

Supplementary Information

Green tide development associated with submarine groundwater discharge in a coastal harbor, Jeju, Korea

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Table S1. The concentrations of salinity, ^{222}Rn , and nutrients in fresh groundwater, saline groundwater, harbor seawater, and open-ocean seawater in July 2015 in Jocheon, Jeju Island (S = surface, B = bottom and n.d. = non detect). Uncertainties of ^{222}Rn activities are based on 1σ counting error propagations.

Sample		Salinity	^{222}Rn	Nutrients (μM)		N:P ratio
			(Bq m^{-3})	DIN	DIP	
Fresh groundwater	F7	2.2	5920±60	400	2.2	182
	F8	4.6	-	390	2.3	170
	F9	0.3	4920±70	460	2.3	200
Saline groundwater	S2	31.5	-	12	0.32	37
	S6	31.5	-	7.7	0.35	22
	S9	24.8	-	99	0.80	124
	S10	25.4	-	83	0.71	117
Harbor seawater	H2 (S)	29.8	250±10	43	0.27	158
	H2 (B)	32.1	98±7	10	0.02	505
	H3 (S)	27.8	740±20	70	0.38	184
	H3 (B)	32.0	89±7	13	0.07	180
	H9 (S)	23.8	590±30	112	0.22	509
	H16 (S)	30.5	230±20	39	0.22	175
	H17 (S)	29.8	100±11	73	0.43	170
	H17 (B)	32.7	71±7	4.8	0.02	240
	H19 (S)	25.8	270±10	81	0.08	1013
	H21 (S)	32.3	44±9	4.5	n.d.	-
	H21 (B)	32.7	20±3	4.5	0.09	50
	H22 (S)	31.7	-	11	n.d.	-
	H23 (S)	28.4	370±20	67	0.39	172
	H23 (B)	32.4	12±3	4.2	n.d.	-
	H24 (S)	31.7	200±10	40	0.23	173
	H24 (B)	32.3	23±7	4.8	n.d.	-
	H27 (S)	29.6	140±10	55	0.35	157
	H27 (B)	32.4	110±10	6.1	0.09	68
H28 (S)	29.9	180±10	72	0.44	164	
H28 (B)	32.4	43±4	6.2	0.05	124	
Open-ocean seawater	O1 (S)	32.4	23±4	n.d.	n.d.	-
	O1 (B)	32.6	16±6	0.88	n.d.	-

Table S2. The concentrations of salinity, ^{222}Rn , and nutrients in fresh groundwater, saline groundwater, harbor seawater, and open-ocean seawater in August 2015 in Jocheon, Jeju Island (S = surface, B = bottom and n.d. = not detected). Uncertainties of ^{222}Rn activities are based on 1σ counting error propagations.

Sample	Salinity	^{222}Rn	Nutrients (μM)		N:P ratio	
		(Bq m^{-3})	DIN	DIP		
Fresh groundwater	F1	1.6	2490 \pm 40	490	2.4	204
	F2	0.2	1550 \pm 30	580	2.8	207
	F3	0.2	2060 \pm 40	490	4.3	114
	F4	2.6	3510 \pm 60	380	2.4	158
	F9	0.2	8270 \pm 190	510	2.2	232
	F10	0.4	-	650	2.5	260
Saline groundwater	S2	15.0	1070 \pm 20	225	3.5	64
	S3	31.6	85 \pm 17	32	1.7	19
	S4	32.5	69 \pm 5	5.1	0.43	12
	S5	32.7	84 \pm 15	9.0	0.48	19
	S6	33.0	130 \pm 10	4.4	0.33	13
	S7	32.7	30 \pm 58	12	0.60	19
	S11	27.8	740 \pm 40	56	n.d.	-
	S12	30.6	130 \pm 10	18	0.07	250
	S13	31.4	150 \pm 20	16	0.06	262
Harbor seawater	H1 (S)	31.7	60 \pm 5	9.8	n.d.	-
	H2 (S)	31.9	60 \pm 5	7.9	n.d.	-
	H5 (S)	28.6	81 \pm 5	42	0.08	521
	H6 (S)	28.4	240 \pm 10	49	0.08	618
	H7 (S)	27.9	200 \pm 10	88	0.26	338
	H8 (S)	30.5	140 \pm 10	55	0.07	786
	H10 (S)	25.2	120 \pm 10	41	n.d.	-
	H11 (S)	28.4	160 \pm 10	23	0.04	575
	H12 (S)	29.2	130 \pm 10	13	n.d.	-
	H13 (S)	31.3	100 \pm 10	18	n.d.	-
	H14 (S)	28.7	290 \pm 10	55	0.09	611
	H15 (S)	28.4	190 \pm 10	51	0.09	567
	H16 (S)	29.0	210 \pm 10	37	0.05	738
	H18 (S)	31.9	26 \pm 7	17	n.d.	-
	H20 (S)	32.1	25 \pm 10	6.5	n.d.	-
	H21 (S)	32.0	16 \pm 3	2.5	n.d.	-
	H22 (S)	32.1	10 \pm 3	2.9	n.d.	-
	H23 (S)	32.1	13 \pm 5	2.4	n.d.	-
	H24 (S)	32.2	26 \pm 6	2.2	n.d.	-
	H25 (S)	31.6	40 \pm 5	7.7	n.d.	-
H26 (S)	32.3	24 \pm 3	0.9	n.d.	-	
H28 (S)	30.3	68 \pm 5	15	n.d.	-	
Open-ocean seawater	O1 (S)	32.5	4 \pm 2	0.8	n.d.	-

