

## Temporal changes in the nutrient status of Matsushima Bay after a wastewater plant was destroyed by a tsunami on 11 March 2011

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URL	<a href="https://fra.repo.nii.ac.jp/records/72">https://fra.repo.nii.ac.jp/records/72</a>

Fig.1

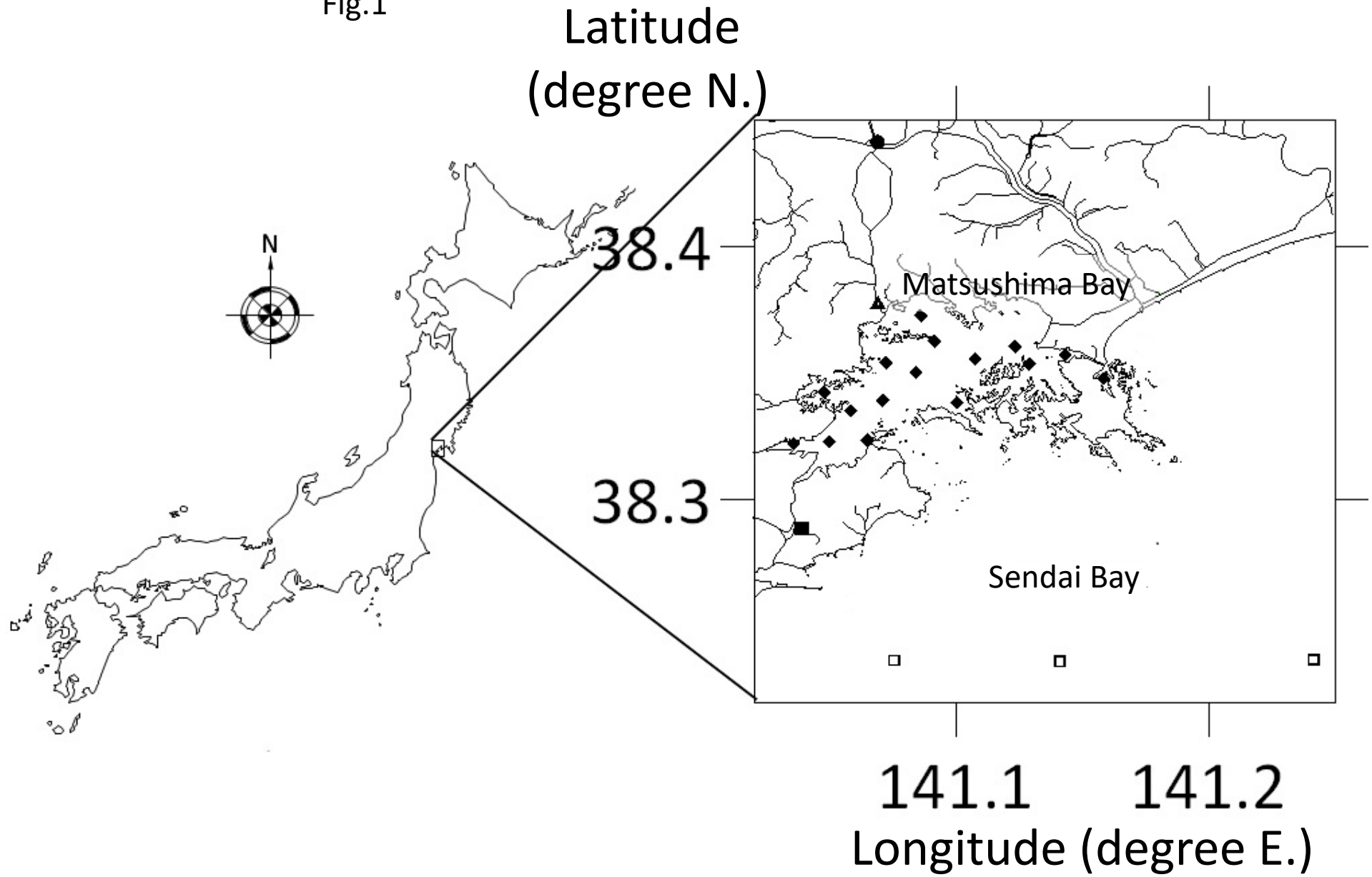
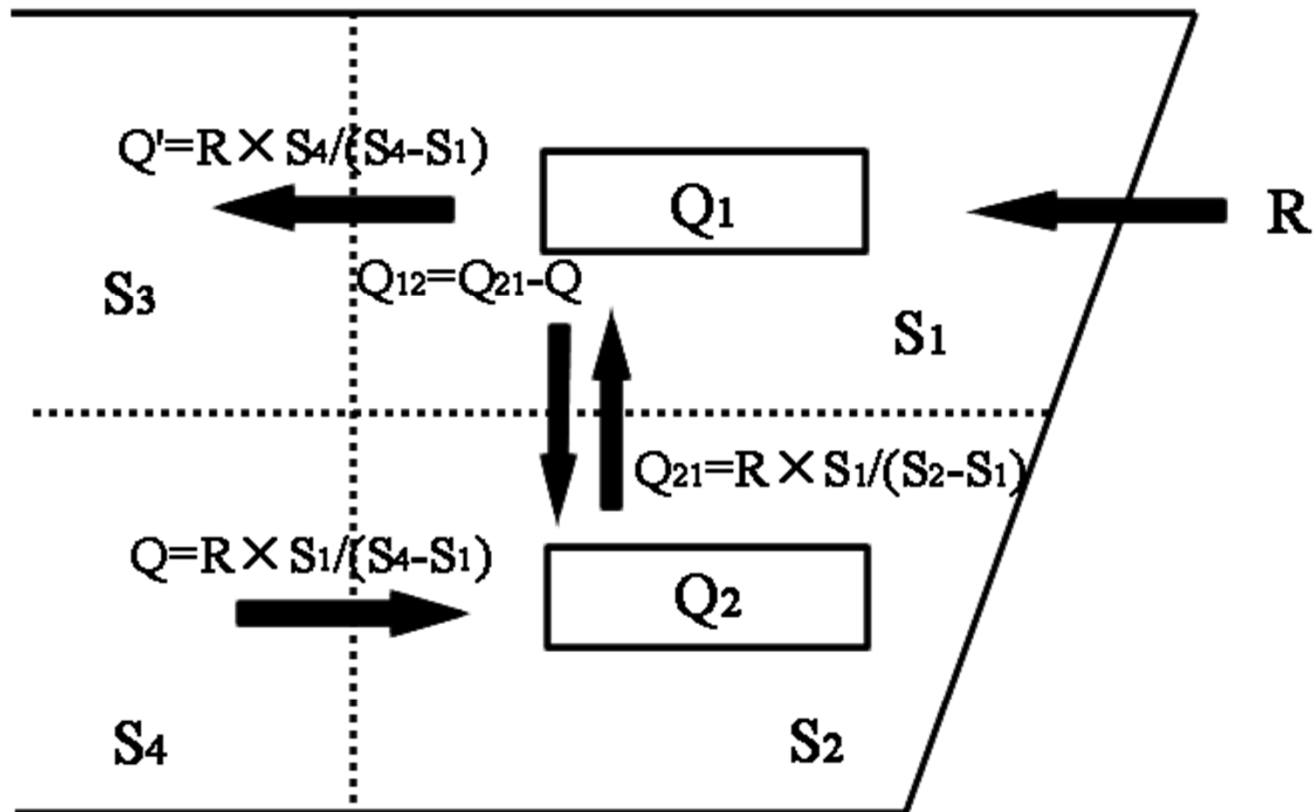


