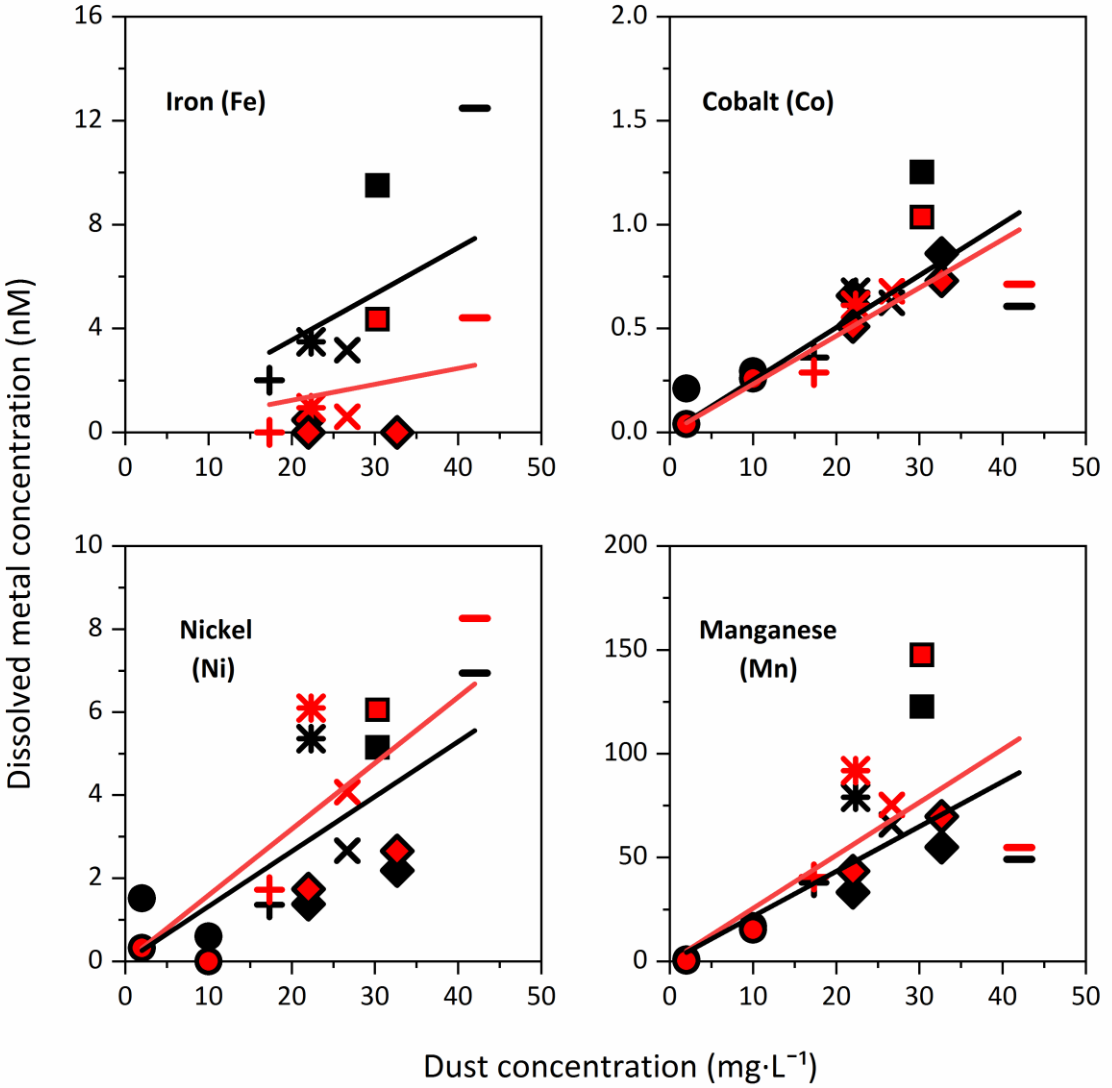


Figure S5. Percentage (%) death of Red Sea colonies after a 24-hour incubation with varying concentrations of dissolved Cu ($CuSO_4$) in seawater. The mortality was determined by dividing the number of dead colonies by the total colonies in each treatment prior to the incubation.