Table S3. The concentrations of salinity, ^{222}Rn , and nutrients in fresh groundwater, saline groundwater, harbor seawater, and open-ocean seawater in February 2016 in Jocheon, Jeju Island (S = surface, B = bottom and n.d. = not detected). Uncertainties of ^{222}Rn activities are based on 1σ counting error propagations.

Sample	Salinity	^{222}Rn	Nutrients (μM)		N:P ratio	
		(Bq m^{-3})	DIN	DIP		
Fresh groundwater	F1	0.8	1700±30	400	2.9	138
	F2	0.7	1400±40	430	3.0	143
	F3	0.3	1910±30	440	4.0	110
	F4	0.9	5720±90	400	2.3	182
	F5	1.0	6310±80	480	2.0	240
	F6	0.2	6100±70	440	2.3	191
	F7	1.0	5690±60	460	2.0	230
	F8	0.4	3860±40	490	2.2	223
	F9	1.4	3540±40	490	1.9	258
Saline groundwater	S1	34.1	-	9.2	0.47	20
	S2	34.0	-	13	0.73	18
	S3	33.8	-	11	0.53	21
	S8	33.8	-	11	0.36	32
	S11	34.1	-	10	0.46	22
	S13	34.4	-	6.5	0.48	13
	S14	34.2	-	10	0.48	21
Harbor seawater	H2 (S)	32.9	100±10	19	0.34	54
	H2 (B)	34.1	13±3	6.9	0.36	19
	H3 (S)	33.2	6±4	8.1	0.37	22
	H3 (B)	34.4	13±5	7.5	0.37	20
	H5 (S)	31.8	120±10	32	0.36	89
	H5 (B)	34.0	100±10	27	0.40	68
	H6 (S)	31.4	160±10	44	0.34	129
	H6 (B)	31.7	140±10	27	0.41	67
	H8 (S)	31.0	260±10	41	0.34	121
	H8 (B)	32.9	106±9	23	0.41	57
	H10 (S)	33.4	28±4	11	0.34	31
	H10 (B)	34.4	31±5	6.7	0.30	22
	H14 (S)	34.1	40±5	5.9	0.34	17
	H14 (B)	34.3	44±6	11	0.40	28
	H16 (S)	34.0	110±10	25	0.36	70
	H16 (B)	34.4	5±3	7.1	0.36	20
	H21 (S)	34.0	20±5	7.3	0.39	19
	H21 (B)	34.5	8±4	6.4	0.34	19
H24 (S)	34.3	6±3	8.6	0.38	23	
H24 (B)	34.5	12±4	7.2	0.35	21	
Open-ocean seawater	O2 (S)	34.6	4±3	6.0	0.39	15
	O3 (S)	34.6	21±4	5.1	0.38	13
	O4 (S)	34.5	24±5	5.1	0.41	12

Table S4. The concentrations of salinity, ^{222}Rn , and nutrients in fresh groundwater, harbor seawater, and open-ocean seawater in March 2016 in Jocheon, Jeju Island (S = surface, B = bottom and n.d. = not detected). Uncertainties of ^{222}Rn activities are based on 1σ counting error propagations.

Sample	Salinity	^{222}Rn	Nutrients (μM)		N:P ratio	
		(Bq m^{-3})	DIN	DIP		
Fresh groundwater	F1	0.2	2780±50	410	2.6	158
	F2	0.2	2170±40	430	2.6	165
	F3	0.2	1880±40	410	3.8	108
	F4	0.9	4840±80	390	2.8	139
	F7	0.2	4260±60	460	2.5	184
	F8	0.2	3360±50	480	2.3	209
	F9	0.2	5360±100	480	2.4	200
Harbor seawater	H2 (S)	33.2	160±10	20	0.06	337
	H2 (B)	34.6	47±8	0.8	n.d.	-
	H3 (S)	32.8	160±20	14	0.10	142
	H3 (B)	34.2	33±5	1.7	0.02	85
	H4 (S)	29.4	430±20	35	0.14	251
	H4 (B)	34.4	55±7	1.3	0.03	43
	H6 (S)	27.9	560±20	63	0.26	242
	H8 (S)	30.7	260±10	45	0.12	378
	H10 (S)	31.7	240±10	35	0.14	252
	H10 (B)	34.6	29±10	0.5	0.01	50
	H14 (S)	31.3	-	50	0.14	357
	H14 (B)	34.6	-	0.5	0.07	7
	H16 (S)	31.2	140±10	18	0.07	254
	H16 (B)	34.6	23±6	1.1	0.02	55
	H21 (S)	33.7	51±12	11	0.03	373
	H21 (B)	34.7	17±4	0.3	n.d.	-
H24 (S)	34.2	58±7	4.6	0.01	460	
H24 (B)	34.6	19±9	0.5	0.01	50	
Open-ocean seawater	O2 (S)	34.8	4±4	1.0	0.02	50
	O3 (S)	34.7	19±4	0.6	0.01	60
	O4 (S)	34.7	14±7	0.7	n.d.	-

