Supplementary Material

Nordic microalgae immobilized to a sulfur–cooking oil copolymer form a highly efficient, sustainable and reusable sorbent to remove heavy metals from complex mixtures

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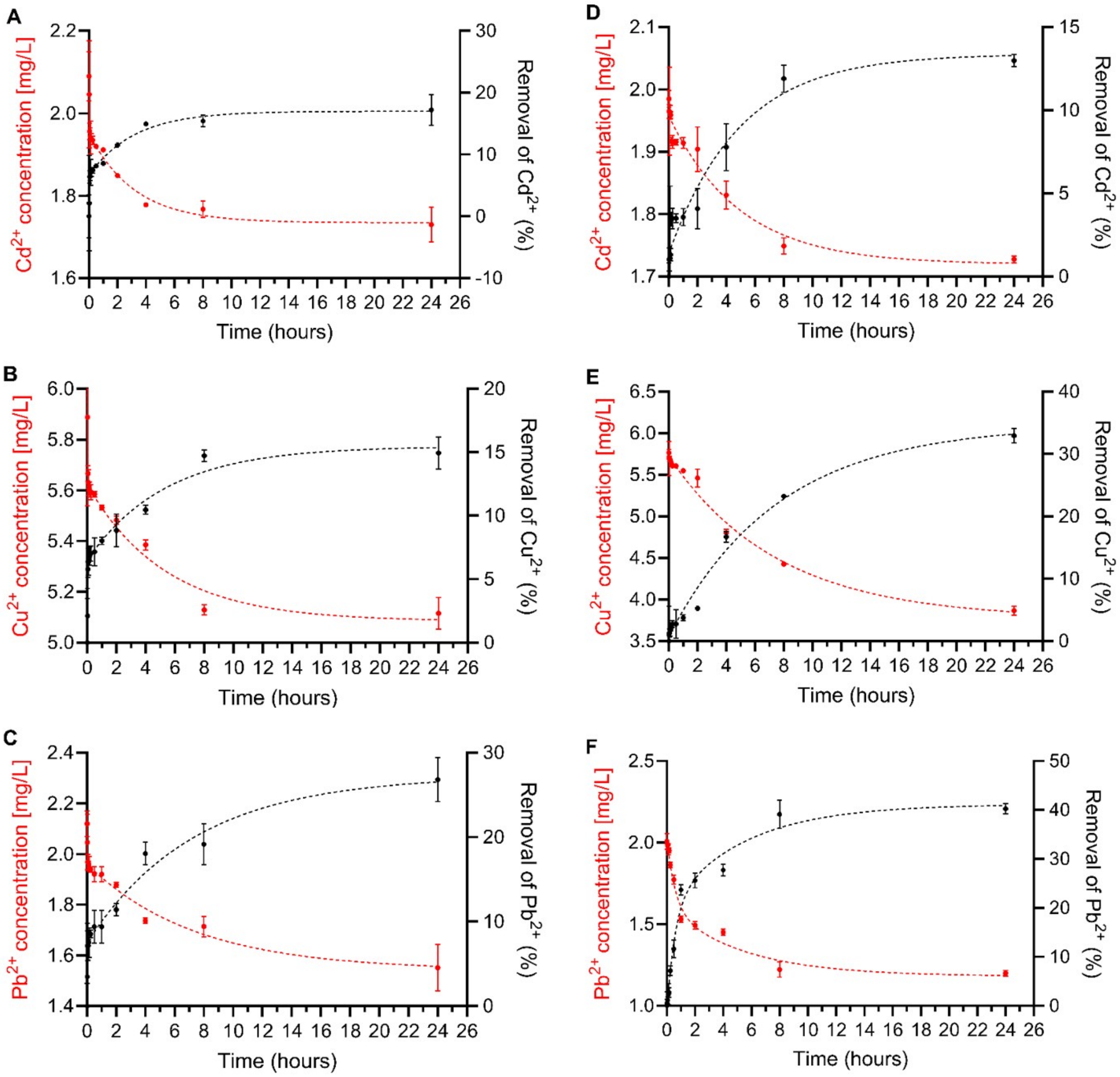

Fig. S1. Removal of 5 mg L^{-1} Cd^{2+}, 2 mg L^{-1} Cu^{2+} and 1.8 mg L^{-1} Pb^{2+} in a multi-elemental mixture by *Scotelliopsis reticulata* (UFA-2) in the absence of copolymer (A-C) and after immobilization to the copolymer (D-F). Mean ± SD of three biological replicates. Dashed lines represent the fitted curves of two-phase association (black) and decay (red). Solid lines in D and E show the sigmoidal curve fitting for removal of the corresponding elements.