Table S7. Compilation data of seawater soluble aerosol metal in nM (aerosol concentrations = 2-42 mg·L^{-1}; data were obtained from this study and from Mackey et al., 2015 – Supplemental Table 2). Values were corrected using the average values of two operational blanks (seawater). Dissolution data were separated into rapid (<6 hrs) and gradual (1-7 days) dissolution and their median values were calculated. Boxes colored in green and red indicate dissolution of the same dust particles, respectively.

Data source		This study		Mackey et al. (2015)						
[Dust] mg·L^{-1}		2	10	17	22	22	27	30	33	42
Metal	Dissolution time	[Metal] nM								
Ni	10min			0.1	4.3	0.7	2.5	4.2	1.1	5.5
	6h			2.6	6.4	2.1	2.9	6.1	3.3	8.4
	Rapid (Median)	1.5	0.6	1.4	5.4	1.4	2.7	5.1	2.2	6.9
	1d			1.3	5.3	1.1	3.4	5.1	2.2	7.6
	3d			1.7	6.1	1.7	4.1	6.0	2.7	8.3
	7d			2.5	7.4	2.3	4.7	6.6	3.8	9.1
	Gradual (Median)	0.3	0.0	1.7	6.1	1.7	4.1	6.0	2.7	8.3
Zn	10min			42	82	27	59	201	54	99
	6h			55	96	38	65	226	55	107
	Rapid	0	33	49	89	32	62	214	54	103
	1d			52	97	35	69	226	54	105
	3d			50	97	36	71	221	54	106
	7d			52	109	35	68	202	61	111
	Gradual	0	40	52	97	35	69	221	54	106
Pb	10min			3.4	2.9	6.8	3.4	5.2	9.4	6.2
	6h			3.7	2.8	7.9	3.2	3.8	9.3	7.3
	Rapid	1.5		3.6	2.9	7.3	3.3	4.5	9.3	6.7
	1d			3.1	2.4	7.3	2.7	2.9	7.9	6.2
	3d			3.1	2.2	7.0	2.7	2.5	7.3	6.0
	7d			2.9	2.0	6.8	2.4	2.2	7.1	5.9
	Gradual	2.2		3.1	2.2	7.0	2.7	2.5	7.3	6.0
Co	10min			0.4	0.7	0.4	0.7	0.8	0.5	0.6
	6h			0.3	0.7	0.9	0.5	1.7	1.2	0.6
	Rapid	0.2	0.3	0.4	0.7	0.7	0.6	1.3	0.9	0.6
	1d			0.0	0.3	0.0	0.2	1.1	0.3	0.4
	3d			0.3	0.7	0.5	0.7	0.8	0.7	0.7
	7d			0.4	0.6	0.5	0.7	1.0	0.7	0.7
	Gradual	0.0	0.3	0.3	0.6	0.5	0.7	1.0	0.7	0.7
Cu	10min			3.1	8.4	0.8	5.8	4.8	1.3	5.8
	6h			5.6	11.8	1.5	7.9	8.1	2.1	8.7
	Rapid	0.4	1.8	4.3	10.1	1.2	6.8	6.4	1.7	7.3
	1d			6.3	13.1	1.8	8.9	9.2	2.7	9.5
	3d			5.7	12.1	1.6	9.0	9.0	2.7	8.8
	7d			5.6	11.9	1.3	9.3	8.2	2.3	8.8
	Gradual	1.0	1.1	5.7	12.1	1.6	9.0	9.0	2.7	8.8

