



Supplement of

Factors controlling dissolved ^{137}Cs activities in Matsukawa-ura lagoon, a semi-closed estuary, after the Fukushima accident

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Table S1

Catchment mean rainfall and flux of river water discharge.

	Weather station		Catchment				Total	Groundwater	
	Hippo	Soma	Koizumi	Uda	Ume	Nikkeshi			
Catchment area (km ²)			17.8	100.6	10.7	22.6	151.6		
Land use (%)	Forest		51	85	27	62			
	Paddy field		18	5	41	22			
	Farmland		6	6	6	4			
	Urban area		22	1	20	3			
Ratio to entire catchment (%)	Koizumi river (KZ)	0	100						
	Uda river (UD)	60	40						
	Ume river (UM)	0	100						
	Nikkeshi river (NK)	0	100						
Rainfall in the 30 days prior to sample collection (mm)	Jun-21	91	74	74	84	74	74		
	Jul-21	165	197	197	177	197	197		
	Aug-21	346	321	321	336	321	321		
	Sep-21	211	195	195	204	195	195		
	Oct-21	181	177	177	179	177	177		
	Dec-21	117	64	64	96	64	64		
	Feb-22	21	12	12	17	12	12		
	Jun-22	217	235	235	224	235	235		
	Aug-22	141	99	99	124	99	99		
	Oct-22	54	97	97	71	97	97		
	Feb-23	47	28	28	39	28	28		
	Flux of river water and groundwater discharge ($\times 10^6 \text{ m}^3 \text{ 12 h}^{-1}$) ^a	Jun-21			0.011	0.073	0.0068	0.014	0.11
Jul-21				0.030	0.15	0.018	0.039	0.24	0.018
Aug-21				0.050	0.29	0.030	0.063	0.44	0.033
Sep-21				0.030	0.18	0.018	0.038	0.26	0.020
Oct-21				0.027	0.16	0.016	0.035	0.23	0.018
Dec-21				0.010	0.083	0.0059	0.013	0.11	0.0084
Feb-22				0.0019	0.015	0.0011	0.0024	0.020	0.0015
Jun-22				0.036	0.20	0.022	0.046	0.30	0.022
Aug-22				0.015	0.11	0.0092	0.019	0.15	0.011
Oct-22				0.015	0.062	0.0090	0.019	0.10	0.0078
Feb-23				0.0043	0.034	0.0026	0.0055	0.047	0.0035

^a Based on the data from Kamo et al.(2014).

Table S2Analytical results of ^{137}Cs concentration at river inflowing to Matsukawa-ura lagoon. ^{137}Cs activity concentrations were decay-corrected to the sampling date.