Fig.2

## Outline of the box model (Unogi, 1998)



$S_1, S_2, S_3, S_4$ : Average of salinity

$R$ : Quantity of freshwater

$Q, Q', Q_{12}, Q_{21}$ : Flow

$Q_1, Q_2$ : Volume of each box

Fig.3a

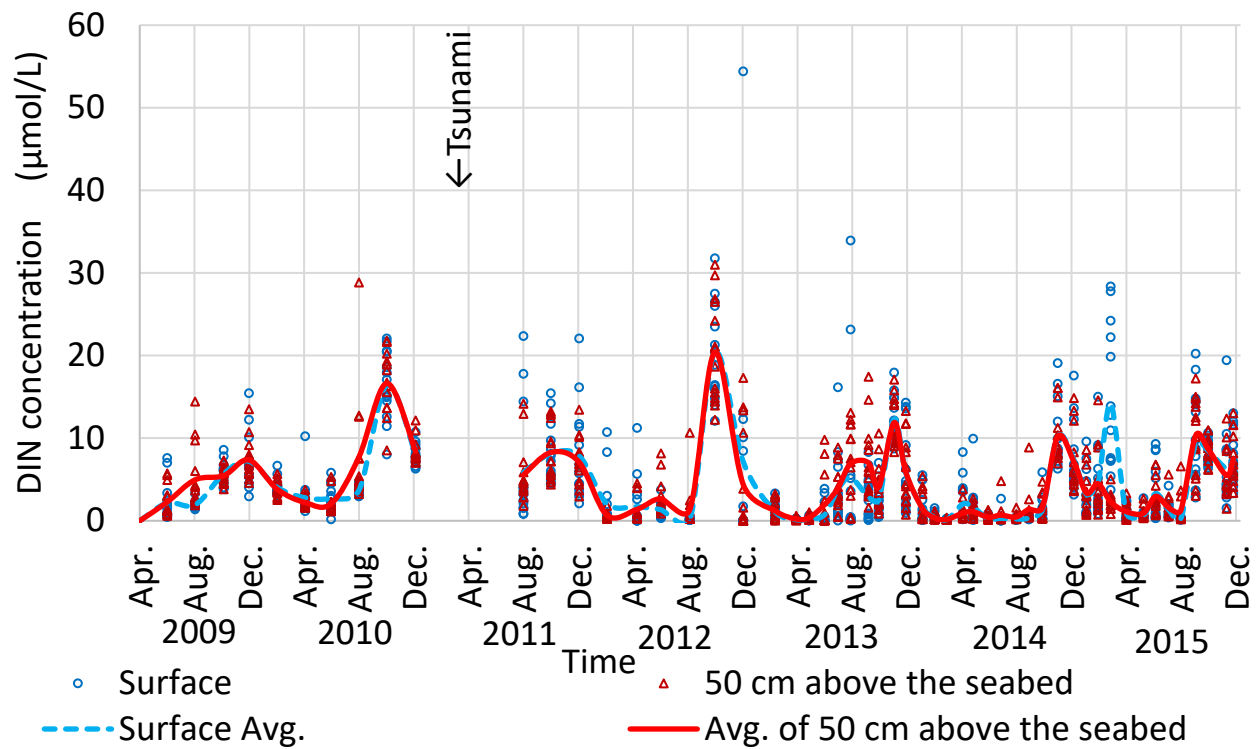


Fig.3b

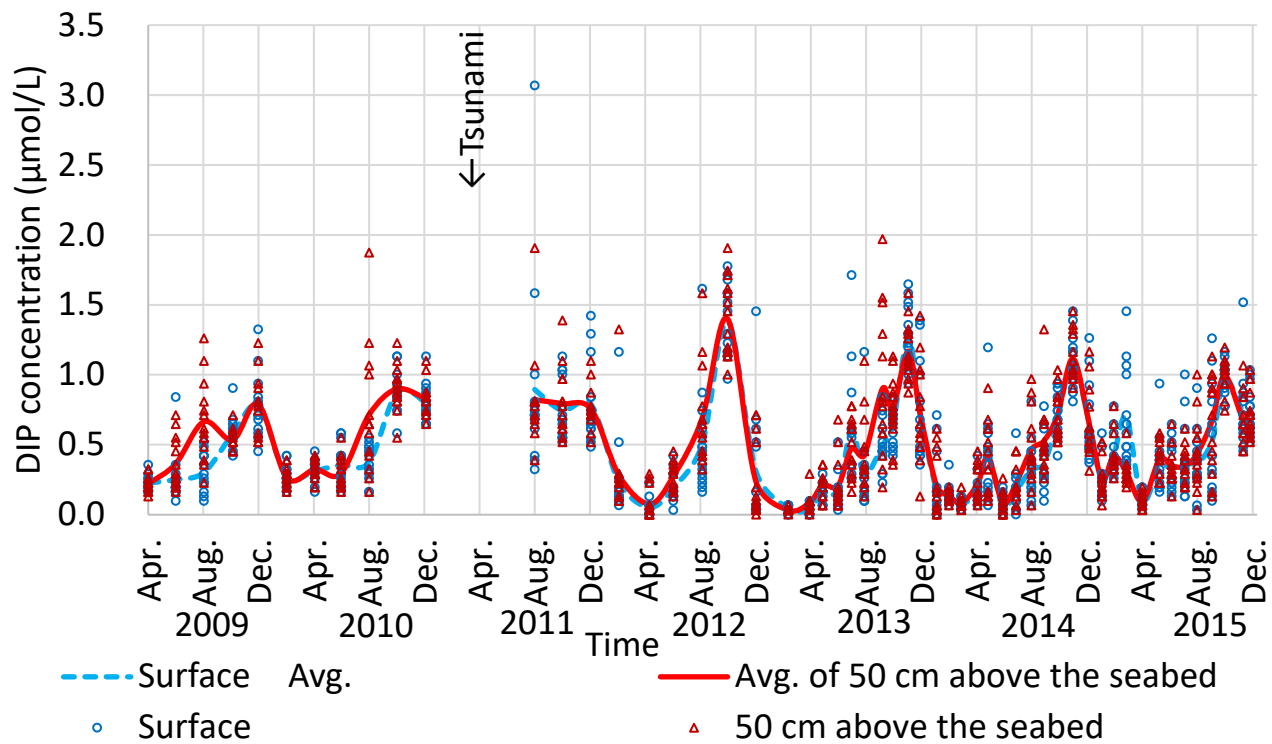


Fig.4a