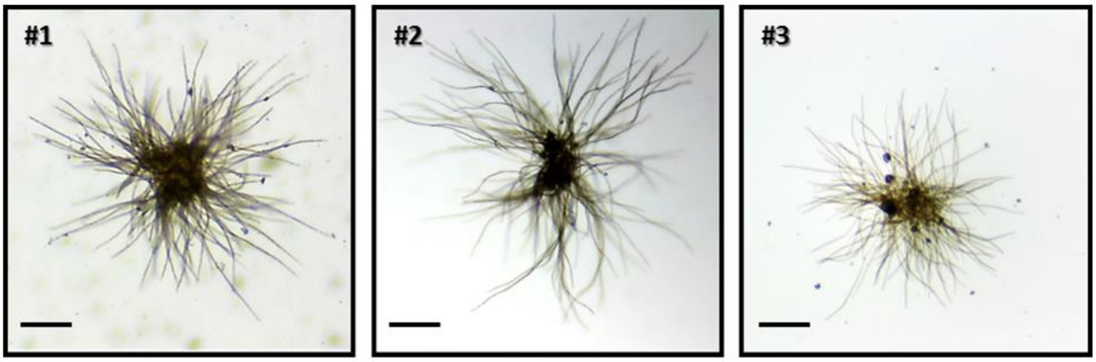
Cd	10min			0.4	0.5	0.1	0.5	0.5	0.1	0.3
	6h			0.4	0.4	0.0	0.4	0.5	0.1	0.3
	Rapid	0.0	0.1	0.4	0.4	0.1	0.5	0.5	0.1	0.3
	1d			0.4	0.4	0.0	0.4	0.5	0.0	0.3
	3d			0.4	0.4	0.0	0.4	0.5	0.1	0.3
	7d			0.4	0.5	0.0	0.4	0.5	0.1	0.3
	Gradual	0.1	0.3	0.4	0.4	0.0	0.4	0.5	0.1	0.3
Mn	10min			35	72	28	62	108	46	46
	6h			41	86	39	70	137	64	52
	Rapid	1	17	38	79	33	66	122	55	49
	1d			41	89	42	74	140	68	54
	3d			41	92	43	76	147	70	55
	7d			43	96	47	75	148	75	56
	Gradual	0	15	41	92	43	75	147	70	55
Al	10min			35	38	17	30	60	21	115
	6h			67	83	56	82	171	75	176
	Rapid			51	61	37	56	116	48	146
	1d			82	105	80	112	236	151	193
	3d			114	129	190	144	327	253	211
	7d			135	180	310	180	441	421	198
	Gradual			114	129	190	144	327	253	198
Fe	10min			3.2	4.7	1.0	5.3	10.6	0.0	8.2
	6h			0.8	2.3	0.0	1.1	8.4	0.0	16.7
	Rapid			2.0	3.5	0.5	3.2	9.5	0.0	12.5
	1d			0.4	0.9	0.0	0.6	4.2	0.0	8.1
	3d			0.0	4.7	0.0	0.0	5.9	0.0	4.4
	7d			0.0	0.0	0.0	4.1	4.4	6.1	0.0
	Gradual			0.0	0.9	0.0	0.6	4.4	0.0	4.4



Metal (nM)	Regression slopes (nmol · (mg dust)$^{-1}$)			
	Fe	Co	Ni	Mn
Rapid diss.	0.18	0.025	0.13	2.16
Gradual diss.	0.06	0.023	0.16	2.55

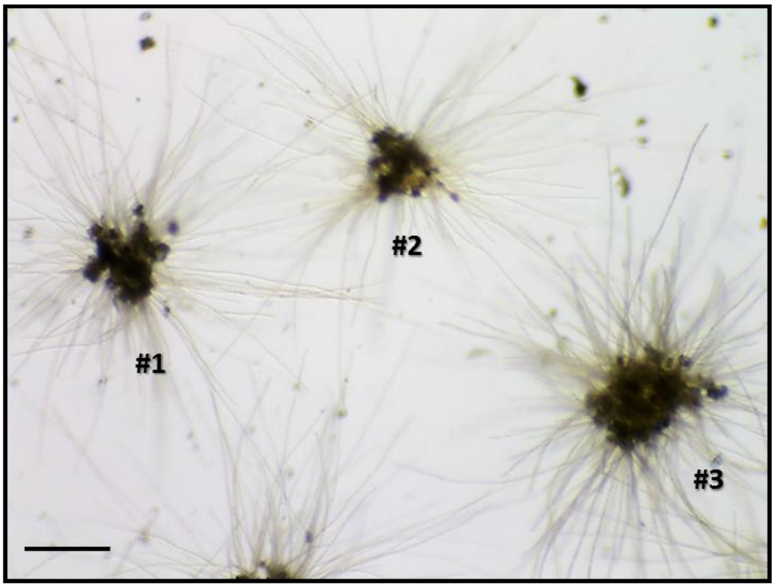
Figure S6. The release kinetics of four additional metals (Fe, Co, Ni and Mn) in dust dissolution experiments, related to the main text - Fig. 4.

