Supplementary information for:

Trawling effects on biogeochemical processes are mediated by fauna in high energy biogenic reef–inhabited coastal sediments

Justin C. Tiano, Jochen Depestele, Gert Van Hoey, João Fernandes, Pieter van Rijswijk, Karline Soetaert

S.1. Supplementary figures

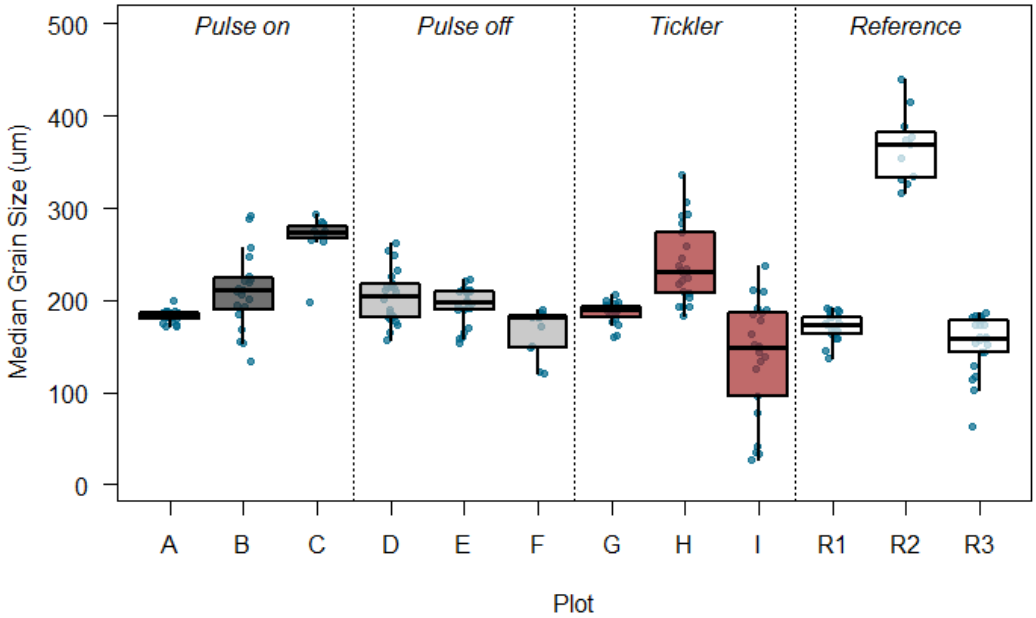


Figure S1: Median grain sizes found in T0 experimental (pulse on, pulse off, tickler) plots and reference locations. Note. Reference station R3 was not used in the statistical analysis as no T0 samples were taken.

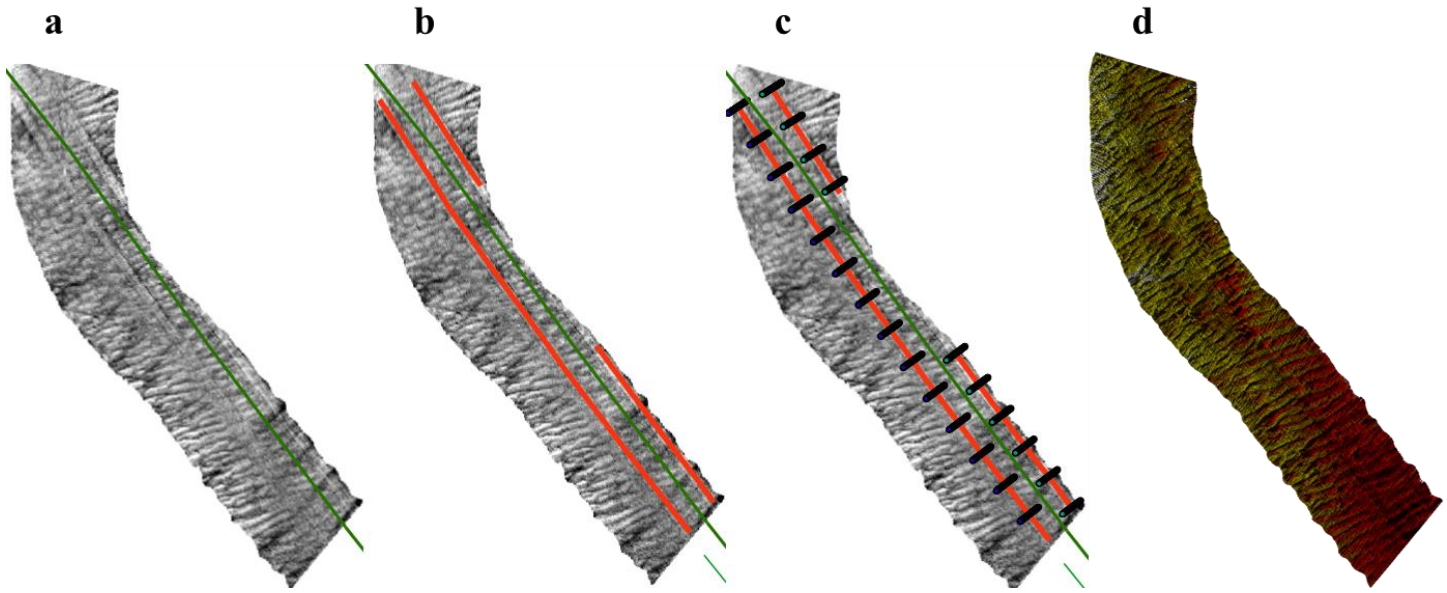


Figure S2: Identification of trawl tracks using backscatter (a-c) and bathymetry (d) imagery.

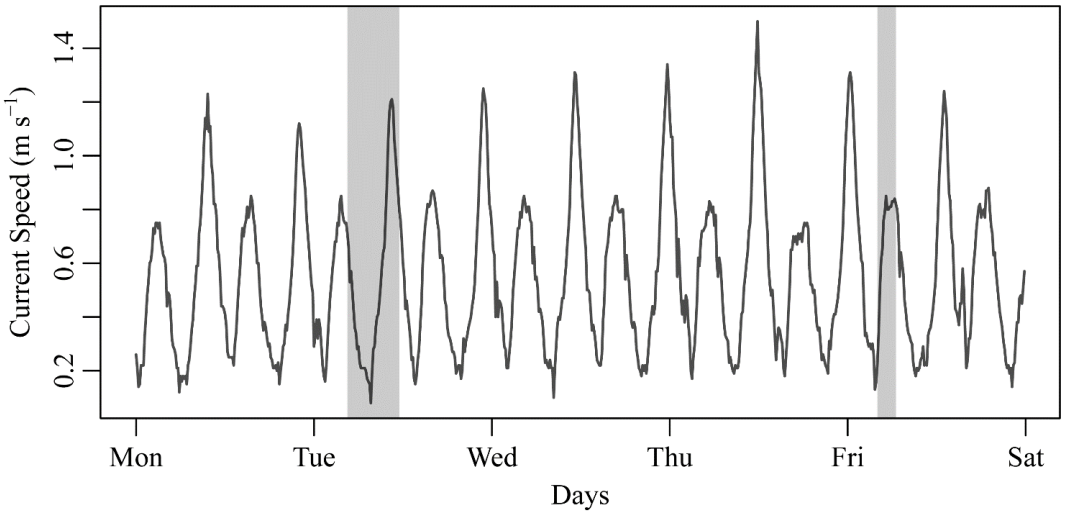


Figure S3: Water current speeds during the week of bottom trawl measurements. The shaded region on the left indicates the time of pulse trawling while the shaded region on the right indicates the time of beam trawling. This data was obtained from the "Scheur Wielingen" measuring station located in the Vlakte van de Raan.