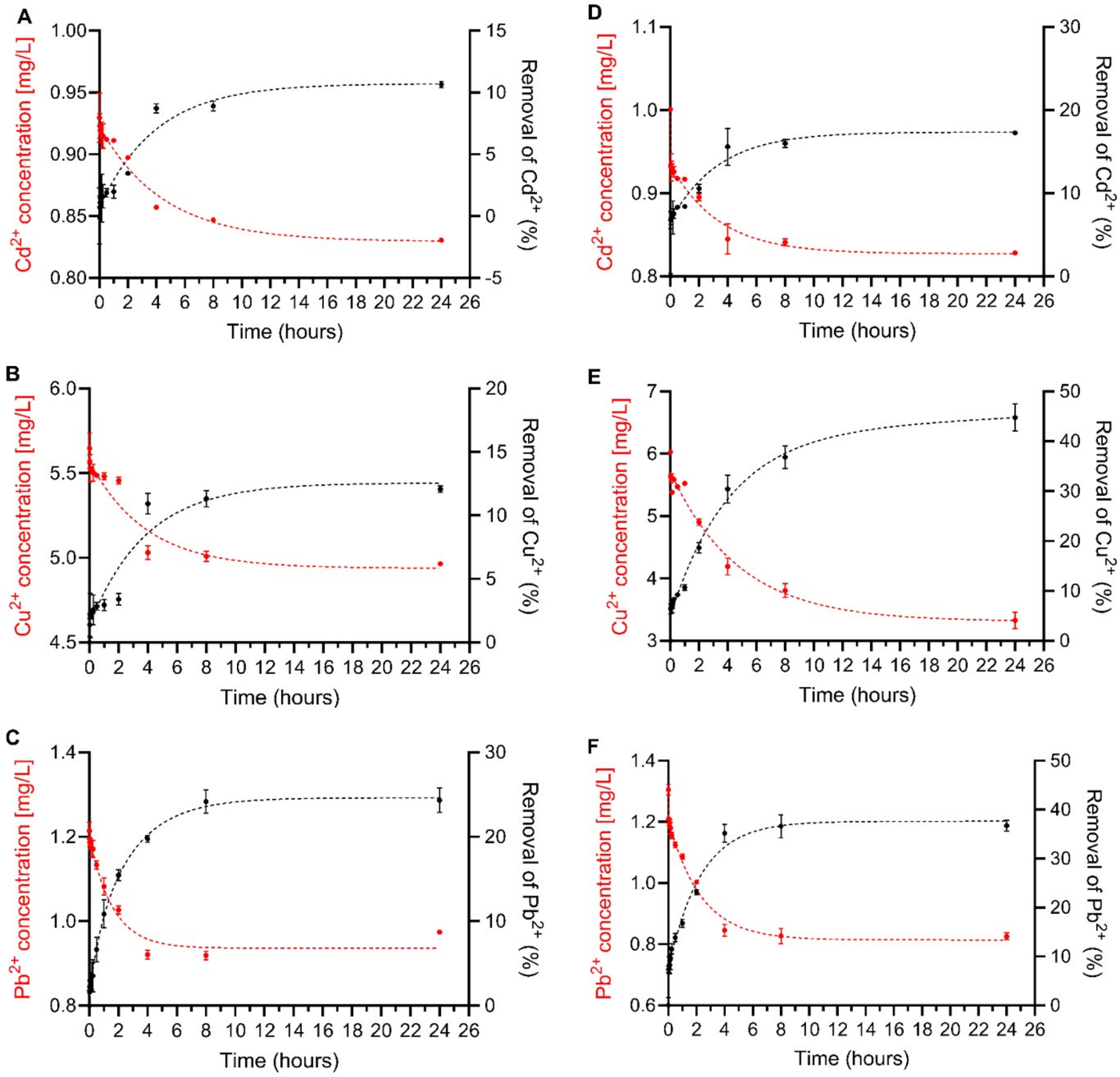

Fig. S2. Removal of 5 mg L^{-1} Cd^{2+}, 1 mg L^{-1} Cu^{2+} and 1 mg L^{-1} Pb^{2+} in a multi-elemental setup by *Scenedesmus obliquus* (13-8) in the absence of copolymer (A-C) and after immobilization on the copolymer (D-F). Mean ± SD of three biological replicates. Dashed lines represent the fitted curves of two-phase association (black) and decay (red). Solid lines in D and E show the sigmoidal curve fitting for removal of the corresponding elements.