The dataset combines new measurements (circles) and published data from Mackey et al., 2015, which includes seven dust samples plotted as different symbols. Dissolution kinetics is presented in two categories - rapidly released metals (black, up to 6hrs) and gradually released metals (red, up to 7 days). A summary table of regression slopes is shown below.



Colony	Colony radius	Colony volume	Dust load	Effective dust concn.
#	mm	mm^3; μL	ng	$mg \cdot L^{-1}$
1	0.410	0.29	69	239
2	0.689	1.37	675	492
3	0.381	0.23	214	925

Figure S7. Effective dust concentrations calculated for three representative natural/freshly collected Red Sea colonies, related to the main text section 3.2.2. The concentration ($mg \cdot L^{-1}$) was derived by dividing dust load (ng) by the colony volume (μL). Scale bar = 200 μm.



Colony	Incubation time	Colony radius	Colony volume	Dust load	Effective dust concn.
#	hours	mm	mm^3; μL	ng	$mg \cdot L^{-1}$
1	24	0.53	0.62	2490	4039
2	24	0.49	0.48	1948	4051
3	24	0.43	0.33	4127	12391

Figure S8. Images of Red Sea *Trichodesmium* colonies following a 24-hour *in situ* incubation with dust particles (10 $mg \cdot L^{-1}$). Effective dust concentrations within colony sphere were observed at levels exceeding 1000 $mg \cdot L^{-1}$. Scale bar = 200 μm.

Supplementary text S5. Characterizations of toxic particle removal via SEM-EDX analysis.

To investigate the ability of natural *Trichodesmium* colonies to remove toxic particles, incubation experiments were performed during the autumn of 2021, using 16 Red Sea colonies with Cu-containing mineral (malachite) and Fe-containing mineral (hematite). Briefly, 16 freshly collected colonies were first placed into a Nalgene bottle containing 2 $mg \cdot L^{-1}$ malachite and 2 $mg \cdot L^{-1}$ hematite (total particle concentration = 4 $mg \cdot L^{-1}$). The bottle was then incubated *in situ* (under the pier of Interuniversity of Marine Science in Eilat, Israel) for up to 24 hrs. 5-6 colonies were subsampled at 2h, 6h and 24h, placed on a PES membrane filter (Supor®), air-dried and frozen prior to SEM-EDX analysis at Environmental Molecular Sciences Laboratory (EMSL), USA (Fig. S9a). Stereoscopic images of each colony after the incubation were taken prior to (Fig. S9b) and after the air-drying procedure (Fig. S9c), before SEM-EDX analysis.