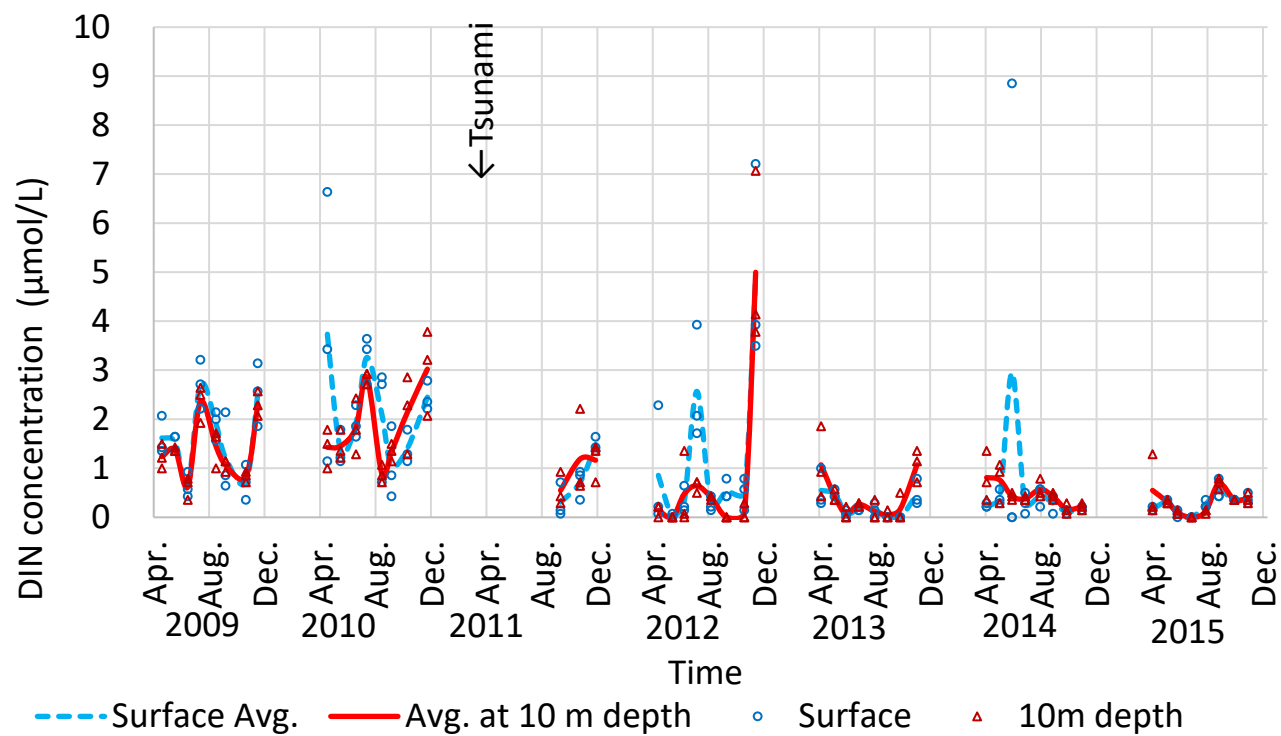


Fig.4b

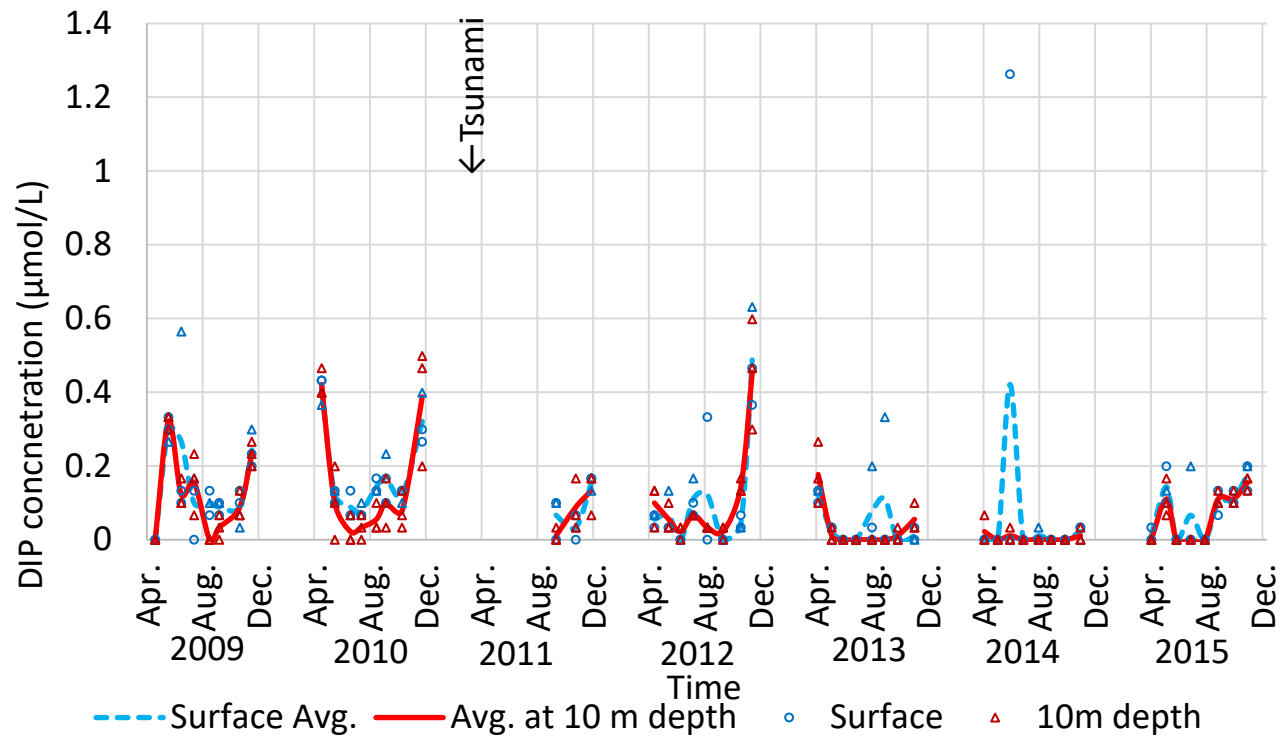


Fig.5a