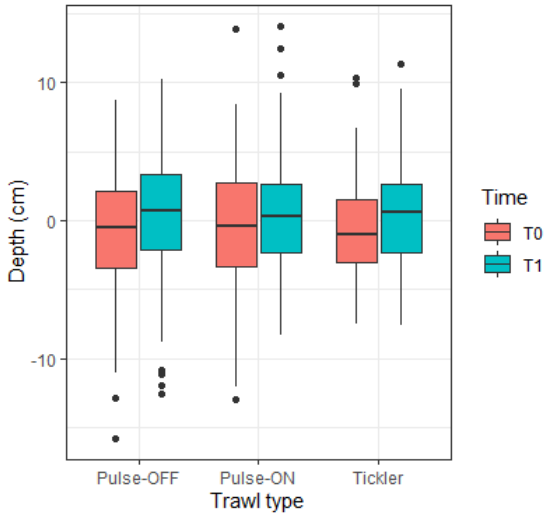


Figure S4: Bathymetrical changes. Delta-values give the differences in water depth outside and inside the location of the track before (T0) and after (T1) trawling

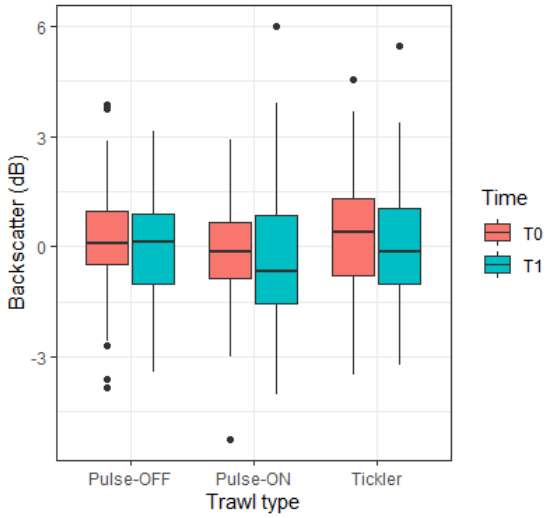


Fig S5: Changes in backscatter. Delta-values give the differences in backscatter outside and inside the location of the track before (T0) and after (T1) trawling.

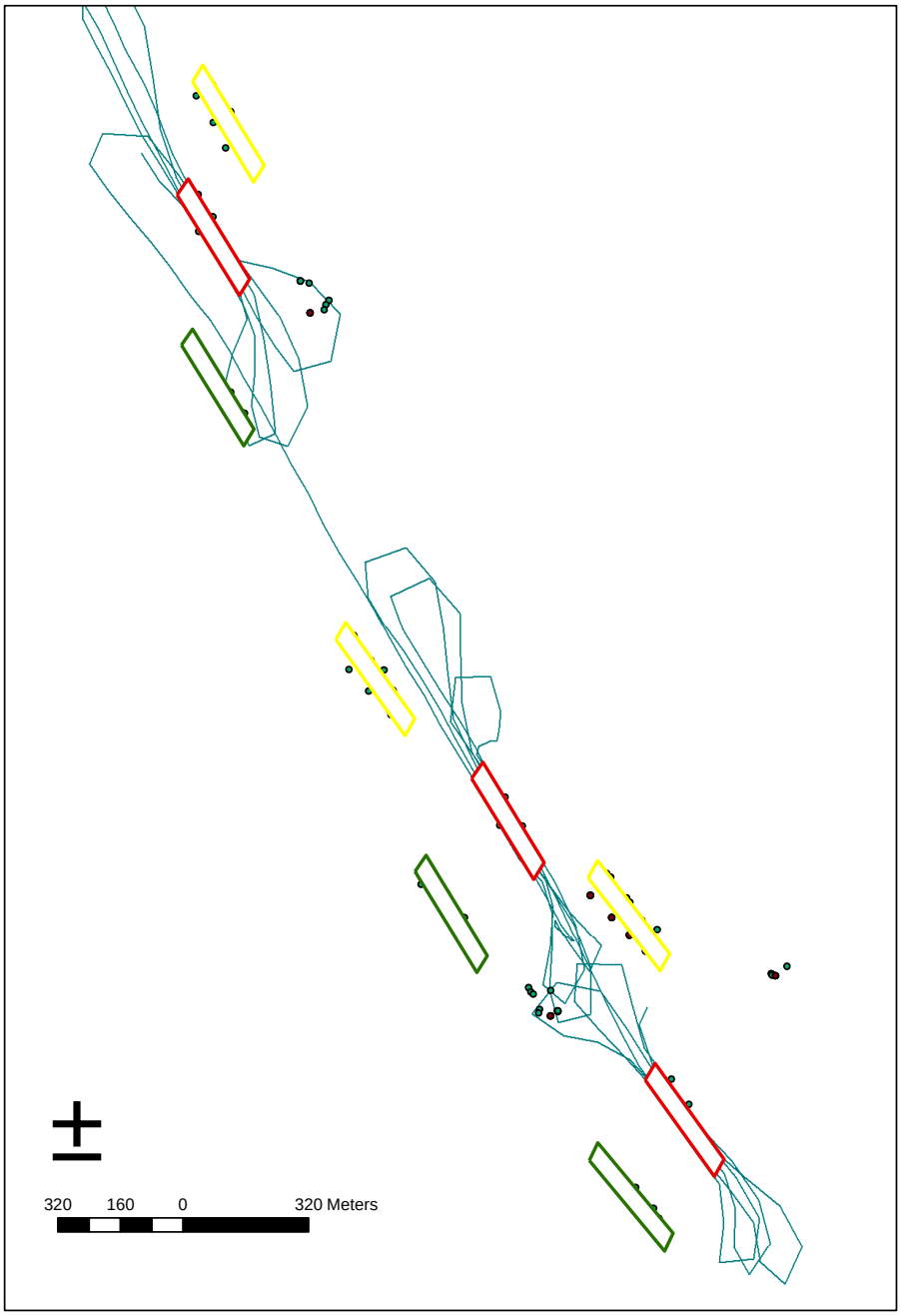


Figure S6: Beam trawl fishing paths through "tickler" treatment plots. Dots are SPI and box core sample locations.

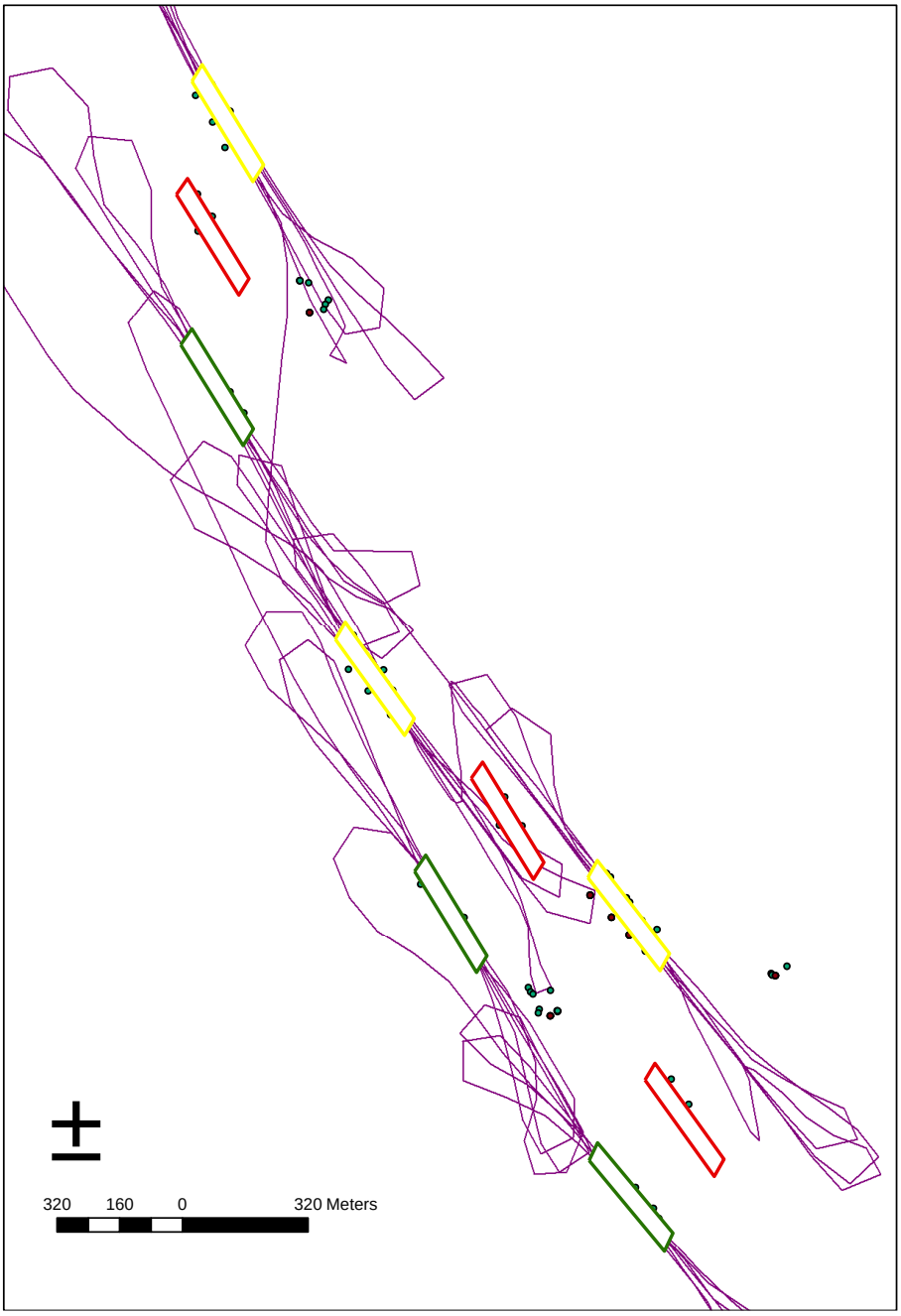


Figure S7: Pulse trawl fishing paths through "pulse on" and "pulse off" treatment plots. Dots are SPI and box core sample locations.