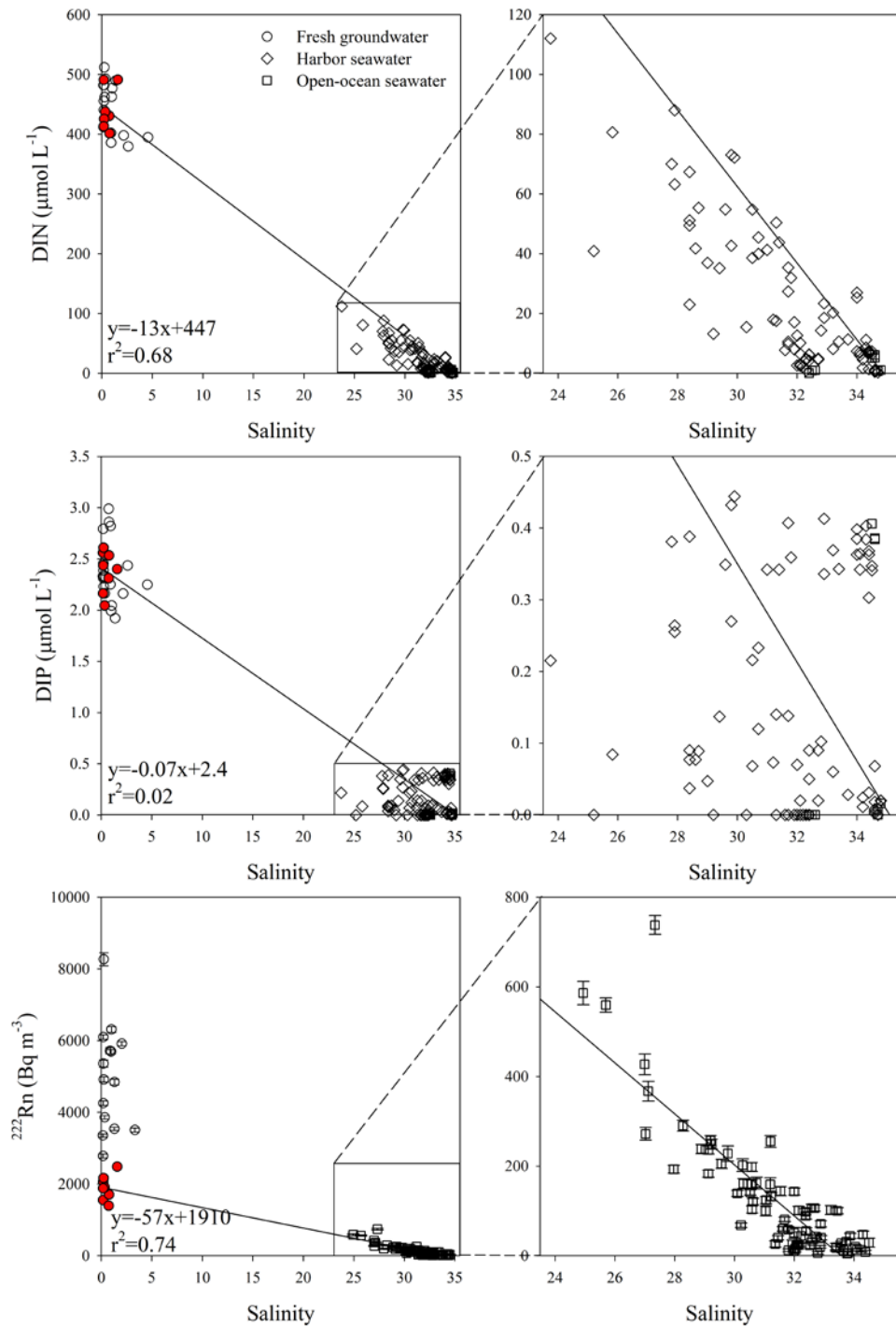


Figure S1. Plots of salinity versus DIN, DIP, and ^{222}Rn concentrations in fresh groundwater and seawater. The solid line indicates the conservative mixing between the two end-members (fresh groundwater and seawater). The red circles represent the major springs based on the ^{222}Rn extrapolation from harbor seawater.

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