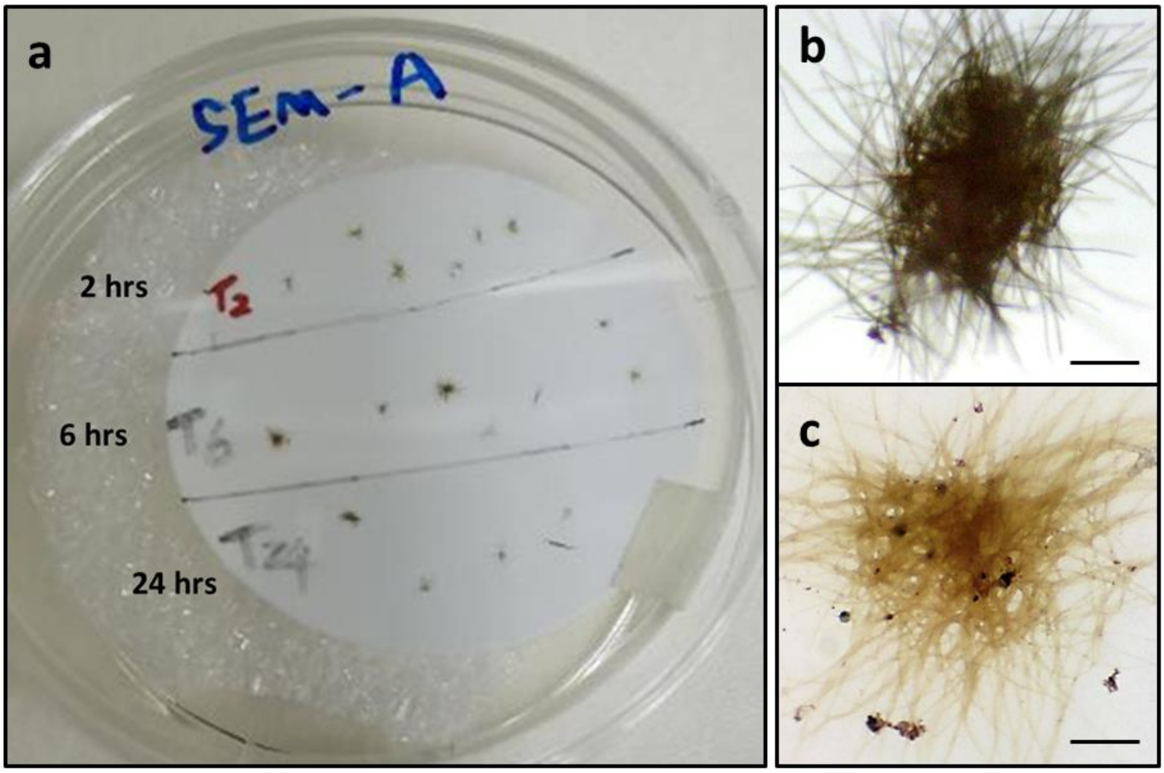


Figure S9. An illustrative figure of sample collection for SEM-EDX analysis (a), stereoscopic images of a colony prior to (b) and after the air-dried procedure (c). Scale bar = 200 µm.