S.2 Supplementary Tables

Table S1. Backscatter changes following the one trawl pass (dB).

Treatment	Time	mean	sd	Q25	median	Q75	Q025	Q975	CI95	n
Pulse-OFF	T1-T0	-0.23	1.87	-0.30	-1.39	0.92	-3.49	3.31	6.81	88
Pulse-ON	T1-T0	-0.20	2.25	-0.47	-1.62	0.98	-4.00	4.58	8.58	74
Tickler	T1-T0	-0.30	2.09	-0.38	-1.70	1.31	-4.54	3.24	7.78	89

Table S2: Comparison of backscatter statistics (dB) of the entire plot for each treatment (6 trawl passes)

Treatment	Time	mean	sd	Q25	median	Q75	Q025	Q975	CI95	n
Pulse-OFF	T0	-26.57	2.51	-28.43	-26.54	-24.65	-31.26	-21.50	9.76	156016
Pulse-OFF	T1	-26.64	2.20	-28.12	-26.54	-24.97	-30.95	-22.45	8.50	162561
Pulse-ON	T0	-25.74	2.30	-27.17	-25.60	-24.34	-30.32	-21.19	9.13	129962
Pulse-ON	T1	-25.83	2.22	-27.17	-25.91	-24.34	-30.32	-21.50	8.82	162605
Tickler	T0	-25.66	2.18	-27.17	-25.60	-24.34	-30.00	-21.19	8.81	147976
Tickler	T1	-25.40	2.12	-26.86	-25.44	-24.02	-29.53	-21.19	8.34	162578

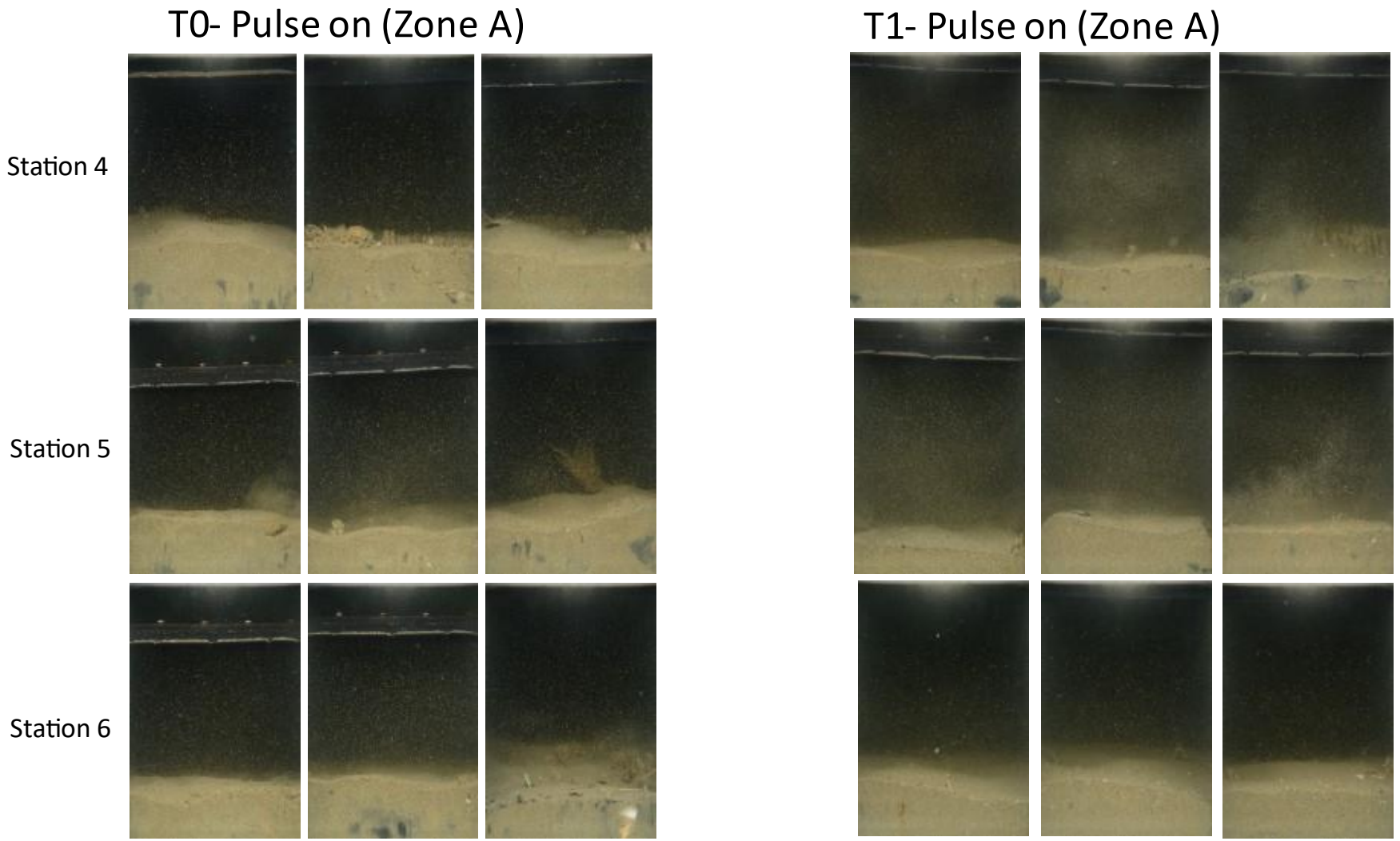
Table S3: Measured oxygen, ammonium, nitrite, nitrate, phosphate, and silica fluxes.