Station	Sampling date	Long E	Lat N	Salinity	^{137}Cs in suspended particles (Bq kg ⁻¹)	Particulate ^{137}Cs (Bq m ⁻³)	Dissolved ^{137}Cs (Bq m ⁻³)	Suspended particle concentration (Bq m ⁻³)	Apparent distribution coefficient (L kg ⁻¹)			
KZ	2021/6/17	140.9272	37.8076	0.1	1128 ± 87	4.5 ± 0.3	3.5 ± 0.2	4.0	321075			
	2021/7/20			0.2	3677 ± 221	6.0 ± 0.4	2.7 ± 0.3	1.6	1343027			
	2021/8/27			0.1	4835 ± 854	1.8 ± 0.3	3.7 ± 0.3	0.4	1290839			
	2021/9/24			0.1	1419 ± 68	6.5 ± 0.3	2.2 ± 0.3	4.6	641397			
	2021/10/28			0.1	2368 ± 196	3.6 ± 0.3	1.2 ± 0.3	1.5	1976150			
	2021/12/24			0.4	1833 ± 115	4.8 ± 0.3	2.6 ± 0.3	2.6	712516			
	2022/2/8			1.0	191 ± 34	0.5 ± 0.1	2.7 ± 0.3	2.4	71815			
	2022/6/23			0.1	386 ± 65	1.4 ± 0.2	1.0 ± 0.3	3.7	391027			
	2022/8/30			0.1	955 ± 19	47.0 ± 0.9	1.8 ± 0.3	49.2	531742			
	2022/10/27			0.1	776 ± 144	1.1 ± 0.2	1.2 ± 0.3	1.5	669661			
	2023/2/20			0.1	653 ± 119	1.7 ± 0.3	2.1 ± 0.3	2.5	314126			
	UD			2021/6/17	140.9126	37.7902	0.1	1110 ± 163	1.9 ± 0.3	2.0 ± 0.3	1.8	551470
				2021/7/20			0.1	1790 ± 447	1.1 ± 0.3	2.3 ± 0.2	0.6	777173
2021/8/27		0.1	2368 ± 272	2.4 ± 0.3			2.5 ± 0.3	1.0	965710			
2021/9/24		0.1	988 ± 149	2.0 ± 0.3			1.8 ± 0.2	2.0	550703			
2021/10/28		0.1	1435 ± 91	5.1 ± 0.3			1.3 ± 0.3	3.6	1110440			
2021/12/24		0.1	4452 ± 352	3.1 ± 0.2			1.8 ± 0.3	0.7	2419522			
2022/2/8		0.1	3750 ± 327	2.9 ± 0.3			1.0 ± 0.2	0.8	3698272			
2022/6/23		0.1	376 ± 122	0.4 ± 0.1			2.2 ± 0.3	1.1	167708			
2022/8/30		0.1	670 ± 15	45.7 ± 1.0			1.0 ± 0.2	68.2	648187			
2022/10/27		0.1	1308 ± 211	0.7 ± 0.1			1.3 ± 0.3	0.5	1016381			
2023/2/20		0.1	2331 ± 541	1.2 ± 0.3			1.3 ± 0.3	0.5	1813976			
UM		2021/6/17	140.9494	37.7863			0.1	1496 ± 30	45.6 ± 0.9	3.4 ± 0.2	30.5	434323
		2021/7/20					0.1	2331 ± 51	37.6 ± 0.8	2.3 ± 0.2	16.1	992628
	2021/8/27	0.1			9140 ± 384	13.7 ± 0.6	3.0 ± 0.3	1.5	3024999			
	2021/9/24	0.1			974 ± 29	15.8 ± 0.5	3.4 ± 0.4	16.2	285496			
	2021/10/28	0.1			1034 ± 28	15.8 ± 0.4	2.3 ± 0.3	15.3	444498			
	2021/12/24	0.1			1244 ± 53	8.7 ± 0.4	3.3 ± 0.3	7.0	379072			
	2022/2/8	0.1			789 ± 36	7.3 ± 0.3	3.0 ± 0.3	9.2	264015			
	2022/6/23	0.1			1346 ± 24	33.2 ± 0.6	2.4 ± 0.3	24.7	554292			
	2022/8/30	0.1			2707 ± 49	54.1 ± 1.0	1.7 ± 0.3	20.0	1630890			
	2022/10/27	0.1			1014 ± 60	5.6 ± 0.3	2.6 ± 0.3	5.5	394389			
	2023/2/20	0.2			454 ± 28	5.5 ± 0.3	1.6 ± 0.3	12.1	287519			
	NK	2021/6/17			140.9428	37.7594	0.1	1360 ± 65	10.0 ± 0.5	3.9 ± 0.2	7.3	349932
		2021/7/20					0.1	560 ± 88	1.5 ± 0.2	3.3 ± 0.2	2.8	171579
2021/8/27		0.1	1861 ± 210	3.3 ± 0.4			3.8 ± 0.3	1.8	490207			
2021/9/24		0.1	2176 ± 74	15.3 ± 0.5			3.2 ± 0.3	7.1	690292			
2021/10/28		0.1	2224 ± 80	12.0 ± 0.4			3.2 ± 0.3	5.4	701280			
2021/12/24		0.1	373 ± 51	2.1 ± 0.3			3.9 ± 0.4	5.6	95406			
2022/2/8		0.1	360 ± 65	1.5 ± 0.3			3.5 ± 0.3	4.1	102398			
2022/6/23		0.1	1208 ± 146	2.3 ± 0.3			2.4 ± 0.3	1.9	513555			
2022/8/30		0.1	1702 ± 32	55.8 ± 1.0			4.0 ± 0.4	32.8	425506			
2022/10/27		0.1	1039 ± 75	3.7 ± 0.3			4.0 ± 0.4	3.6	258130			
2023/2/20		0.1	595 ± 31	6.0 ± 0.3			3.5 ± 0.3	10.1	168108			

Table S3

Analytical results of ^{137}Cs activity concentration in surface water collected at station UME, OSS, IWS and UDE in Matsukawa-ura lagoon. ^{137}Cs activity concentrations were decay-corrected to the sampling date.