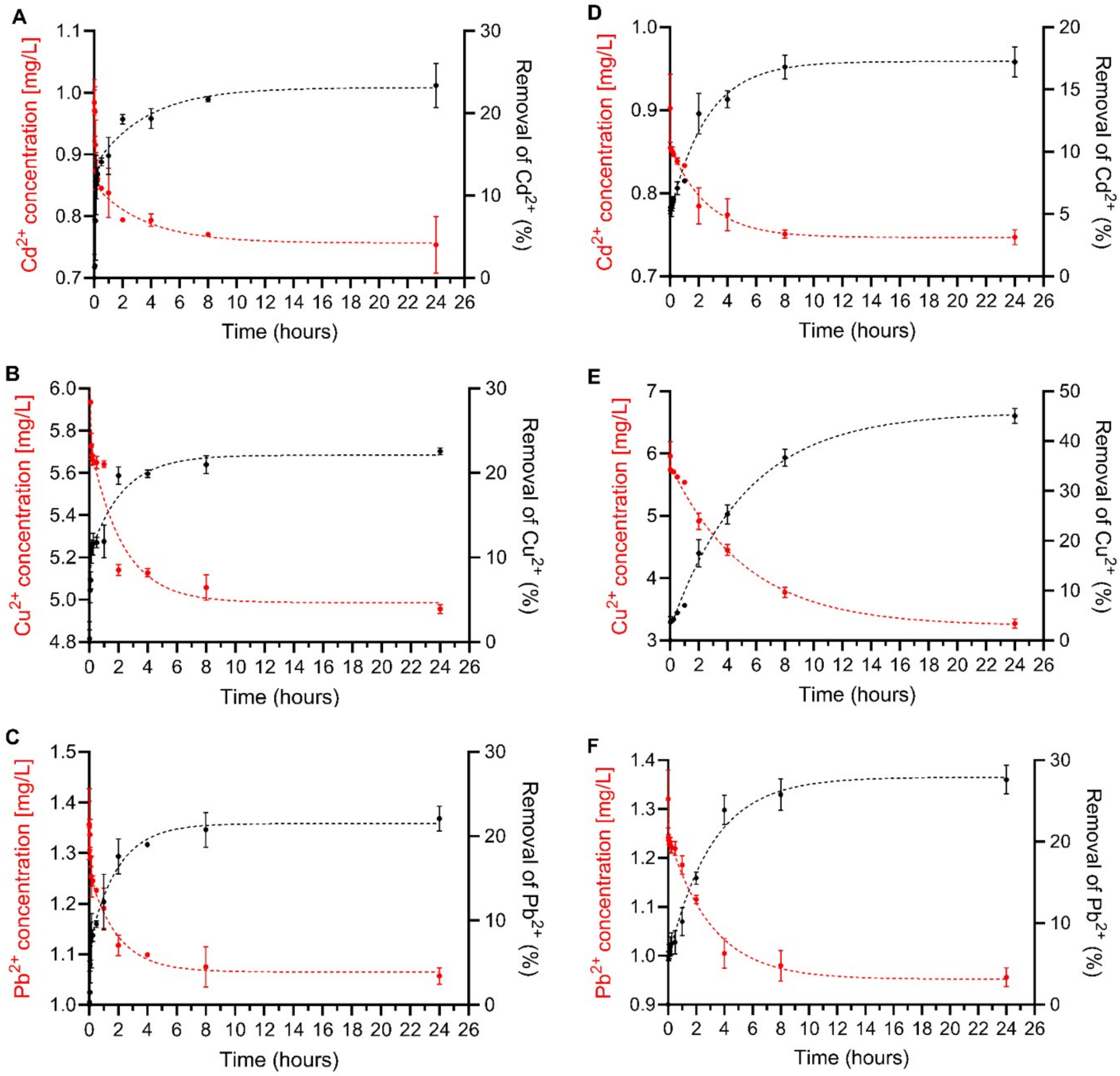

Fig. S3. Removal of 5 mg L^{-1} Cd^{2+}, 1 mg L^{-1} Cu^{2+} and 1 mg L^{-1} Pb^{2+} in a multi-elemental setup by *Micractinium* sp. (P9-1) in the absence of copolymer (A-C) and after immobilization on the copolymer (D-F). Mean ± SD of three biological replicates. Dashed lines represent the fitted curves of two-phase association (black) and decay (red). Solid lines in D and E show the sigmoidal curve fitting for removal of the corresponding elements.

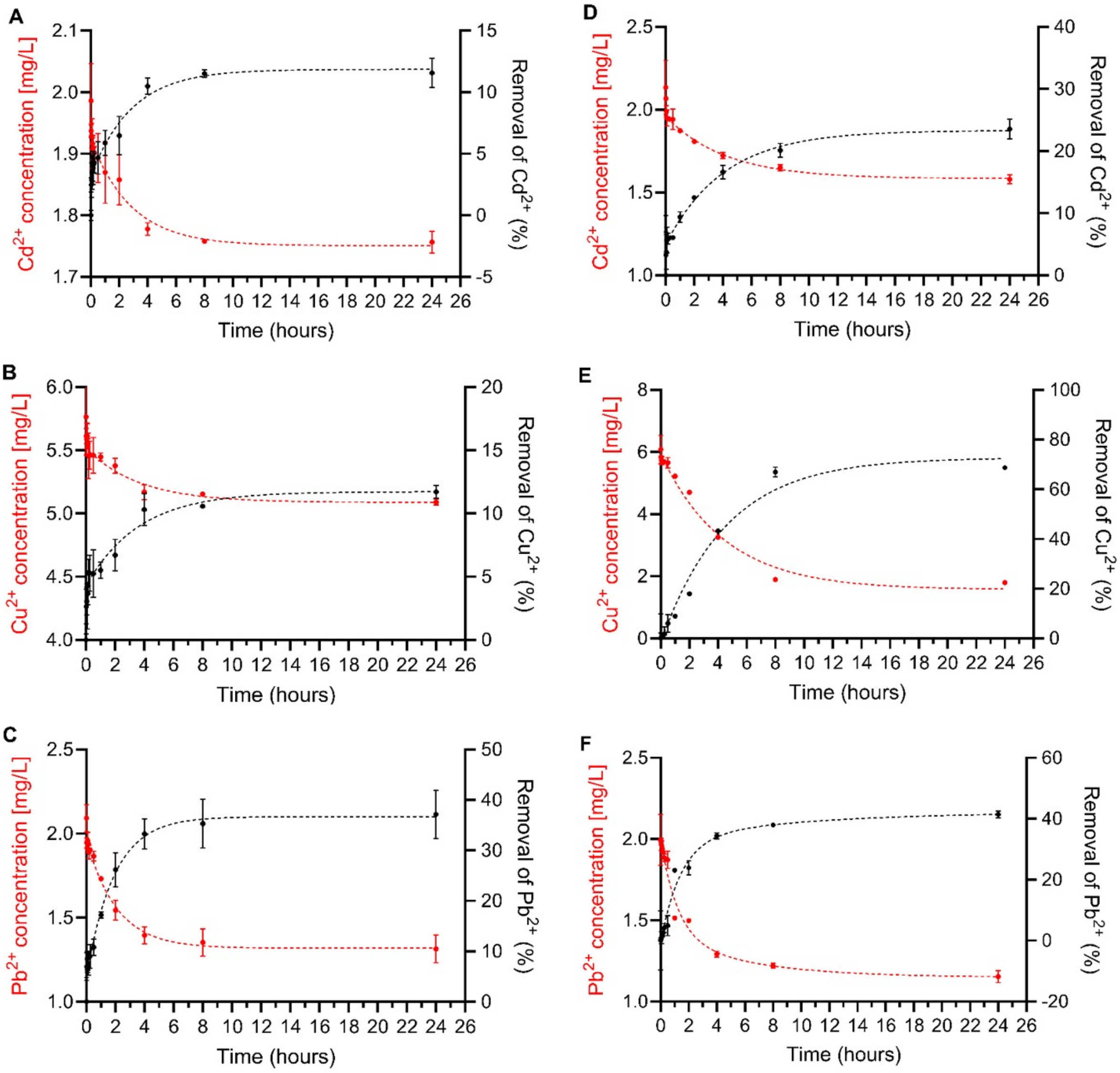

Fig. S4. Removal of 5 mg L^{-1} Cd^{2+}, 2 mg L^{-1} Cu^{2+} and 1.8 mg L^{-1} Pb^{2+} in a multi-elemental setup by *Coelastrella* sp. (3-4) in the absence of copolymer (A-C) and after immobilization on the copolymer (D-F). Mean ± SD of three biological replicates. Dashed lines represent the fitted curves of two-phase association (black) and decay (red). Solid lines in D and E show the sigmoidal curve fitting for removal of the corresponding elements.