2h-incubation

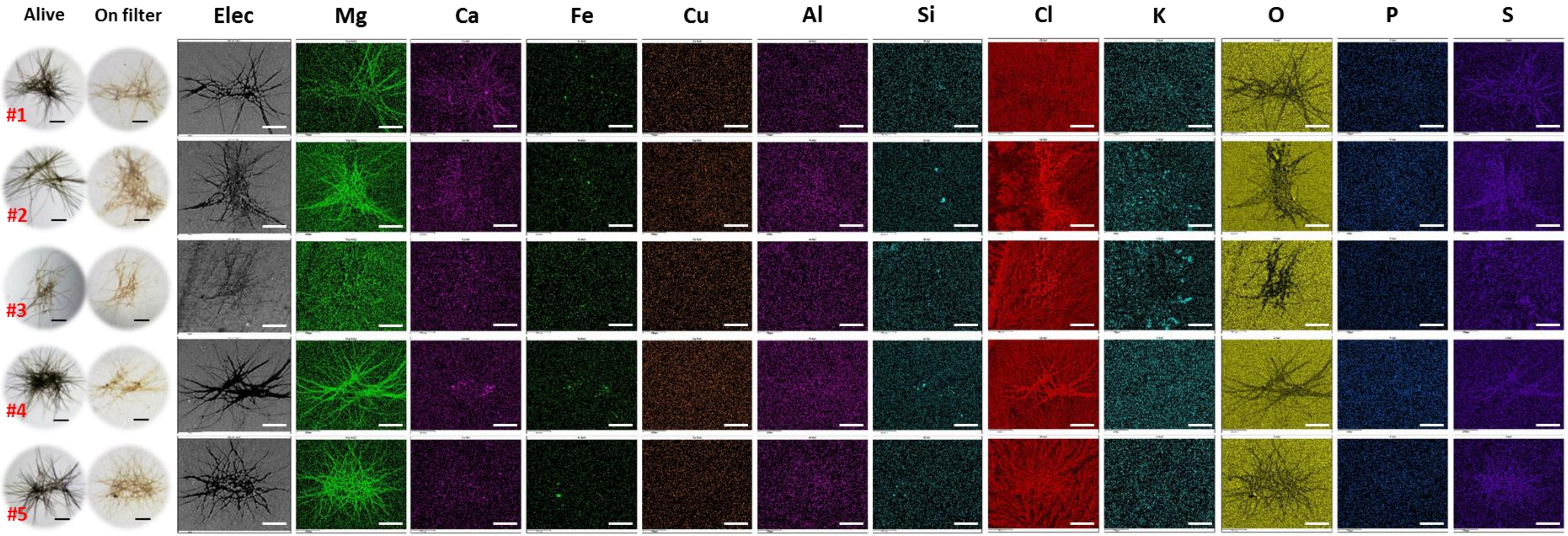


Figure S10. SEM-EDX images of five natural *Trichodesmium* colonies incubated with Cu-minerals (malachite) and Fe-minerals (hematite) for 2 hrs, related to the main text - Section 3.3.2. Stereoscopic images taken prior to (alive, 1st column) and after the air-drying procedure (on filter, 2nd column). “Elec” means electron. Scale bars for stereoscopic (1st and 2nd columns) and SEM images (3rd to 14th columns) are 200 and 250 µm, respectively.