Station	Sampling date	Long E	Lat N	Salinity	^{137}Cs in suspended particles (Bq kg ⁻¹)	Particulate ^{137}Cs (Bq m ⁻³)	Dissolved ^{137}Cs (Bq m ⁻³)	Suspended particle concentration (Bq m ⁻³)	Apparent distribution coefficient (L kg ⁻¹)			
UME	2021/6/17	140.9698	37.7869	6.0	730 ± 14	103.3 ± 2.0	23.5 ± 0.4	141.5	31057			
	2021/7/20			26.8	489 ± 16	18.0 ± 0.6	31.3 ± 0.7	36.8	15602			
	2021/8/27			28.3	16433 ± 770	12.3 ± 0.6	18.0 ± 0.5	0.7	914863			
	2021/9/24			28.7	594 ± 7	123.3 ± 1.4	24.6 ± 0.8	207.6	24181			
	2021/10/28			26.7	853 ± 26	13.2 ± 0.4	14.4 ± 0.6	15.5	59062			
	2021/12/24			23.3	2005 ± 108	5.6 ± 0.3	7.2 ± 0.5	2.8	278607			
	2022/2/8			31.0	779 ± 34	7.2 ± 0.3	9.0 ± 0.4	9.2	86841			
	2022/6/23			28.4	1001 ± 34	12.7 ± 0.4	25.1 ± 0.8	12.7	39801			
	2022/8/30			15.6	1369 ± 19	121.9 ± 1.7	14.4 ± 0.6	89.0	94935			
	2022/10/27			32.0	1509 ± 30	28.2 ± 0.6	17.7 ± 0.6	18.7	85289			
	2023/2/20			32.5	570 ± 31	7.3 ± 0.4	8.3 ± 0.5	12.8	68412			
	OSS			2021/6/17	140.9792	37.7967	30.9	751 ± 26	13.6 ± 0.5	21.0 ± 0.4	18.2	35753
				2021/7/20			28.8	1708 ± 85	7.6 ± 0.4	24.0 ± 0.6	4.4	71195
2021/8/27		26.1	1482 ± 141	2.8 ± 0.3			12.5 ± 0.4	1.9	118460			
2021/9/24		28.7	1162 ± 35	16.4 ± 0.5			14.0 ± 0.6	14.1	83068			
2021/10/28		26.8	1224 ± 147	2.2 ± 0.3			8.9 ± 0.5	1.8	137625			
2021/12/24		29.7	447 ± 105	0.9 ± 0.2			5.2 ± 0.4	1.9	85873			
2022/2/8		31.7	232 ± 36	1.4 ± 0.2			6.4 ± 0.4	6.1	36525			
2022/6/23		30.1	869 ± 68	4.0 ± 0.3			17.2 ± 0.6	4.6	50544			
2022/8/30		9.7	503 ± 21	15.8 ± 0.7			9.7 ± 0.5	31.4	51996			
2022/10/27		32.6	632 ± 68	2.5 ± 0.3			10.0 ± 0.5	3.9	62913			
2023/2/22		33.4	888 ± 176	1.2 ± 0.2			5.9 ± 0.4	1.3	149918			
IWS		2021/6/17	140.9745	37.8048			31.1	1985 ± 64	15.6 ± 0.5	14.8 ± 8.9	7.9	134223
		2021/7/20					29.0	898 ± 58	4.9 ± 0.3	22.6 ± 0.7	5.5	39780
	2021/8/27	26.7			1780 ± 200	2.2 ± 0.3	12.9 ± 0.5	1.3	138376			
	2021/9/24	29.4			641 ± 42	4.4 ± 0.3	10.5 ± 0.5	6.9	60845			
	2021/10/28	27.8			788 ± 92	2.2 ± 0.3	7.4 ± 0.5	2.8	106667			
	2021/12/24	30.0			399 ± 84	1.0 ± 0.2	5.4 ± 0.4	2.5	74509			
	2022/2/8	32.0			436 ± 143	0.5 ± 0.2	3.3 ± 0.4	1.3	133630			
	2022/6/23	28.3			398 ± 29	4.1 ± 0.3	14.1 ± 0.5	10.4	28239			
	2022/8/30	27.7			340 ± 40	2.1 ± 0.3	11.2 ± 0.5	6.3	30257			
	2022/10/27	33.9			286 ± 45	1.2 ± 0.2	10.1 ± 0.5	4.3	28324			
	2023/2/22	33.8			177 ± 43	0.4 ± 0.1	4.3 ± 0.3	2.3	40616			
	UDE	2021/6/17			140.9742	37.8133	32.6	751 ± 34	8.7 ± 0.4	9.5 ± 0.4	11.6	79448
		2021/7/20					30.7	440 ± 28	5.0 ± 0.3	9.4 ± 0.2	11.3	46919
2021/8/27		28.9	9719 ± 885	3.2 ± 0.3			10.0 ± 0.3	0.3	976626			
2021/9/24		10.4	751 ± 76	2.4 ± 0.2			4.4 ± 0.4	3.2	169362			
2021/10/28		15.7	879 ± 77	2.5 ± 0.2			3.8 ± 0.4	2.9	234156			
2021/12/24		23.7	648 ± 114	1.2 ± 0.2			3.5 ± 0.4	1.8	183115			
2022/2/8		27.2	307 ± 83	0.5 ± 0.1			2.5 ± 0.3	1.5	123684			
2022/6/23		31.9	595 ± 61	2.1 ± 0.2			6.9 ± 0.4	3.5	86026			
2022/8/30		19.5	460 ± 20	7.0 ± 0.3			8.4 ± 0.4	15.2	54988			
2022/10/27		34.6	471 ± 37	3.6 ± 0.3			7.3 ± 0.4	7.7	64978			
2023/2/22		27.2	631 ± 106	1.3 ± 0.2			4.4 ± 0.3	2.1	143594			