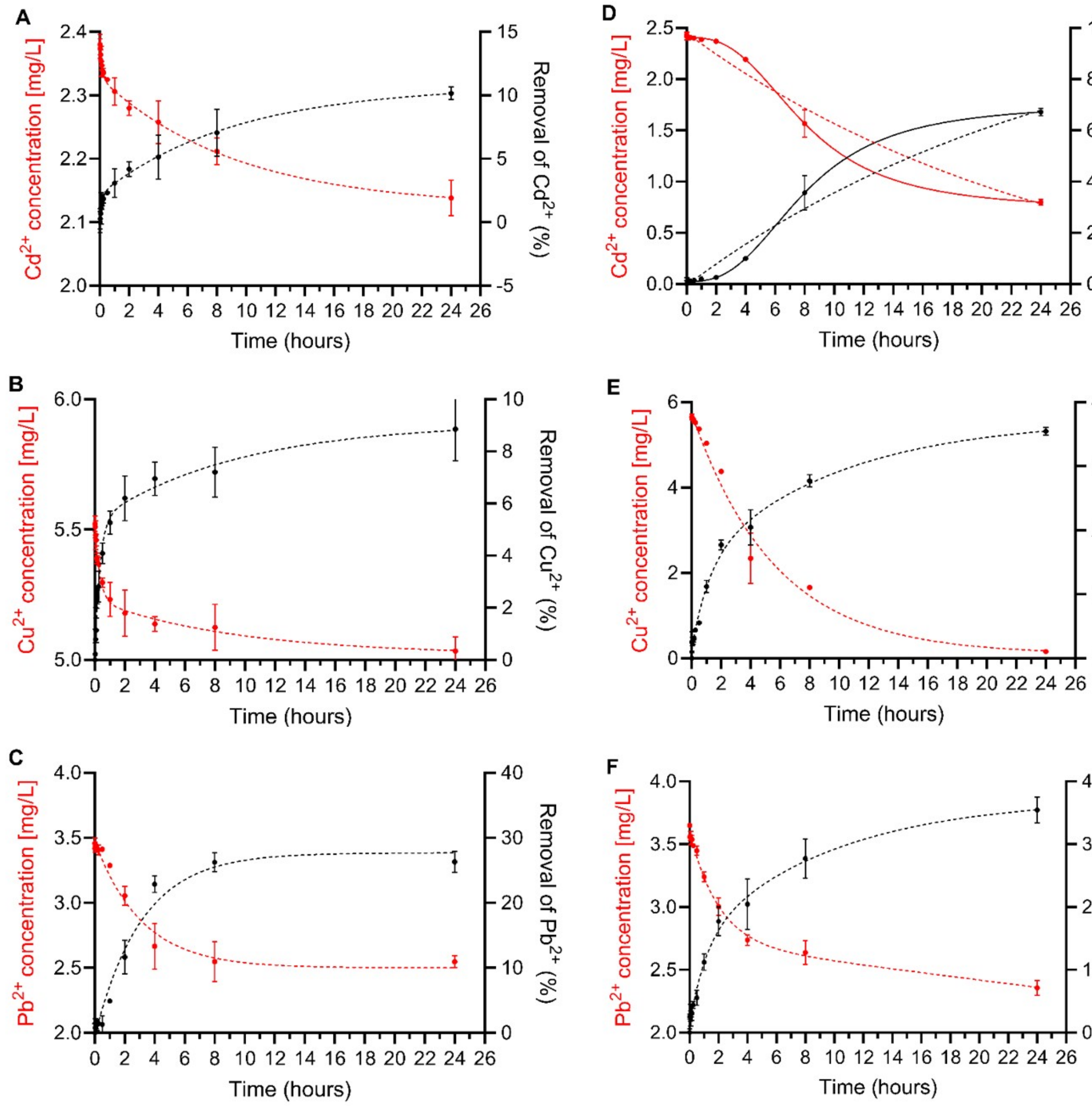

Fig. S5. Removal of 5 mg L^{-1} Cd^{2+}, 2.5 mg L^{-1} Cu^{2+} and 3.6 mg L^{-1} Pb^{2+} in a multi-elemental setup by *Chlorella sorokiniana* (2-21-1) in the absence of copolymer (A-C) and after immobilization on the copolymer (D-F). Mean ± SD of three biological replicates. Dashed lines represent the fitted curves of two-phase association (black) and decay (red). Solid lines in D and E show the sigmoidal curve fitting for removal of the corresponding elements.