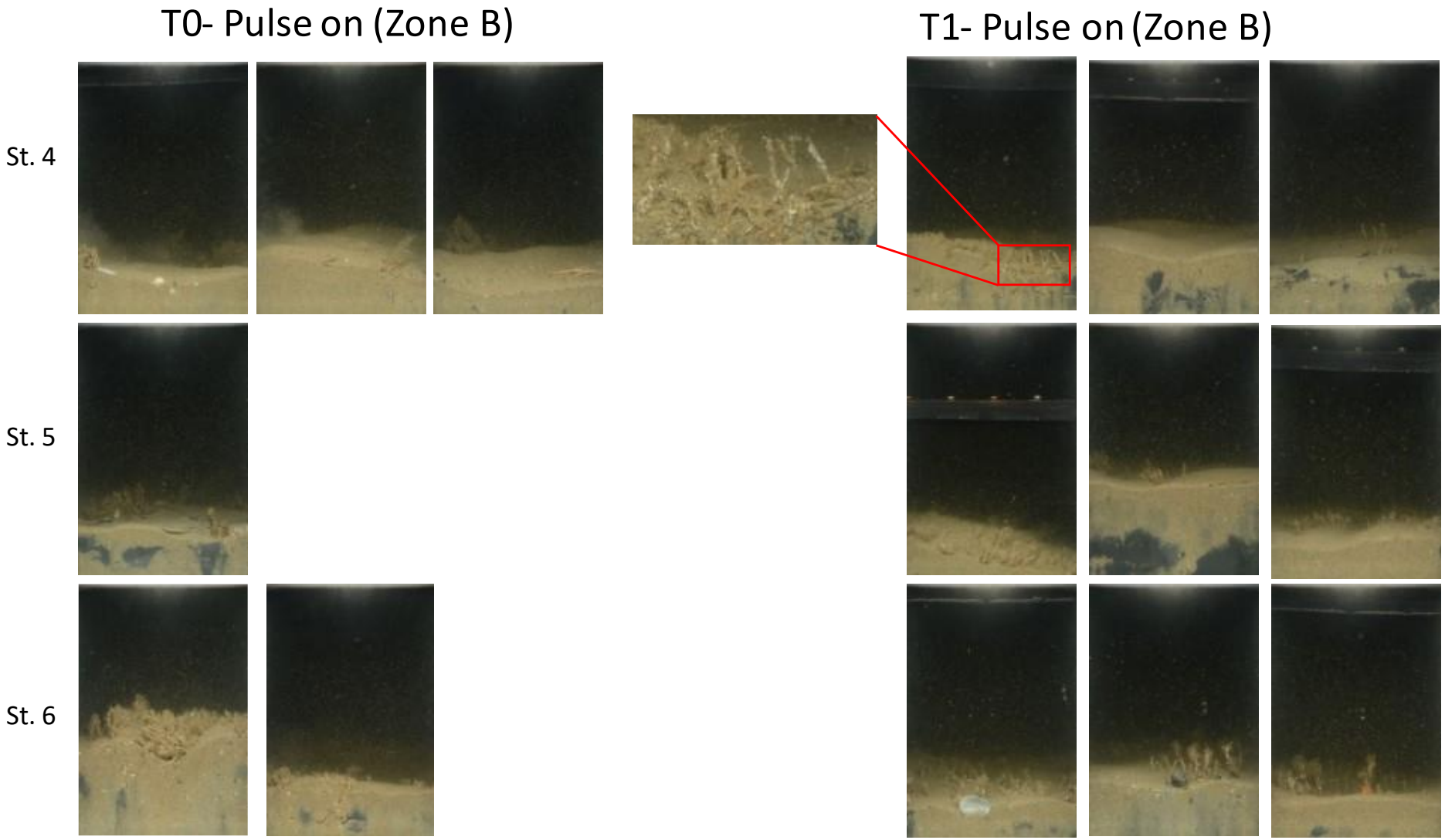
Date	Treatment	Timestep	Station	O_2	NH_4^+	NO_2^-	NO_3^-	PO_4^{3-}	$Si(OH)_4$
11/06/2018	Pulse-On	T0	A1	54.4	1.322388	-0.00176	-0.0409	0.003019	1.502305
11/06/2018	Pulse-On	T0	A2	92.7	0.139169	0.001392	-0.00321	0.014998	0.657903
11/06/2018	Pulse-On	T0	A3	108.2	0.554142	0.004476	0.012188	-0.00351	1.124502
11/06/2018	Pulse-On	T0	B1	56.5	0.651116	0.016224	0.009448	0.027477	1.142998
11/06/2018	Pulse-On	T0	B2	19.6	-0.04049	-0.00114	-0.01082	-0.00682	0.065741
11/06/2018	Pulse-On	T0	B3	663	6.594582	0.0005	-0.01643	0.082861	1.679338
11/06/2018	Pulse-On	T0	C1	36.2	0.074603	0.001244	0.006951	-0.00196	0.058721
11/06/2018	Pulse-On	T0	C2	109.7	0.661143	0.010191	0.045088	0.007934	0.394313
11/06/2018	Pulse-On	T0	C3	158.5	0.207107	-0.0024	0.007238	0.013541	0.13535
11/06/2018	Pulse-Off	T0	D1	53.6	0.145824	0.006729	0.011901	0.011653	0.427993
11/06/2018	Pulse-Off	T0	D2	26.1	0.039232	0.003662	0.007277	-0.01057	0.239532
11/06/2018	Pulse-Off	T0	D3	121.6	1.974257	0.006894	0.003297	0.151651	2.990156
11/06/2018	Pulse-Off	T0	E1	52.5	0.117448	0.007425	0.043257	0.003275	0.645689
11/06/2018	Pulse-Off	T0	E2	82.9	1.413247	0.014597	0.009125	0.152576	2.671718
11/06/2018	Pulse-Off	T0	E3	36.3	-0.0248	-0.00071	-0.00229	-0.00331	-0.08571
11/06/2018	Pulse-Off	T0	F1	89.5	0.554718	0.005072	0.014719	0.03939	1.76666
11/06/2018	Pulse-Off	T0	F2	61.7	1.4835	0.009861	-0.01858	0.155192	2.880961
11/06/2018	Pulse-Off	T0	F3	123.5	0.027173	-0.00599	-0.02072	-0.01243	0.635104
11/06/2018	Reference	T0	R1	227.9	1.356657	-0.00216	-0.04145	0.092367	2.031453
11/06/2018	Reference	T0	R1	242.4	0.198848	0.003306	0.016845	0.003147	0.073745
11/06/2018	Reference	T0	R1	158.7	1.352932	0.005423	0.000918	0.021089	0.910114
11/06/2018	Reference	T0	R2	29.4	0.018708	0.000313	-0.00115	0.000365	0.059177
11/06/2018	Reference	T0	R2	21.8	0.409393	0.020398	0.046459	0.015765	0.382709
11/06/2018	Reference	T0	R2	20.1	2.709438	0.004735	-0.00474	0.073882	1.902726
12/06/2018	Pulse-On	T1	A1	54.4	0.401073	0.008325	0.060662	0.002504	0.266571
12/06/2018	Pulse-On	T1	A2	92.7	0.368087	0.008797	0.028548	0.00364	0.412278
12/06/2018	Pulse-On	T1	A3	108.2	0.318517	0.007501	0.023093	-0.00099	0.110648
12/06/2018	Pulse-On	T1	B1	56.5	0.433973	0.004578	0.008824	0.020407	0.591104
12/06/2018	Pulse-On	T1	B2	19.6	1.164796	0.021633	0.019524	0.051963	1.762159
12/06/2018	Pulse-On	T1	B3	663	1.030631	0.008603	0.001468	0.060702	1.40335
12/06/2018	Pulse-On	T1	C1	36.2	0.53565	0.003046	-0.00056	0.038779	1.389946
12/06/2018	Pulse-On	T1	C2	109.7	0.364438	0.005378	0.002388	0.02944	1.417099
12/06/2018	Pulse-On	T1	C3	158.5	0.990005	0.007246	0.004845	0.100381	2.948018
12/06/2018	Pulse-Off	T1	D1	53.6	0.347067	0.004927	0.02797	0.016836	0.820396
12/06/2018	Pulse-Off	T1	D2	26.1	0.341626	0.004265	0.017061	0.026806	0.851807
12/06/2018	Pulse-Off	T1	D3	121.6	0.813778	0.003384	0.001971	0.089322	2.161753
12/06/2018	Pulse-Off	T1	E1	52.5	0.04315	0.001467	0.005843	-0.00113	0.290841
12/06/2018	Pulse-Off	T1	E2	82.9	0.412115	0.003069	0.004529	0.012271	1.135535
12/06/2018	Pulse-Off	T1	E3	36.3	0.657204	0.00629	0.009182	0.032395	1.544447
12/06/2018	Pulse-Off	T1	F1	89.5	1.046453	0.00542	0.00077	0.048544	1.891009
12/06/2018	Pulse-Off	T1	F2	61.7	0.720555	0.006962	0.007132	0.048845	1.579185
12/06/2018	Pulse-Off	T1	F3	123.5	0.061219	0.001797	0.009545	0.001773	0.125198
13/06/2018	Tickler	T0	G1	68.1	3.10201	0.001239	-0.00419	0.075648	2.761714
13/06/2018	Tickler	T0	G2	130.3	1.226622	0.008836	0.008674	0.072835	2.600195
13/06/2018	Tickler	T0	G3	177.9	0.346581	0.006869	0.018325	0.041912	0.629552
13/06/2018	Tickler	T0	H1	163.2	0.598775	0.010125	0.018844	0.014623	0.454567
13/06/2018	Tickler	T0	H2	140.9	1.257456	0.012701	0.009853	0.027586	1.116014
13/06/2018	Tickler	T0	H3	37.3	3.969271	0.00173	-0.00966	0.044787	1.296227
13/06/2018	Tickler	T0	I1	401.6	0.421139	0.006043	0.018276	0.018149	0.487222
13/06/2018	Tickler	T0	I2	276.5	0.879971	0.011333	0.026086	0.022693	0.778676
13/06/2018	Tickler	T0	I3	156	0.042697	0.004479	0.031369	-5.73e-5	0.08793
15/06/2018	Reference	T1	R1	277.5	1.059007	0.002852	-0.00146	0.100852	3.10101
15/06/2018	Reference	T1	R1	78.2	1.025824	0.003821	-0.00166	0.034782	1.319231
15/06/2018	Reference	T1	R1	446.6	1.429481	0.003745	-0.0103	0.061587	2.860022
15/06/2018	Reference	T1	R2	509.8	3.894601	0.000914	-0.08742	0.079029	2.223317
15/06/2018	Reference	T1	R2	170.2	2.754912	0.012857	-0.02417	0.065224	2.928119
15/06/2018	Reference	T1	R2	33.6	1.288843	0.002213	-0.02521	0.09283	2.024736