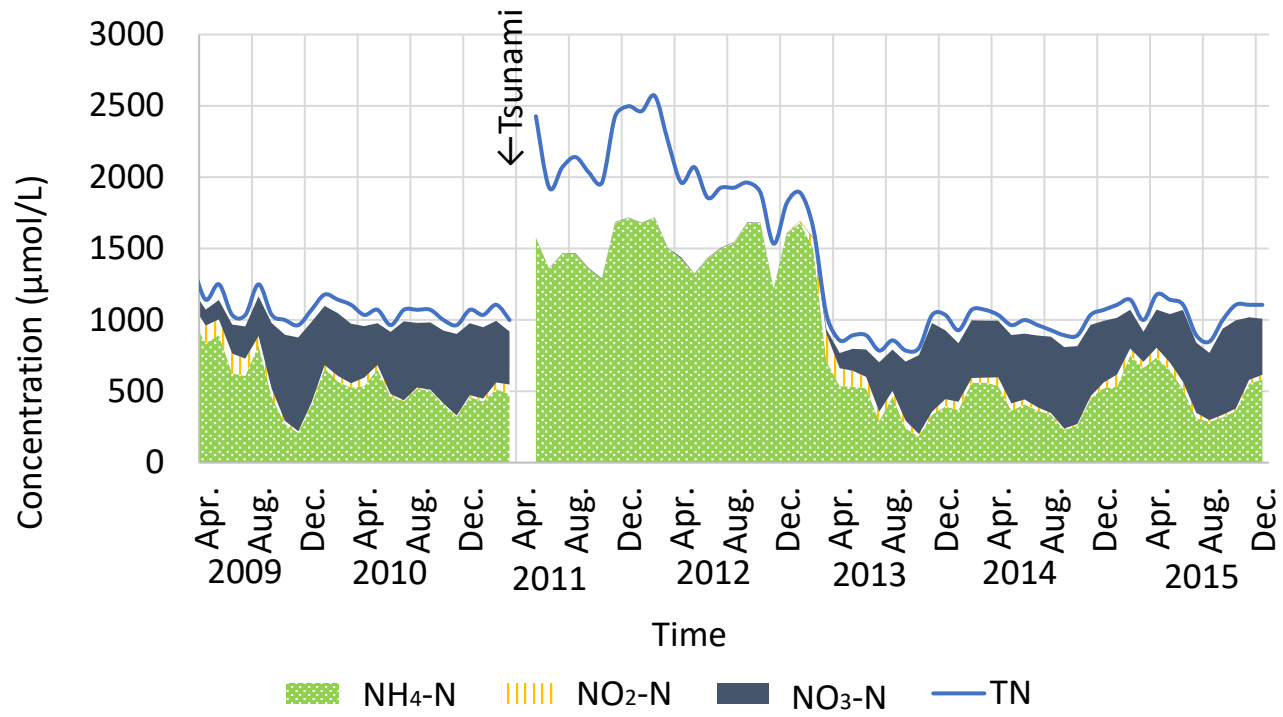




Fig.5b

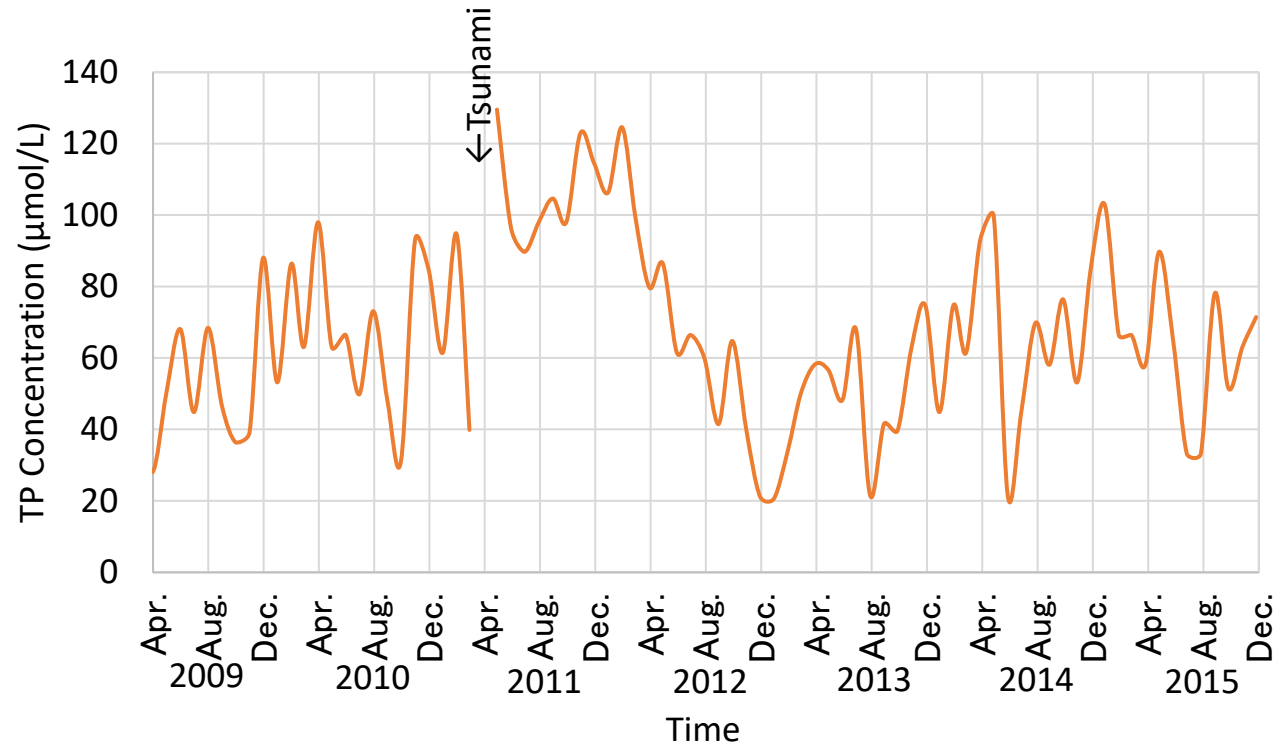


Fig.5c