Table S4

Analytical results of ^{137}Cs activity concentration at Station KZE, WKS, WKO and SKS in Matsukawa-ura lagoon and station URS at offshore of the lagoon. ^{137}Cs activity concentrations were decay-corrected to the sampling date.

Station	Sampling date	Long E	Lat N	Salinity	^{137}Cs in suspended particles (Bq kg ⁻¹)	Particulate ^{137}Cs (Bq m ⁻³)	Dissolved ^{137}Cs (Bq m ⁻³)	Suspended particle concentration (Bq m ⁻³)	Apparent distribution coefficient (L kg ⁻¹)			
KZE	2021/6/17	140.9617	37.8208	32.3	644 ± 32	6.8 ± 0.3	20.3 ± 0.4	10.6	31758			
	2021/7/20			30.4	361 ± 34	2.9 ± 0.3	11.5 ± 0.5	8.0	31282			
	2021/8/27			30.4	2240 ± 171	4.3 ± 0.3	12.3 ± 0.3	1.9	181685			
	2021/9/24			29.6	466 ± 14	14.5 ± 0.4	11.8 ± 0.5	31.0	39624			
	2021/10/28			30.7	704 ± 70	2.5 ± 0.2	6.8 ± 0.5	3.5	102786			
	2021/12/24			30.0	193 ± 63	0.4 ± 0.1	4.7 ± 0.3	2.2	41199			
	2022/2/8			32.3	555 ± 153	0.8 ± 0.2	4.7 ± 0.3	1.5	118216			
	2022/6/23			27.8	905 ± 42	7.5 ± 0.3	15.5 ± 0.6	8.3	58171			
	2022/8/30			29.7	483 ± 25	6.5 ± 0.3	12.0 ± 0.5	13.4	40271			
	2022/10/27			34.1	375 ± 72	1.4 ± 0.3	7.7 ± 0.5	3.6	48482			
	2023/2/22			33.9	401 ± 76	1.1 ± 0.2	5.0 ± 0.4	2.8	79378			
	WKS			2021/6/17	140.9807	37.8199	29.0	160 ± 14	4.1 ± 0.3	13.4 ± 0.6	25.5	11979
				2021/7/20			31.5	171 ± 49	1.0 ± 0.3	7.5 ± 0.2	6.0	22819
2021/8/27		29.2	1790 ± 254	2.0 ± 0.3			13.6 ± 0.4	1.1	131290			
2021/9/24		29.6	583 ± 54	3.4 ± 0.3			10.9 ± 0.5	5.8	53455			
2021/10/28		31.4	1086 ± 106	3.3 ± 0.3			6.2 ± 0.5	3.0	175107			
2021/12/24		29.6	557 ± 165	0.7 ± 0.2			5.6 ± 0.4	1.3	100232			
2022/2/8		32.3	347 ± 107	0.5 ± 0.1			4.9 ± 0.3	1.3	71415			
2022/6/23		31.8	404 ± 58	0.8 ± 0.1			8.4 ± 0.5	1.9	48078			
2022/8/30		26.1	407 ± 65	1.5 ± 0.2			11.1 ± 0.5	3.7	36777			
2022/10/27		34.2	9604 ± 261	15.4 ± 0.4			7.9 ± 0.5	1.6	1209155			
2023/2/20		34.6	204 ± 29	0.2 ± 0.0			3.5 ± 0.4	1.0	57484			