Table S3: continued

Date	Treatment	Timestep	Station	O_2	NH_4^+	NO_2^-	NO_3^-	PO_4^{3-}	$Si(OH)_4$
15/06/2018	Tickler	T1	G1	25.9	1.003889	0.012436	0.012926	0.039268	1.583109
15/06/2018	Tickler	T1	G1	25.9	1.003889	0.012436	0.012926	0.039268	1.583109
15/06/2018	Tickler	T1	G2	39.4	0.45367	0.00752	0.007548	0.030028	1.890808
15/06/2018	Tickler	T1	G3	79.8	5.116459	-0.00176	-0.00496	0.038251	2.709731
15/06/2018	Tickler	T1	H1	57.3	3.42085	-0.00361	-0.01438	0.041352	1.666184
15/06/2018	Tickler	T1	H2	103	0.851656	0.008007	0.013321	0.040908	1.083441
15/06/2018	Tickler	T1	H3	21.8	0.126347	0.004572	0.022827	0.004196	0.353571
15/06/2018	Tickler	T1	I1	94.9	1.172677	0.011192	0.010794	0.08578	1.956128
15/06/2018	Tickler	T1	I2	128.8	1.007132	0.008981	0.005344	0.036075	1.755739
15/06/2018	Tickler	T1	I3	120	1.351362	0.008622	0.005089	0.068485	2.84407

S.4. Sediment Profile Images




T0- Pulse on (Zone B)
T1- Pulse on (Zone B)
St. 4
St. 5
St. 6

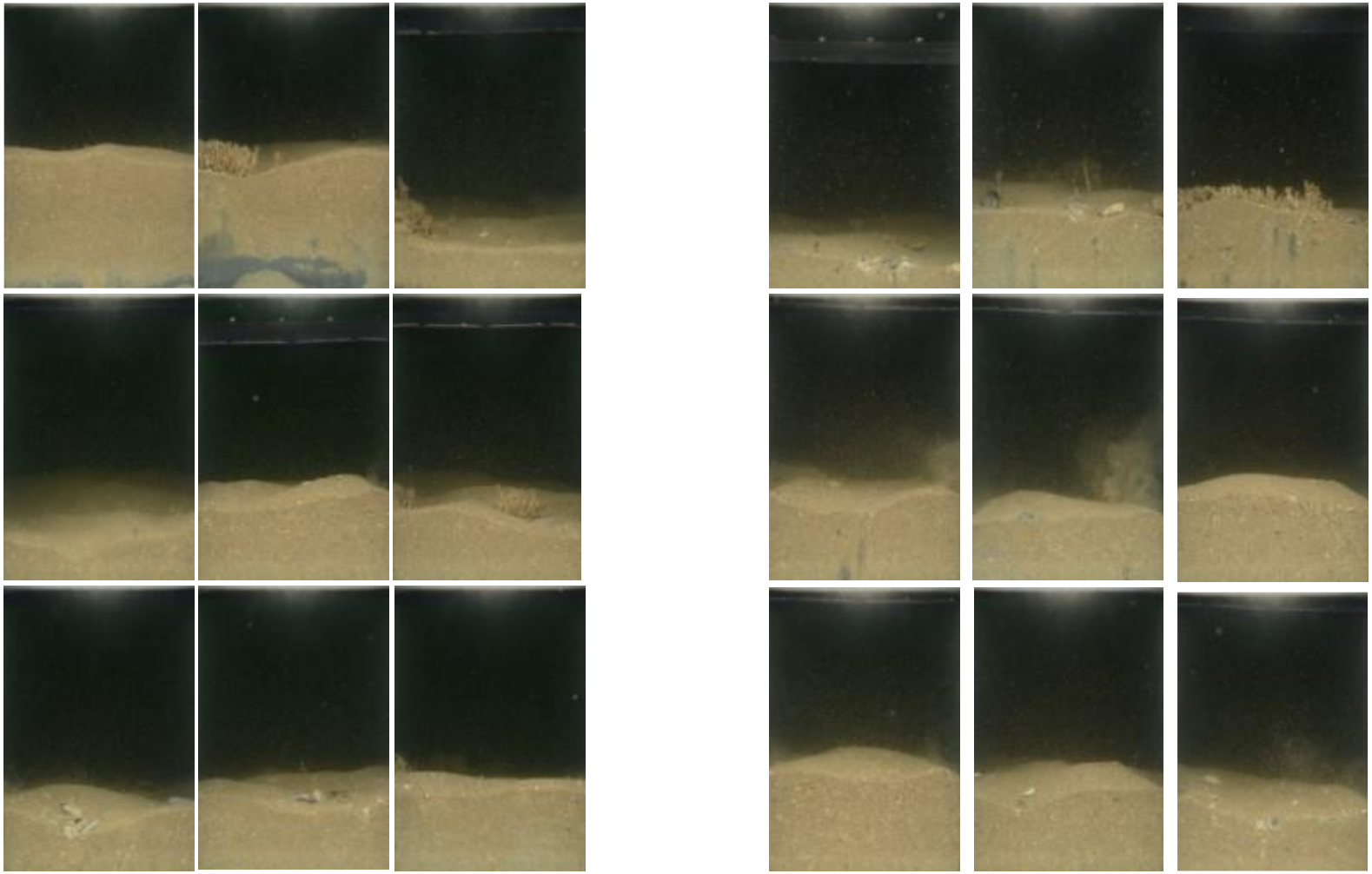
T0- Pulse on (Zone C)

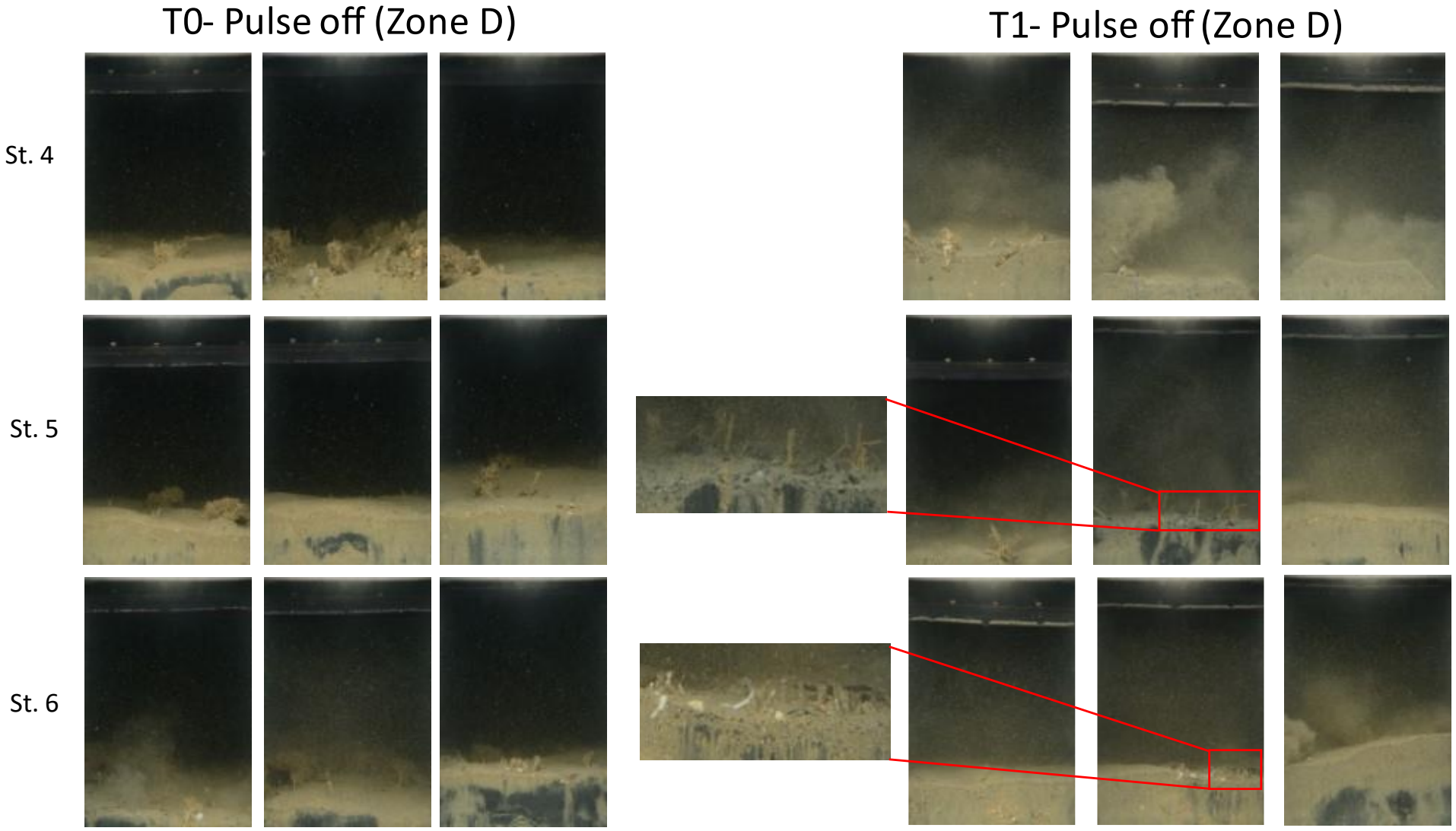
T1- Pulse on (Zone C)