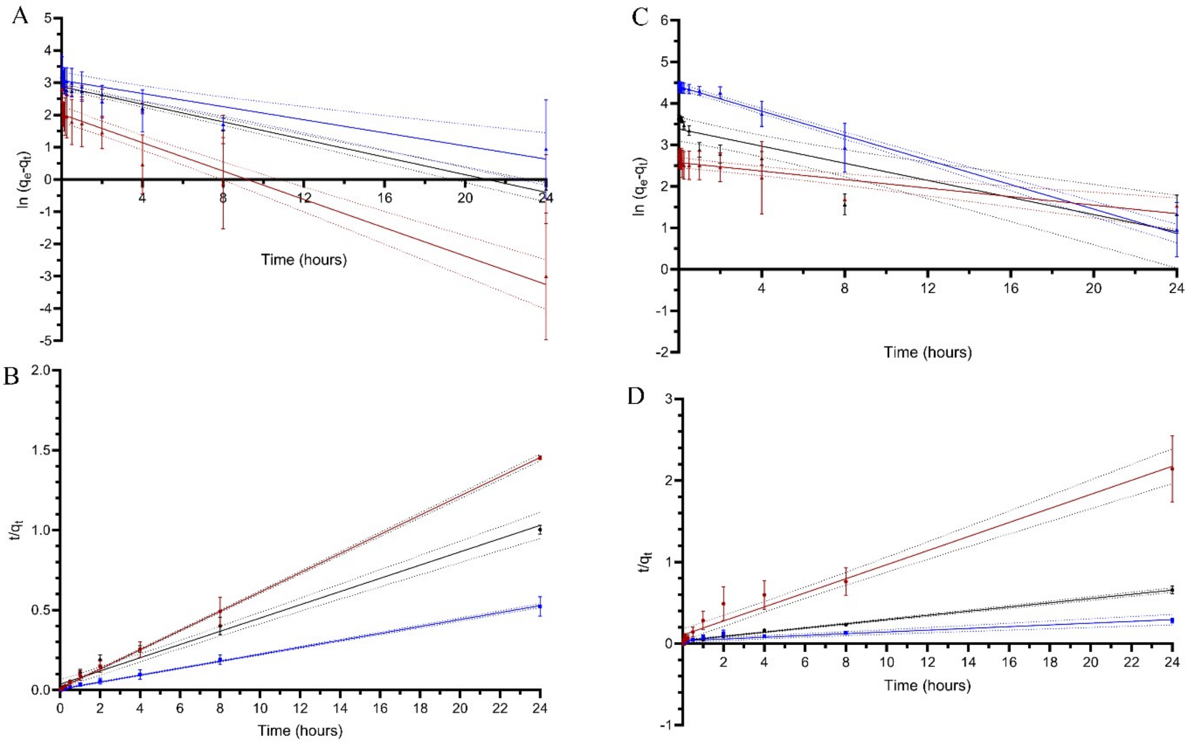

Fig. S6. Kinetic modeling of heavy metal removal for *Scotelliopsis reticulata* (UFA-2) (red: Cd^{2+}; blue: Cu^{2+}, black: Pb^{2+}); data is presented as Mean ± SD of three biological replicates. (**A**) Pseudo-first-order kinetics before immobilization; (**B**) pseudo-second order kinetics before immobilization. (**C**) Pseudo-first-order kinetics after immobilization; (**D**) pseudo-second order kinetics after immobilization.

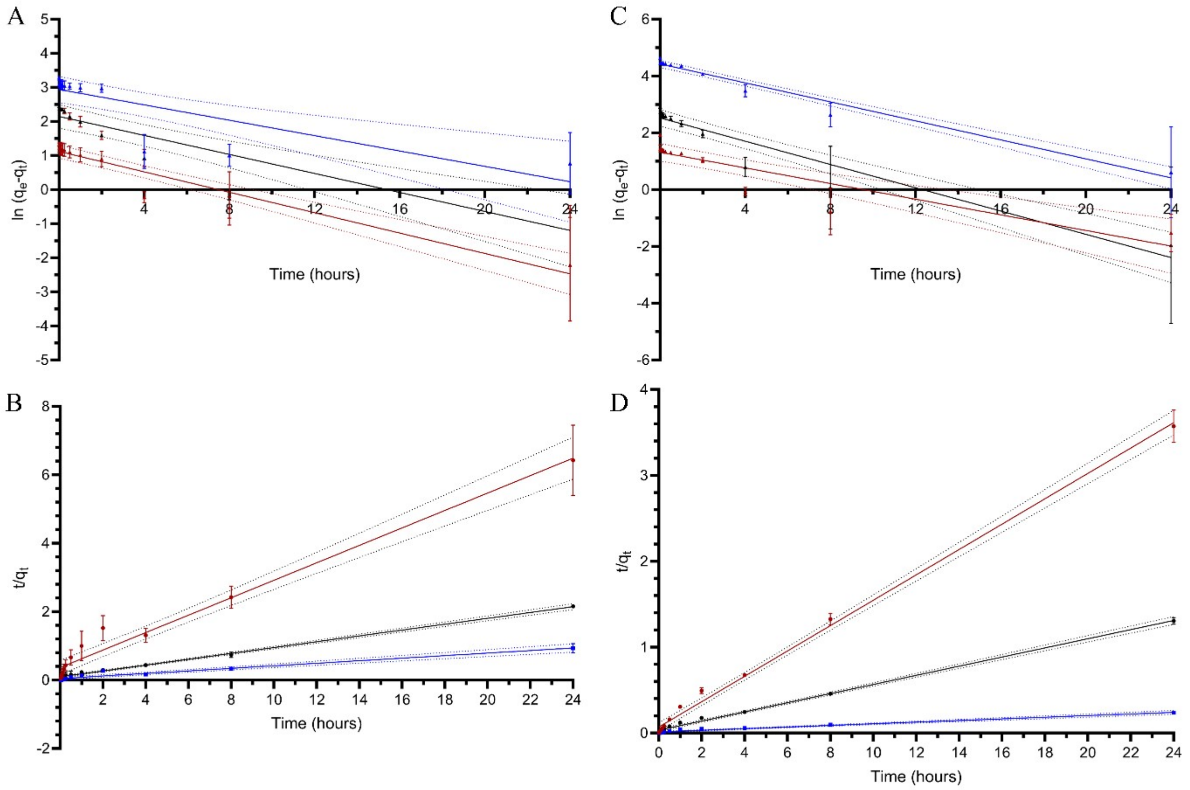

Fig. S7. Kinetic modeling of heavy metal removal for *Scenedesmus obliquus* (13-8) (red: Cd^{2+}; blue: Cu^{2+}, black: Pb^{2+}); data is presented as Mean ± SD of three biological replicates. (**A**) Pseudo-first-order kinetics before immobilization; (**B**) pseudo-second order kinetics before immobilization. (**C**) Pseudo-first-order kinetics after immobilization; (**D**) pseudo-second order kinetics after immobilization.