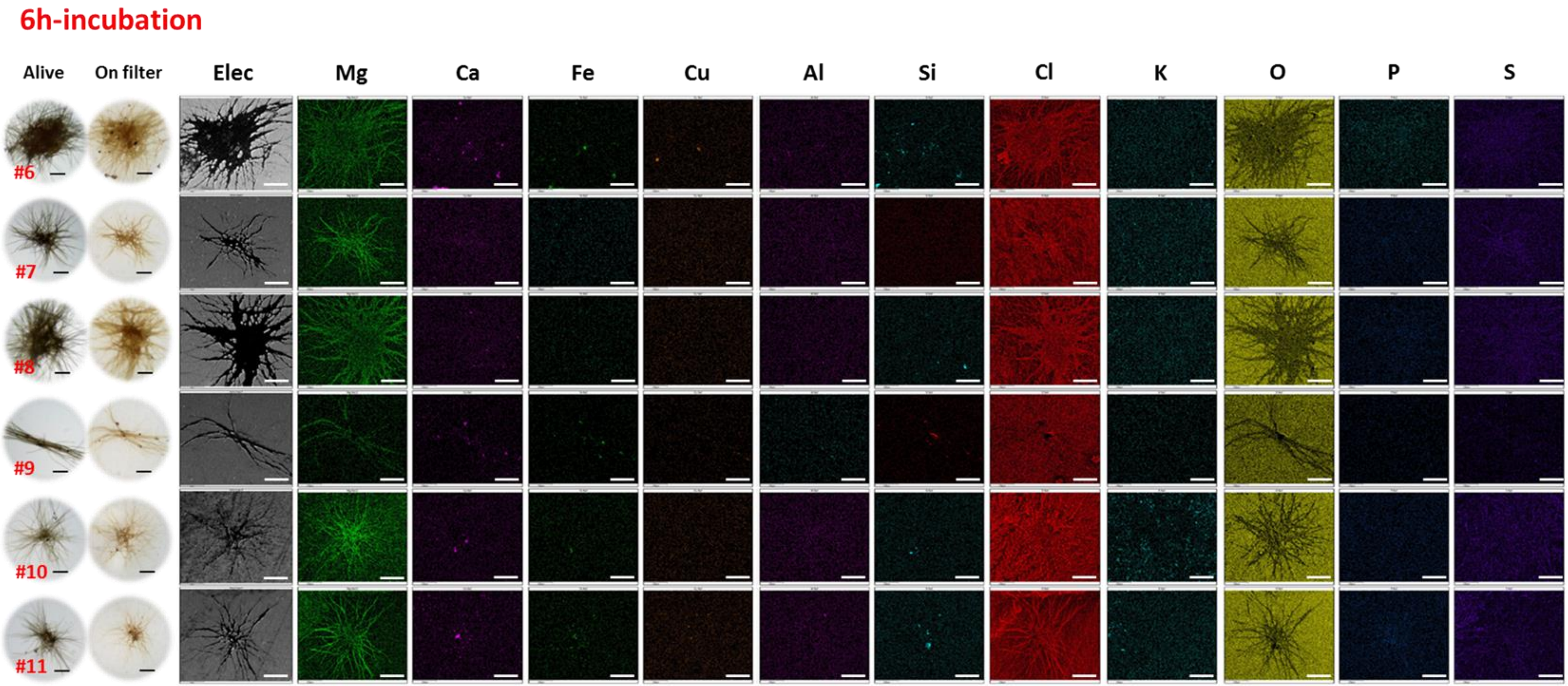


Figure S11. SEM-EDX images of five natural *Trichodesmium* colonies incubated with Cu-minerals (malachite) and Fe-minerals (hematite) for 6 hrs, related to the main text - Section 3.3.2. Stereoscopic images taken prior to (alive, 1st column) and after the air-drying procedure (on filter, 2nd column). "Elec" means electron. Scale bars for stereoscopic (1st and 2nd columns) and SEM images (3rd to 14th columns) are 200 and 250 µm, respectively. The element map (Mg, Ca, Fe and Cu) of colony (#11) was presented in the main text – Fig. 6 (top-left panel).

24h-incubation

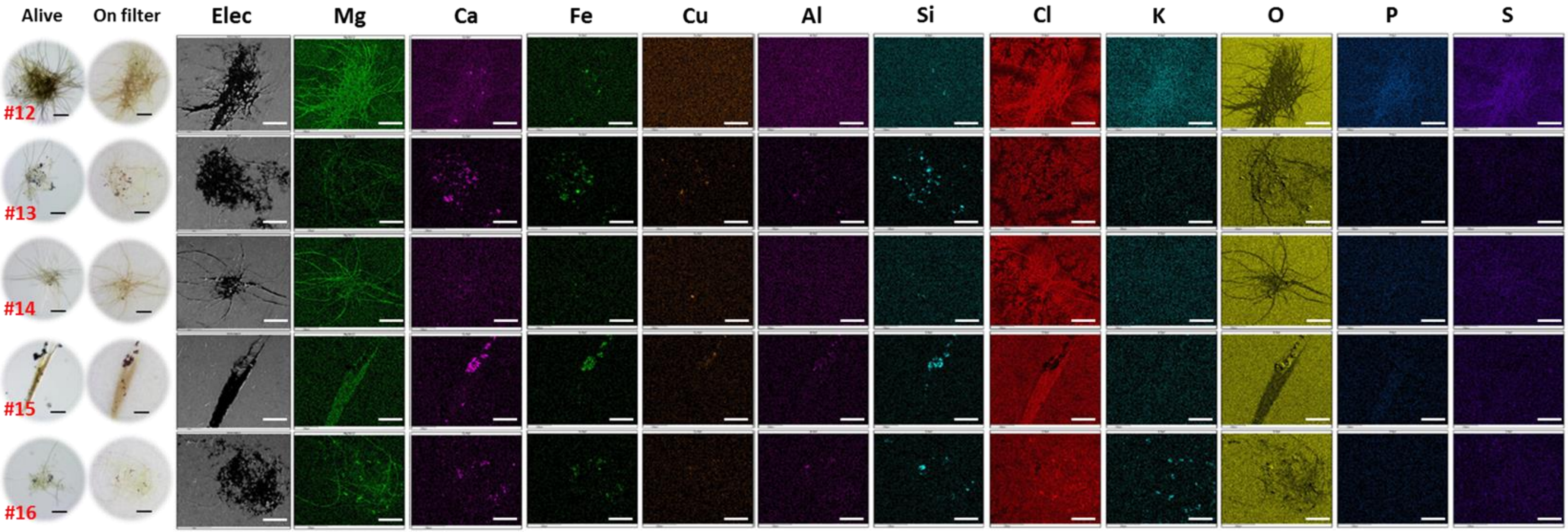


Figure S12. SEM-EDX images of five natural *Trichodesmium* colonies incubated with Cu-minerals (malachite) and Fe-minerals (hematite) for 24 hrs, related to the main text - Section 3.3.2. Stereoscopic images taken prior to (alive, 1st column) and after the air-drying procedure (on filter, 2nd column). “Elec” means electron. Scale bars for stereoscopic (1st and 2nd columns) and SEM images (3rd to 14th columns) are 200 and 250 µm, respectively. The element map (Mg, Ca, Fe and Cu) of colony (#13) was presented in the main text – Fig. 6 (top-right panel).