WKO		2021/6/17	140.9756	37.8219			31.4	699 ± 71	2.3 ± 0.2	7.2 ± 0.2	3.3	96859
		2021/7/20					31.3	287 ± 20	4.0 ± 0.3	6.5 ± 0.2	13.8	44141
	2021/8/27	30.0			553 ± 77	1.8 ± 0.2	8.0 ± 0.3	3.2	68885			
	2021/9/24	29.6			1097 ± 102	2.3 ± 0.2	10.4 ± 0.5	2.1	105583			
	2021/10/28	30.9			1202 ± 192	1.6 ± 0.2	6.8 ± 0.5	1.3	176470			
	2021/12/24	30.2			1007 ± 218	1.1 ± 0.2	5.1 ± 0.4	1.1	199352			
	2022/2/8	32.9			100 ± 29	0.1 ± 0.0	2.9 ± 0.3	1.5	34702			
	2022/6/23	32.0			590 ± 106	1.3 ± 0.2	5.6 ± 0.4	2.2	106005			
	2022/8/30	29.8			871 ± 157	1.2 ± 0.2	7.6 ± 0.5	1.4	114686			
	2022/10/27	33.3			1044 ± 81	3.8 ± 0.3	7.1 ± 0.4	3.7	146499			
	2023/2/22	34.4			765 ± 220	0.4 ± 0.1	4.1 ± 0.4	0.6	185232			
	SKS	2021/6/17			140.9774	37.8277	31.4	190 ± 42	0.9 ± 0.2	7.6 ± 0.6	4.5	25102
		2021/7/20					29.6	199 ± 35	0.9 ± 0.2	14.2 ± 0.3	4.7	14047
2021/8/27		30.0	2024 ± 263	1.7 ± 0.2			7.9 ± 0.4	0.9	255302			
2021/9/24		29.0	208 ± 44	0.4 ± 0.1			7.1 ± 0.4	2.1	29456			
2021/10/28		28.7	631 ± 160	0.9 ± 0.2			7.2 ± 0.5	1.4	87242			
2021/12/24		29.4	387 ± 98	0.6 ± 0.2			6.8 ± 0.5	1.6	57160			
2022/2/8		32.3	522 ± 127	0.9 ± 0.2			4.0 ± 0.4	1.7	130624			
2022/6/23		30.1	749 ± 102	1.8 ± 0.2			9.4 ± 0.5	2.5	80067			
2022/8/30		29.3	148 ± 37	0.2 ± 0.1			6.2 ± 0.4	1.6	23764			
2022/10/27		34.1	551 ± 62	2.3 ± 0.3			9.0 ± 0.4	4.3	61196			
2023/2/22		33.7	1256 ± 329	0.9 ± 0.2			4.4 ± 0.4	0.7	286949			
URS		2021/8/2	141.0039	37.8000			32.0	ND	ND	3.1 ± 0.2	3.0	-
		2021/10/14					30.5	167 ± 53	0.2 ± 0.1	4.8 ± 0.4	1.0	34840
	2022/2/1	34.4			403 ± 76	0.4 ± 0.1	3.1 ± 0.4	1.0	131808			
	2022/6/1	33.7			122 ± 28	0.4 ± 0.1	2.8 ± 0.3	3.2	43007			
	2022/8/3	32.7			ND	ND	2.7 ± 0.3	0.8	-			
	2022/10/3	33.4			247 ± 61	0.8 ± 0.2	2.5 ± 0.3	3.2	98023			
	2023/2/7	34.3			175 ± 48	0.2 ± 0.1	2.2 ± 0.3	1.2	77673			

Table S5

Estimated input and output fluxes of dissolved ^{137}Cs in Matsukawa-ura Lagoon.