St.4

St. 5

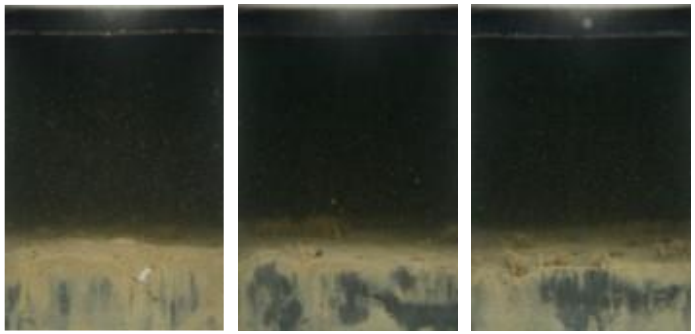
St. 6



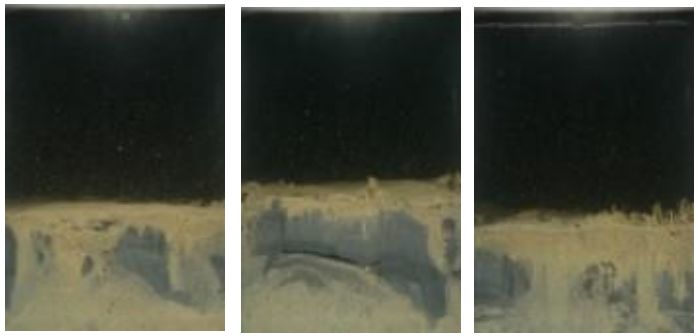

T0- Pulse off (Zone D)
T1- Pulse off (Zone D)
St. 4
St. 5
St. 6

T0- Pulse off (Zone E)

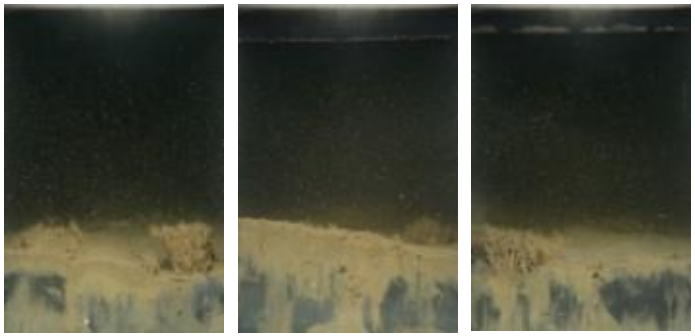
St. 4



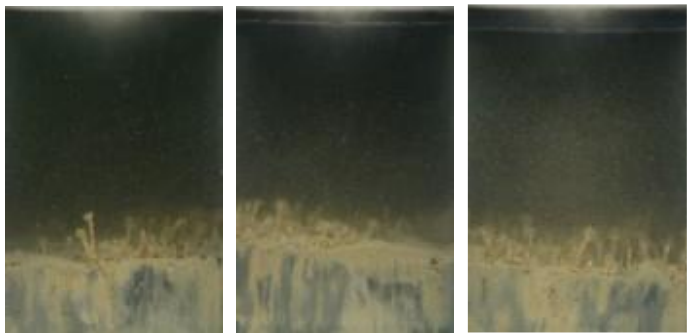
St. 5



St. 6



T1- Pulse off (Zone E)



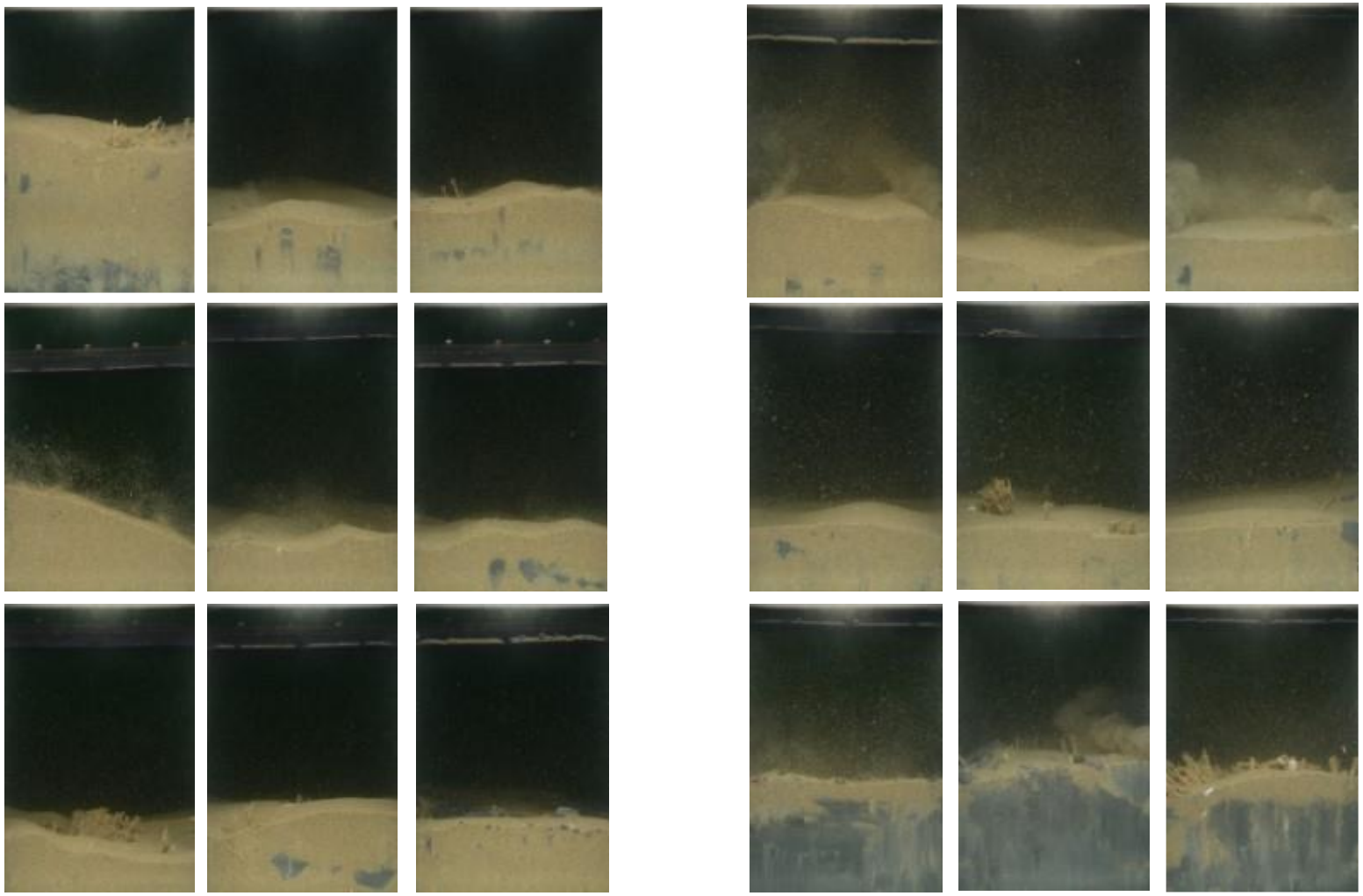
T0- Pulse off (Zone F)

T1- Pulse off (Zone F)