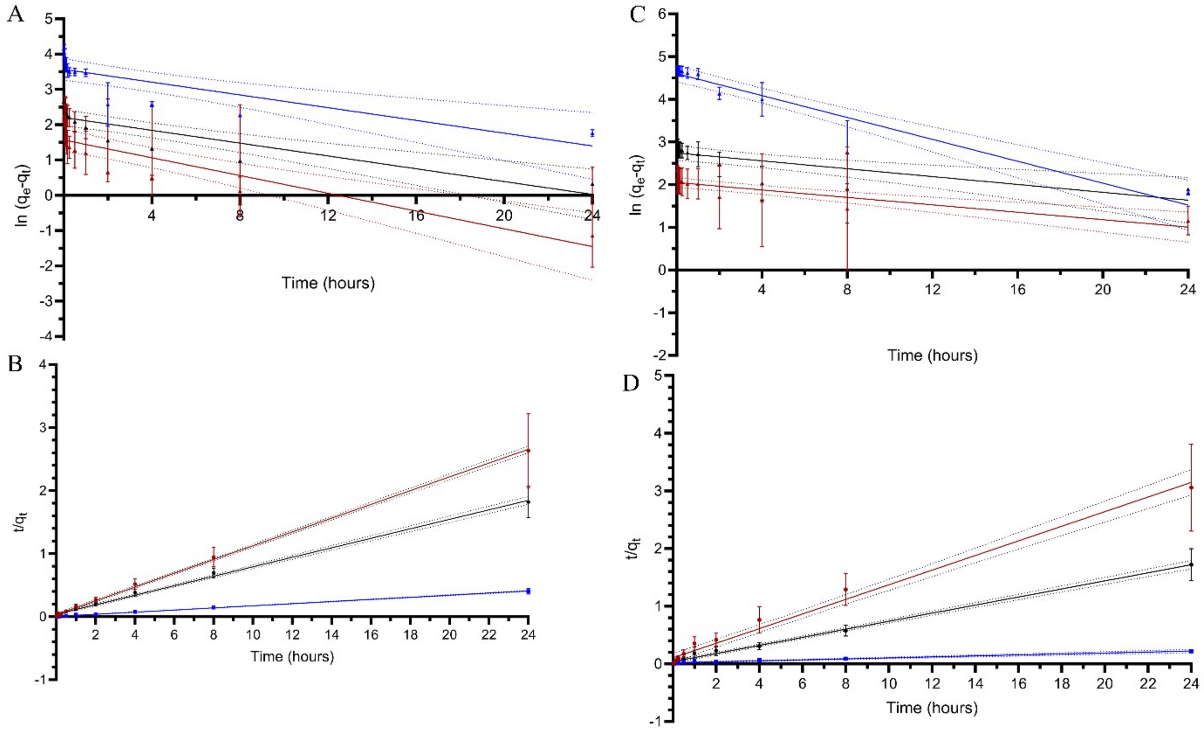

Fig. S8. Kinetic modeling of heavy metal removal for *Micractinium* sp. (P9-1) (red: Cd^{2+}; blue: Cu^{2+}, black: Pb^{2+}); data is presented as Mean ± SD of three biological replicates. (**A**) Pseudo-first-order kinetics before immobilization; (**B**) pseudo-second order kinetics before immobilization. (**C**) Pseudo-first-order kinetics after immobilization; (**D**) pseudo-second order kinetics after immobilization.

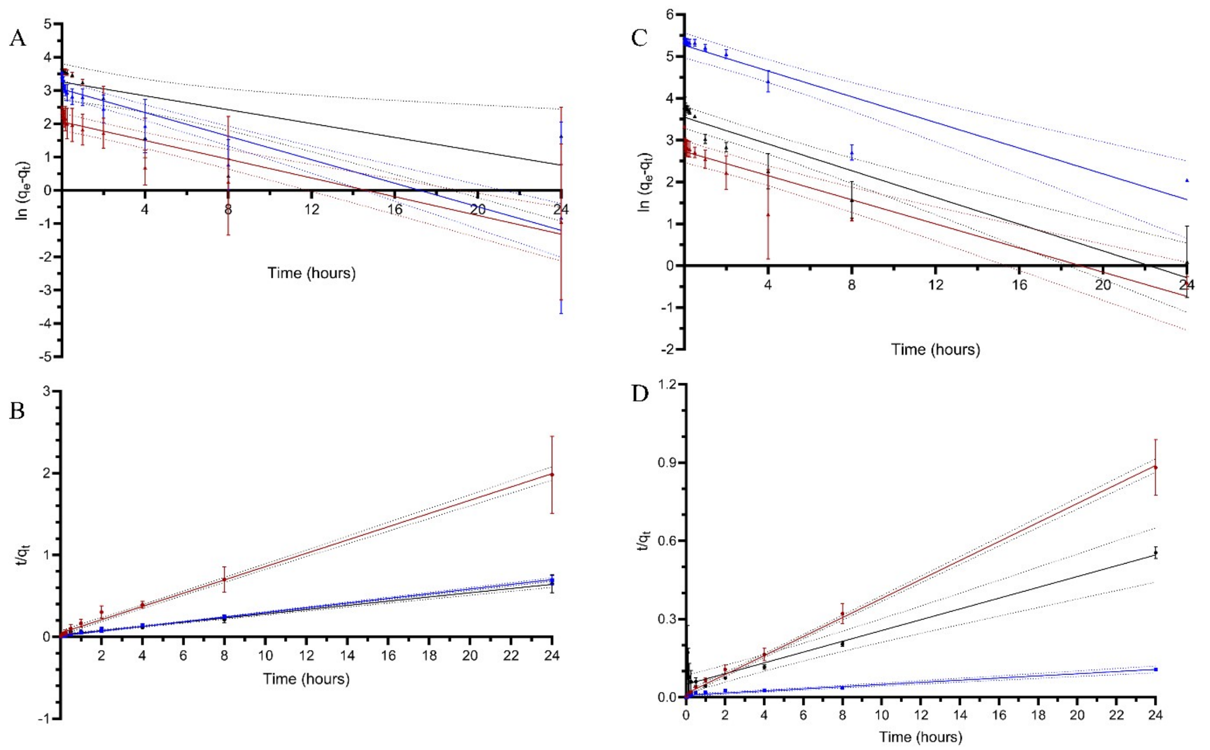

Fig. S9. Kinetic modeling of heavy metal removal for *Coelastrella* sp. (3-4) (red: Cd^{2+}; blue: Cu^{2+}, black: Pb^{2+}); data is presented as Mean ± SD of three biological replicates. (**A**) Pseudo-first-order kinetics before immobilization; (**B**) pseudo-second order kinetics before immobilization. (**C**) Pseudo-first-order kinetics after immobilization; (**D**) pseudo-second order kinetics after immobilization.