	Time after the accident	Water volume in the lagoon	Input of river water	Input of ground water	Input of seawater	Exchange volume ^a	Dissolved ^{137}Cs in coastal water (station URS)	Weighted mean dissolved ^{137}Cs in the lagoon	potential flux of dissolved ^{137}Cs	Flux of riverine dissolved ^{137}Cs	Desorbable fraction of riverine particulate ^{137}Cs ^b	Flux of dissolved ^{137}Cs from the lagoon bottom	Flux of dissolved ^{137}Cs exporting to the Pacific Ocean	
	day	Mm ³	Mm ³ 12h ⁻¹	Mm ³ 12h ⁻¹	Mm ³ 12h ⁻¹	Mm ³ 12h ⁻¹	Bq m ⁻³	Bq m ⁻³	MBq 12 h ⁻¹	MBq 12 h ⁻¹	MBq 12 h ⁻¹	MBq 12 h ⁻¹	MBq 12 h ⁻¹	
	Jun-21	3751	8.0	0.11	0.0079	7.9	4.0	2.2 - 4.8	17	48 - 59	0.27	0.036	48 - 58	67
	Jul-21	3784	8.0	0.24	0.018	7.8	3.9	2.2 - 4.8	19	55 - 65	0.61	0.060	55 - 65	74
	Aug-21	3822	8.0	0.44	0.033	7.6	3.8	2.2 - 4.8	13	31 - 41	1.2	0.077	30 - 40	49
	Sep-21	3850	8.0	0.26	0.020	7.8	3.9	2.2 - 4.8	13	34 - 44	0.57	0.078	33 - 43	52
	Oct-21	3884	8.0	0.23	0.018	7.8	3.9	2.2 - 4.8	8.5	14 - 24	0.38	0.086	14 - 24	33
	Dec-21	3941	8.0	0.11	0.0084	7.9	4.0	2.2 - 4.8	5.4	2.6 - 13	0.25	0.021	2.3 - 13	22
	Feb-22	3987	8.0	0.020	0.0015	8.0	4.0	2.2 - 4.8	5.3	1.9 - 12	0.03	0.0031	1.8 - 12	21
	Jun-22	4122	8.0	0.30	0.022	7.7	3.9	2.2 - 4.8	15	40 - 50	0.64	0.053	39 - 49	58
	Aug-22	4190	8.0	0.15	0.011	7.9	3.9	2.2 - 4.8	11	24 - 34	0.23	0.40	24 - 34	43
	Oct-22	4248	8.0	0.10	0.0078	7.9	4.0	2.2 - 4.8	11	23 - 33	0.20	0.010	23 - 33	42
	Feb-23	4366	8.0	0.047	0.0035	8.0	4.0	2.2 - 4.8	5.5	2.7 - 13	0.076	0.0052	2.6 - 13	22

^a The maximum exchange volume in Matsukawa-ura lagoon assumed 50% during each tidal cycle under spring tide conditions (Kohata et al., 2003).

^b Assumed that 5.5% of riverine particulate ^{137}Cs were desorbed as dissolved ^{137}Cs (Takata et al., 2021)