St. 4

St. 5

St. 6



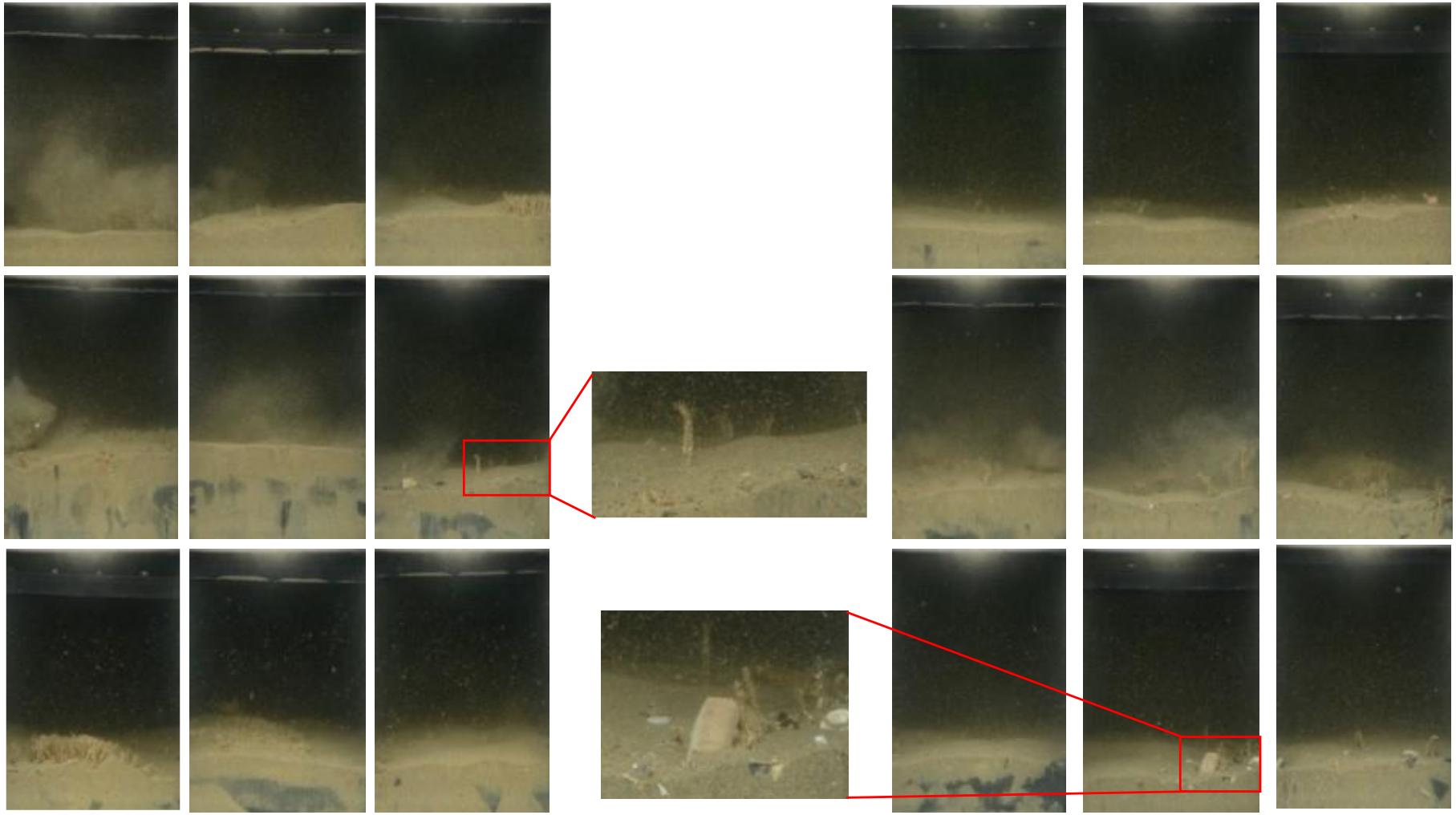
T0- Tickler Chain (Zone G)

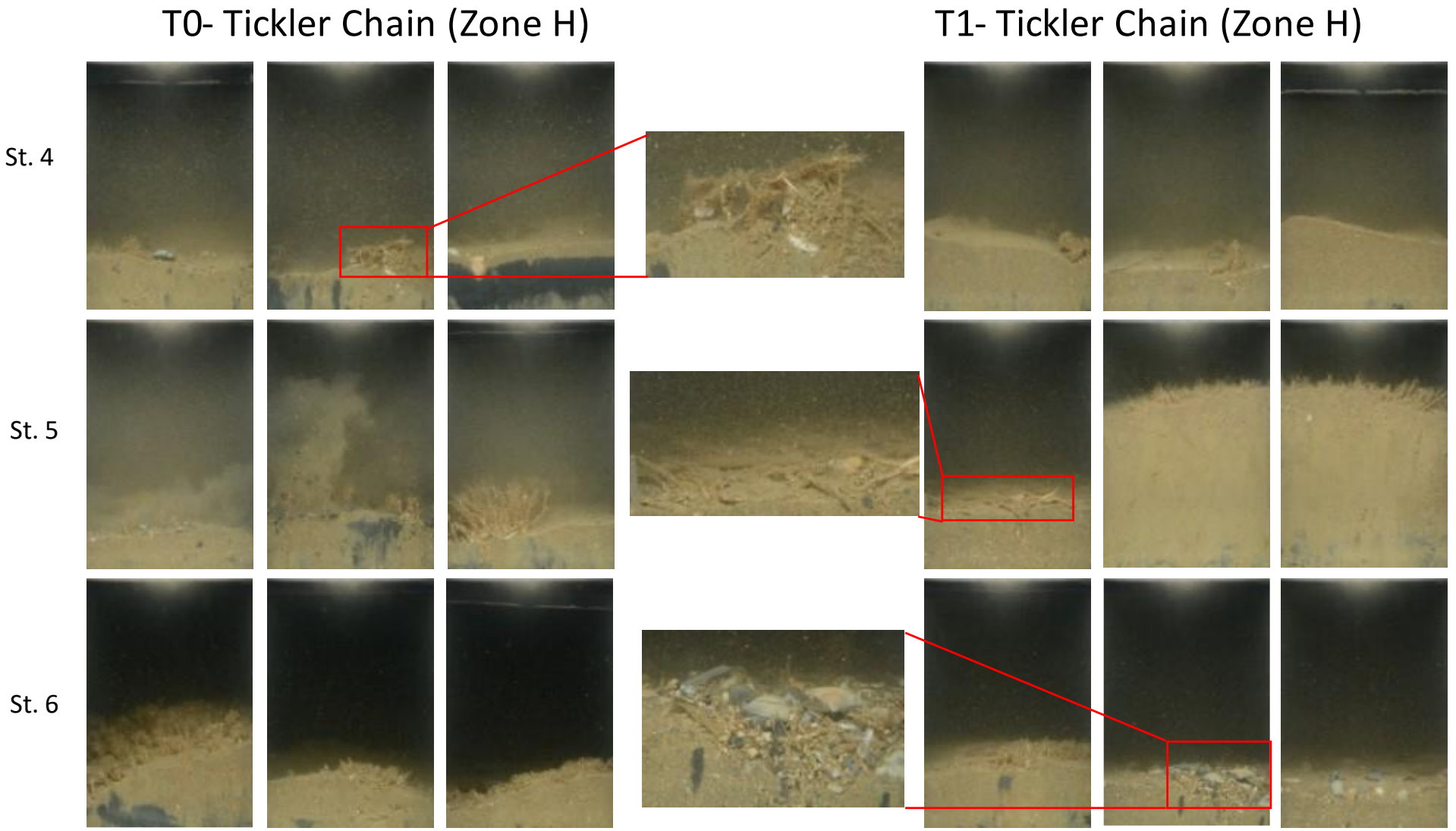
T1- Tickler Chain (Zone G)