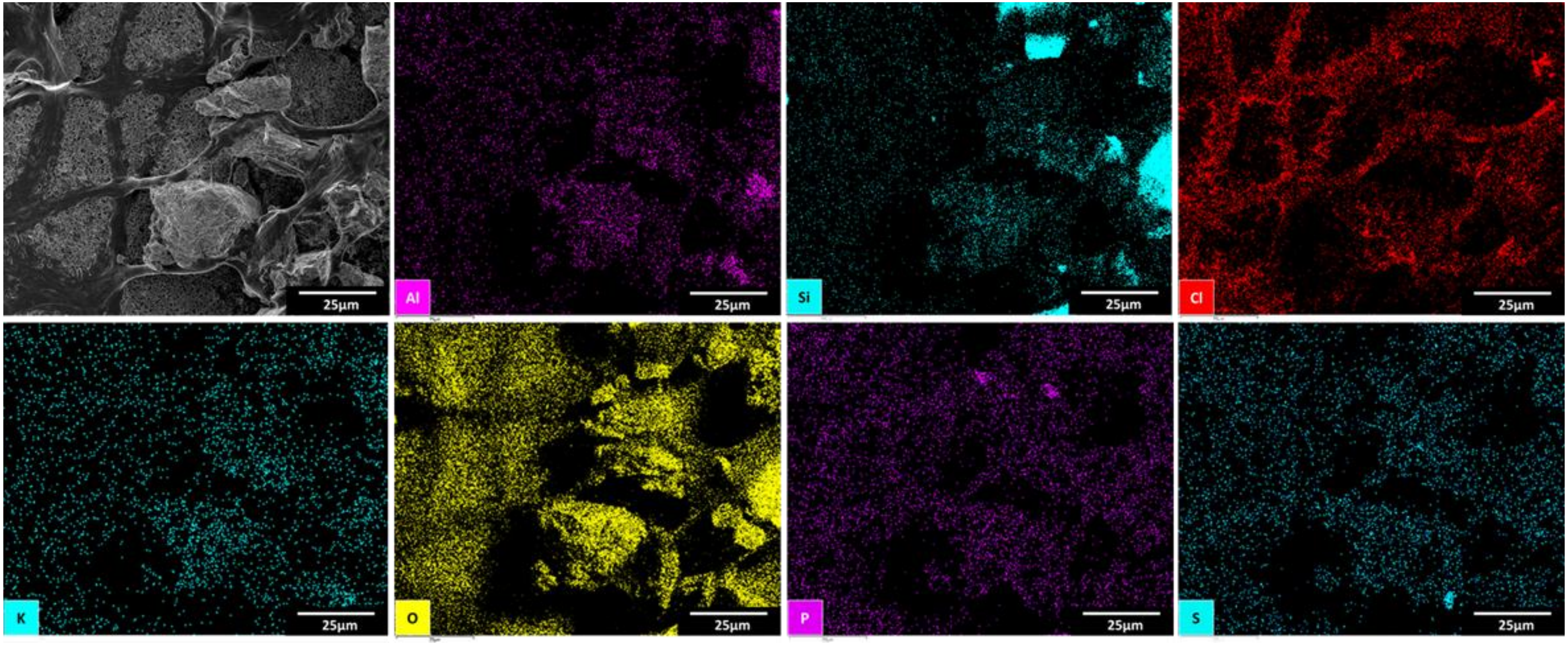


Figure S13. Additional element maps of a *Trichodesmium* colony (#13) incubated with Cu-minerals (malachite) and Fe-minerals (hematite) for 24 hrs, related to the main text - Section 3.3.2 (see Fig.6 – bottom panels). All scale bars = 25 µm.

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