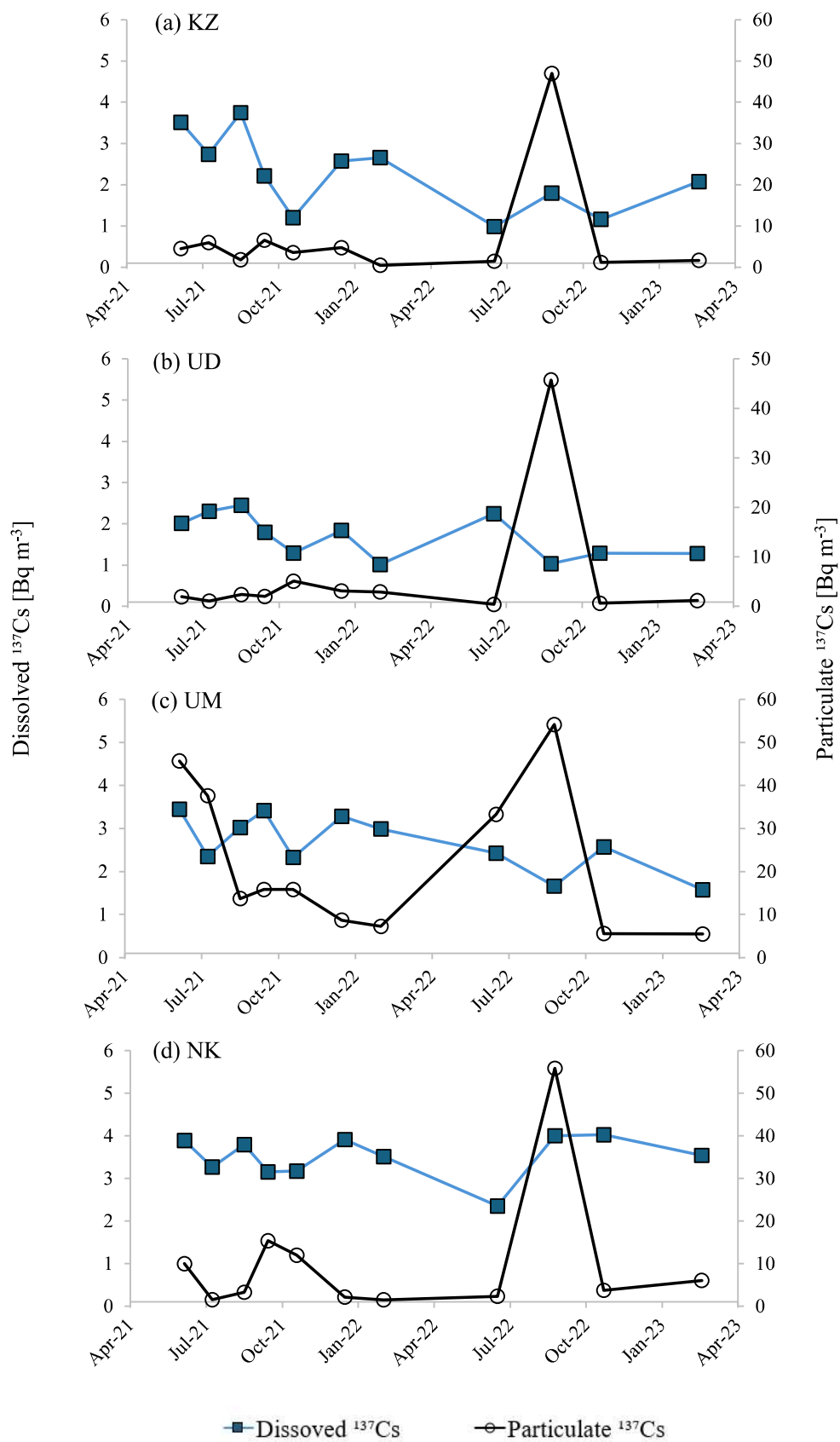


Figure S1: Time series of dissolve ^{137}Cs and particulate ^{137}Cs concentration in Matsukawa-ura lagoon and station URS at offshore of the lagoon. ^{137}Cs concentrations were decay-corrected to the sampling date.

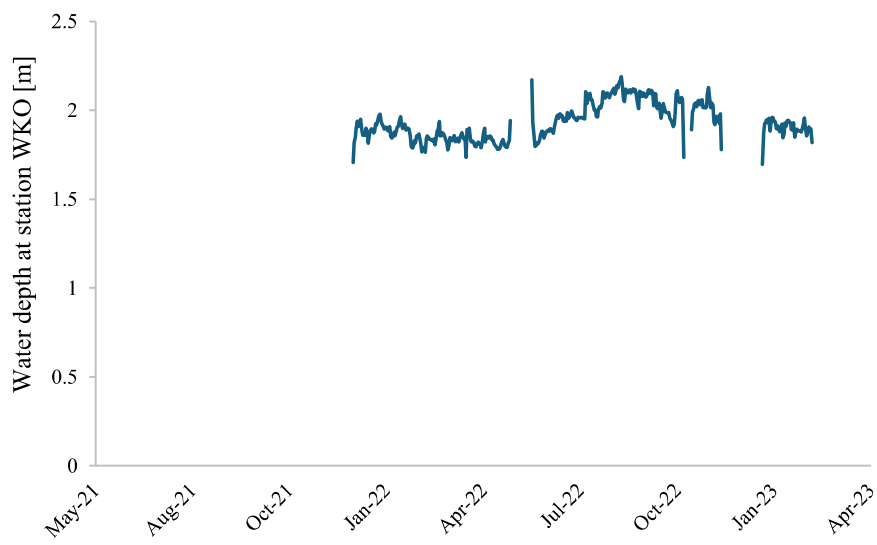


Figure S2: Time series of water depth at Station WKO from December 29, 2021.