St. 4

St. 5

St. 6




T0- Tickler Chain (Zone H)
T1- Tickler Chain (Zone H)
St. 4
St. 5
St. 6

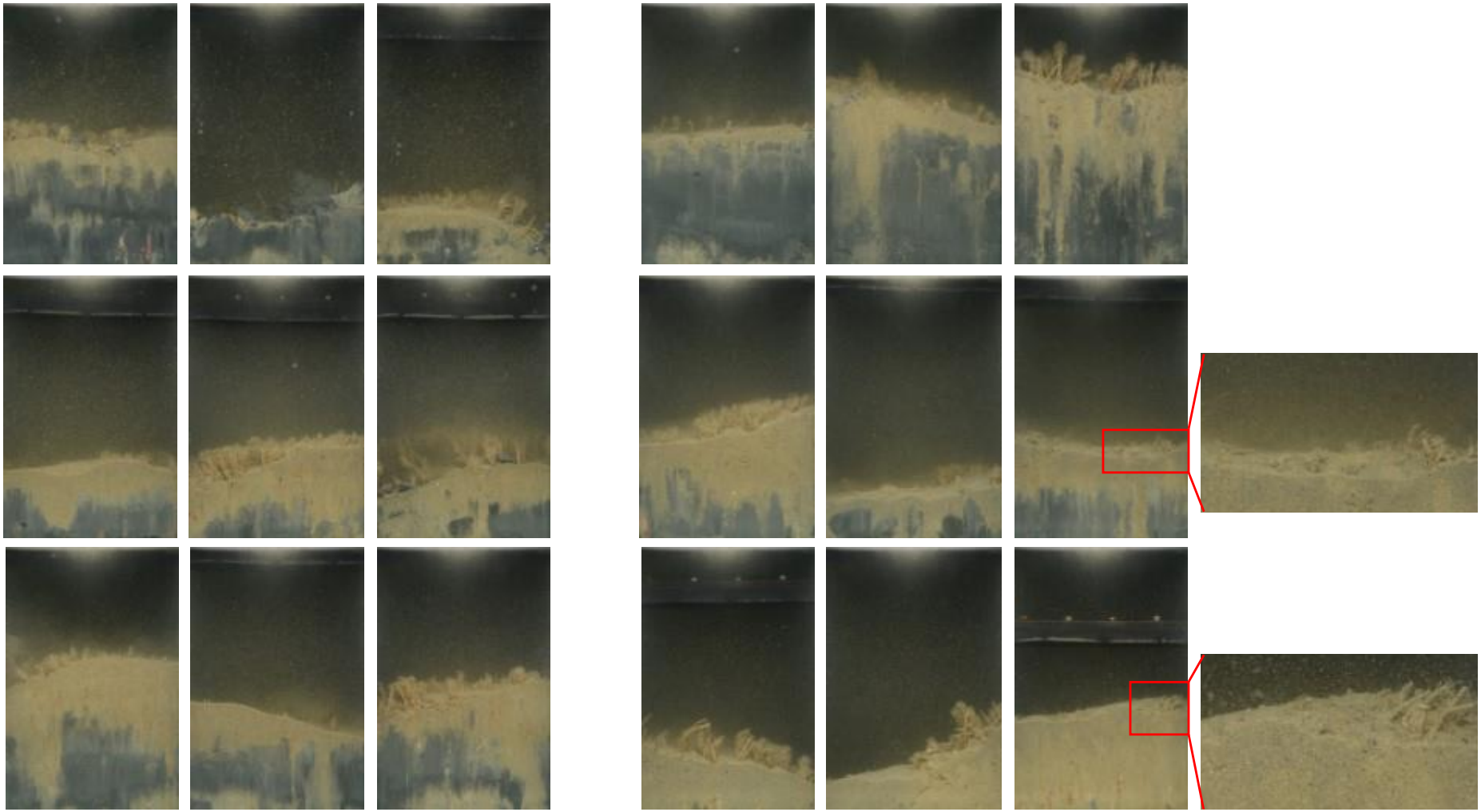
T0- Tickler Chain (Zone I)

T1- Tickler Chain (Zone I)

St. 4

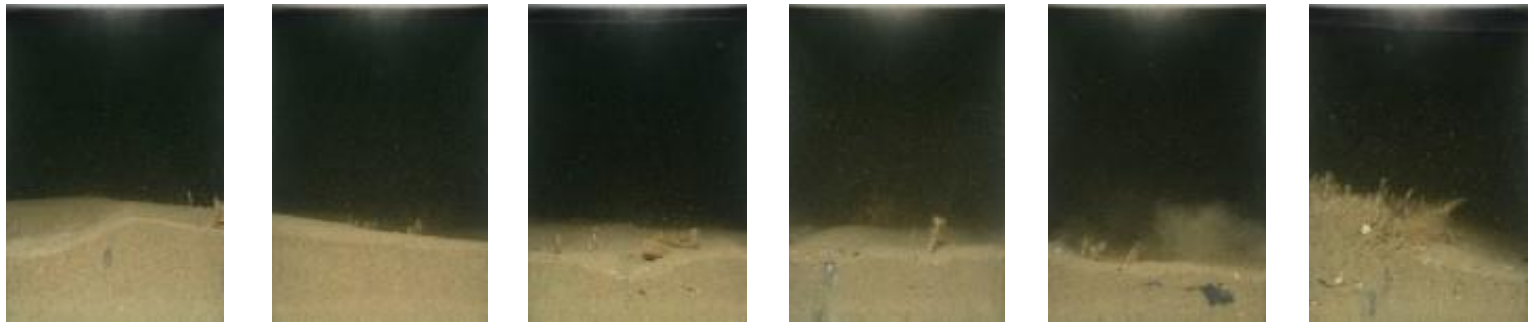
St. 5

St. 6

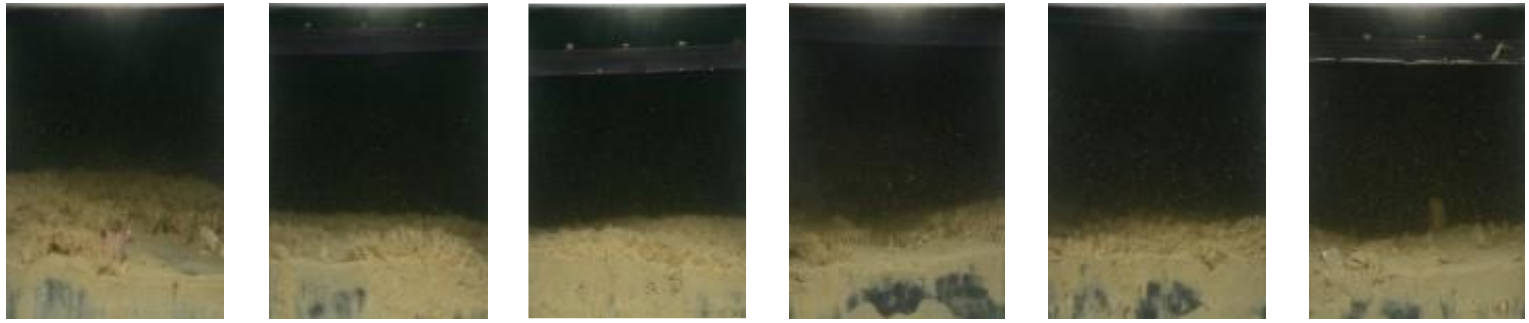


Reference

Reference T0



Reference T1



S.5. Mass budget modeling methodology

Sediment-water exchange fluxes of O_2, NH_4^+, NO_2^-, NO_3^-, and PO_4^{3-} calculated from the core incubations were used to estimate rates for total mineralization of organic matter, denitrification, nitrification and the specific mineralization and sequestration of nitrogen and phosphorous from the sediment. These fluxes were used to obtain integrated mass budget of these solutes within the sediment column following the methods in (Braeckman et al., 2010; Soetaert et al., 2001; Toussaint et al., 2021). Oxygen is consumed (Eq. 1) directly through oxic mineralization (*OxicMin*) and nitrification (2 moles O_2 consumed per 1 mole NO_3^- produced), and indirectly through anoxic mineralization (*AnoxicMin*), which produces reduced substances that are re-oxidized (*Reoxidation*) as they diffuse towards the sediment-water interface (Soetaert et al., 1996). Ammonium is produced through the mineralization of organic nitrogen (*Nmineralization*), which is derived from the total mineralization (*OxicMin* + *AnoxicMin* + *Denitrification*) multiplied by the Redfield N:C ratio (16:106), and removed through nitrification (Eq. 2). The mass balance of nitrate receives its input from nitrification and is removed through denitrification (0.8 moles NO_3^- removed per mole of carbon mineralized; Eq. 3). Inorganic phosphorus enters the system through the degradation of organic phosphorus (*Pmineralization*), which is calculated by multiplying the Redfield P:C ratio (1:106) with the total mineralization, and is removed through adsorption to solid particles (*Premoval*; Eq. 4). The mass balance equations describing these processes are summarized below:

$$\frac{dO_2}{dt} = O_2flux - OxicMin - Reoxidation - 2 * Nitrification \quad \text{(Eq. 1)}$$

$$\frac{dNH_x}{dt} = NH_xflux + Nmineralization - Nitrification \quad \text{(Eq. 2)}$$

$$\frac{dNO_x}{dt} = NO_xflux + Nitrification - 0.8 * Denitrification \quad \text{(Eq. 3)}$$

$$\frac{dPO_4^{3-}}{dt} = PO_4^{3-}flux - Pmineralization - Premoval \quad \text{(Eq. 4)}$$

The rates of sediment water exchange fluxes (O_2flux, NH_xflux, NO_xflux, PO_4^{3-}flux) were obtained from the sediment incubations. The assumption of a geochemical steady-state causes the rate of change for the selected solutes (left side of equations 1 – 4) to be set to zero. Quantities for total OM mineralization, denitrification, nitrification, and *Premoval* were determined using the R package 'limSolve' for linear inverse models using the function 'lsei' (Least Squares with Equality and Inequality Constraints; (Soetaert et al., 2009)). *Nremoval* was estimated as the 0.8 proportion of denitrification while the percent of total nitrogen and phosphorous removed after mineralization was calculated as 100 * Nremoval/Nmineralization (%N sequestered) and 100 * Premoval/Pmineralization (%P sequestered).