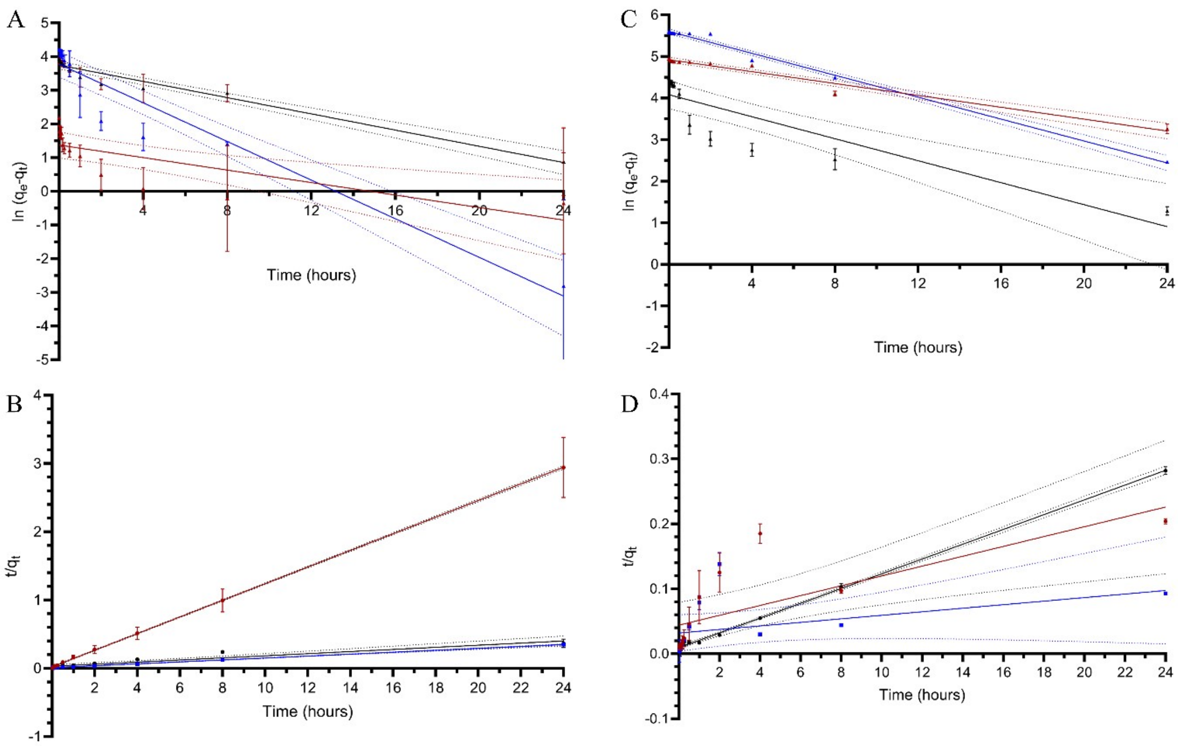

Fig. S10. Kinetic modeling of heavy metal removal by *Chlorella vulgaris* (13-1) (red: Cd^{2+}; blue: Cu^{2+}, black: Pb^{2+}); data is presented as Mean ± SD of three biological replicates. (**A**) Pseudo-first-order kinetics before immobilization; (**B**) pseudo-second order kinetics before immobilization. (**C**) Pseudo-first-order kinetics after immobilization; (**D**) pseudo-second order kinetics after immobilization.

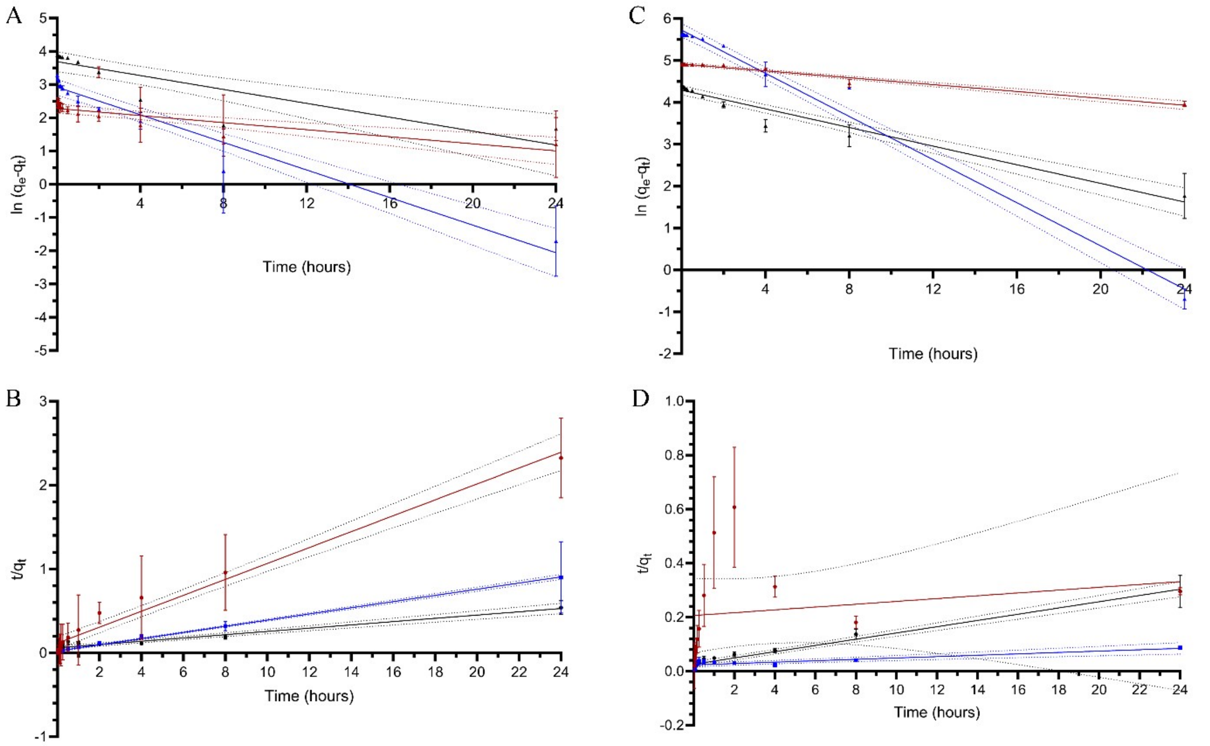

Fig. S11. Kinetic modeling of heavy metal removal for *Chlorella sorokiniana* (2-21-1) (red: Cd^{2+}; blue: Cu^{2+}, black: Pb^{2+}); data is presented as Mean ± SD of three biological replicates. (**A**) Pseudo-first-order kinetics before immobilization; (**B**) pseudo-second order kinetics before immobilization. (**C**) Pseudo-first-order kinetics after immobilization; (**D**) pseudo-second order kinetics after immobilization.

Table S1. Heavy metal concentrations in the mixtures applied to different microalgal strains

		Concentration [mg L^{-1}]		
Heavy metal mix	**Applied to strain**	Cu^{2+}	Cd^{2+}	Pb^{2+}
High (H)	***Chlorella vulgaris* (13-1)** ***Chlorella sorokiniana* (2-21-1)**	5	2.5	3.6
Medium (M)	***Coelastrella* sp. (3-4)** ***Scotelliopsis reticulata* (UFA-2)**	5	2	1.8
Low (L)	***Scenedesmus obliquus* (13-8)** ***Micractinium* sp. (P9-1)**	5	1	1

Table S2. Removal of Cd^{2+}, Cu^{2+} and Pb^{2+} in a multi-elemental mixture under equilibrium conditions calculated with the Freundlich and the Dubinin-Radushkevich model. Data presented for 5 Nordic microalgae and the copolymer individually as well as after immobilization.

		Freundlich			**Dubinin-Radushkevich**		
Strain	**HM**	K_F (mg g^{-1})	n_F	R^2	q_{max} (mg g^{-1})	K_{DR} (mol^2 J^{-2})	R^2
Copolymer alone (CP)	Cd^{2+}	0.14	1.80	0.991	0.76	3.83E-06	0.869
	Cu^{2+}	0.09	1.02	0.930	1.11	4.34E-06	0.957
	Pb^{2+}	0.13	1.24	0.973	1.82	9.61E-06	0.967
***Scotelliopsis reticulata* (UFA-2)**	Cd^{2+}	9.51	2.61	0.887	27.39	6.01E-06	0.955
	Cu^{2+}	9.37	1.40	0.944	57.86	2.54E-06	0.837
	Pb^{2+}	31.14	1.24	0.936	431.80	9.43E-06	0.975
***Scotelliopsis reticulata* (UFA-2) + CP**	Cd^{2+}	36.59	1.69	0.895	243.20	4.59E-06	0.977
	Cu^{2+}	35.58	1.05	0.956	372.30	3.03E-06	0.978
	Pb^{2+}	*	*	*	1044.00	3.67E-06	0.961
***Scenedesmus obliquus* (13-8)**	Cd^{2+}	18.96	3.60	0.962	36.62	1.86E-07	0.658
	Cu^{2+}	17.25	1.16	0.947	153.00	2.91E-06	0.963
	Pb^{2+}	17.89	1.08	0.971	368.40	1.22E-05	0.979
***Scenedesmus obliquus* (13-8) + CP**	Cd^{2+}	13.10	1.84	0.975	71.38	3.87E-06	0.891
	Cu^{2+}	*	*	*	171.20	3.53E-07	0.976
	Pb^{2+}	33.00	1.27	0.899	426.40	8.68E-06	0.969
***Coelastrella* sp. (3-4)**	Cd^{2+}	11.17	2.51	0.965	33.81	8.88E-07	0.850
	Cu^{2+}	14.72	1.06	0.919	171.10	3.99E-06	0.946
	Pb^{2+}	26.30	1.52	0.994	202.50	4.99E-06	0.912
***Coelastrella* sp. (3-4) + CP**	Cd^{2+}	30.75	2.61	0.988	94.48	1.59E-06	0.735
	Cu^{2+}	*	*	*	278.50	5.35E-07	0.963
	Pb^{2+}	37.00	1.29	0.941	412.00	6.66E-06	0.982
***Chlorella vulgaris* (13-1)**	Cd^{2+}	18.41	2.93	0.960	44.04	3.35E-07	0.877
	Cu^{2+}	*	*	*	169.80	7.83E-06	0.883
	Pb^{2+}	24.00	2.05	0.958	101.10	2.24E-06	0.868
***Chlorella vulgaris* (13-1) + CP**	Cd^{2+}	36.55	3.19	0.959	78.48	2.17E-07	0.826
	Cu^{2+}	*	*	*	491.70	6.51E-06	0.947
	Pb^{2+}	*	*	*	446.60	7.59E-06	0.954
***Chlorella sorokiniana* (2-21-1)**	Cd^{2+}	21.33	2.58	0.929	60.76	5.73E-07	0.921
	Cu^{2+}	13.62	1.76	0.978	47.80	6.81E-07	0.892
	Pb^{2+}	27.97	1.32	0.906	333.20	7.89E-06	0.984
***Chlorella sorokiniana* (2-21-1) + CP**	Cd^{2+}	19.19	1.81	0.938	105.40	2.97E-06	0.972
	Cu^{2+}	*	*	*	230.50	6.34E-07	0.930
	Pb^{2+}	29.00	1.14	0.928	505.30	9.76E-06	0.994

* prediction not possible

Table S3. Remaining removal rate of microalgal/copolymer sorbent after desorption of heavy metals with HNO_3 or EDTA (given as % of initial removal rate).

	0.1M HNO_3 % of previous removal rate			**0.1M EDTA % of previous removal rate**		
	Cd^{2+}	**Cu^{2+}**	**Pb^{2+}**	**Cd^{2+}**	**Cu^{2+}**	**Pb^{2+}**
Copolymer (CP) alone	62	91	94	110	90	94
***Scotelliopsis reticulata* (UFA-2) + CP**	72	94	60	115	99	98
***Scenedesmus obliquus* (13-8) + CP**	59	80	39	94	99	82
***Coelastrella* sp. (3-4) + CP**	90	104	94	104	106	105
***Chlorella vulgaris* (13-1) + CP**	41	71	64	84	78	83
***Chlorella sorokiniana* (2-21-1) + CP**	60	73	97	84	86	103