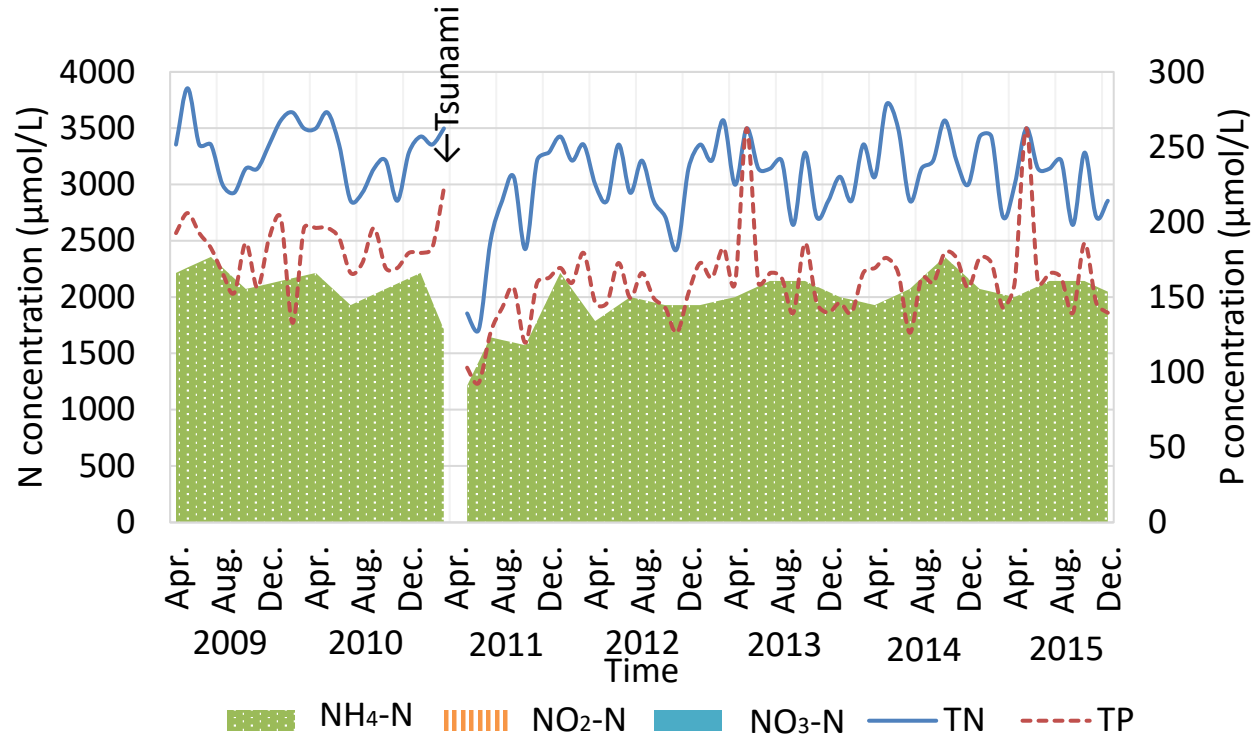


Fig.6a

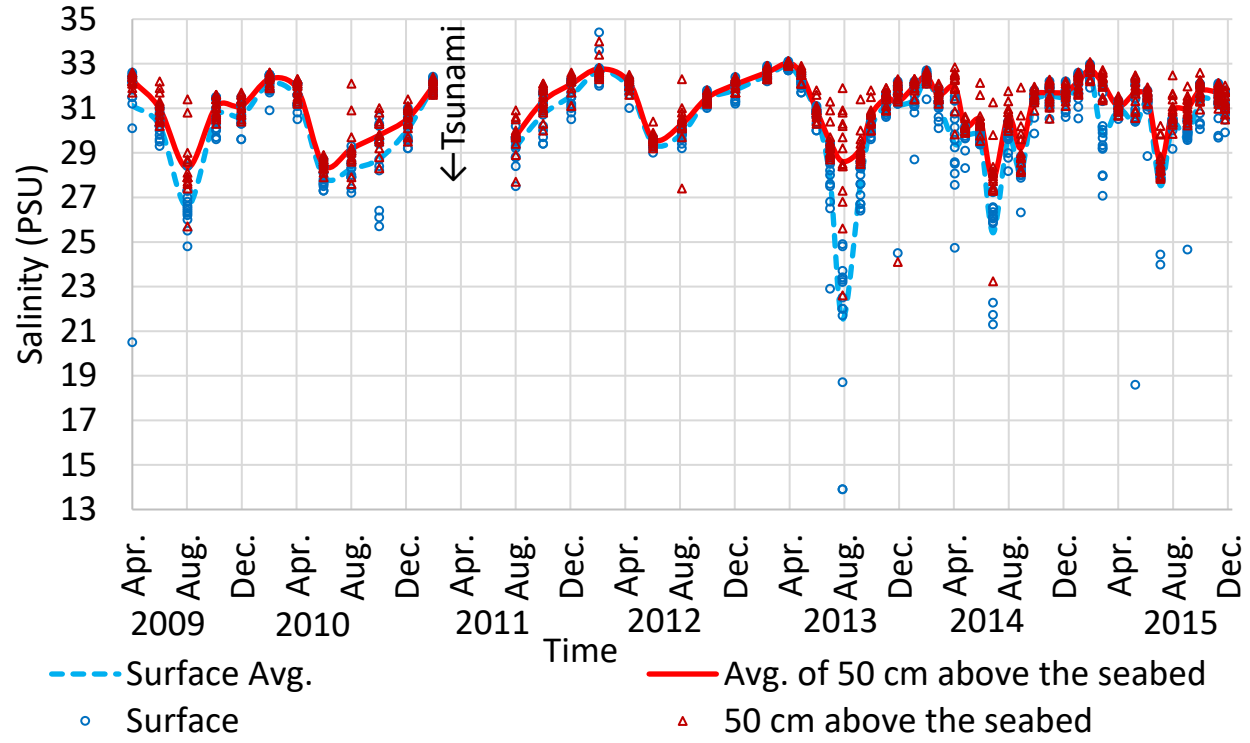


Fig. 6b

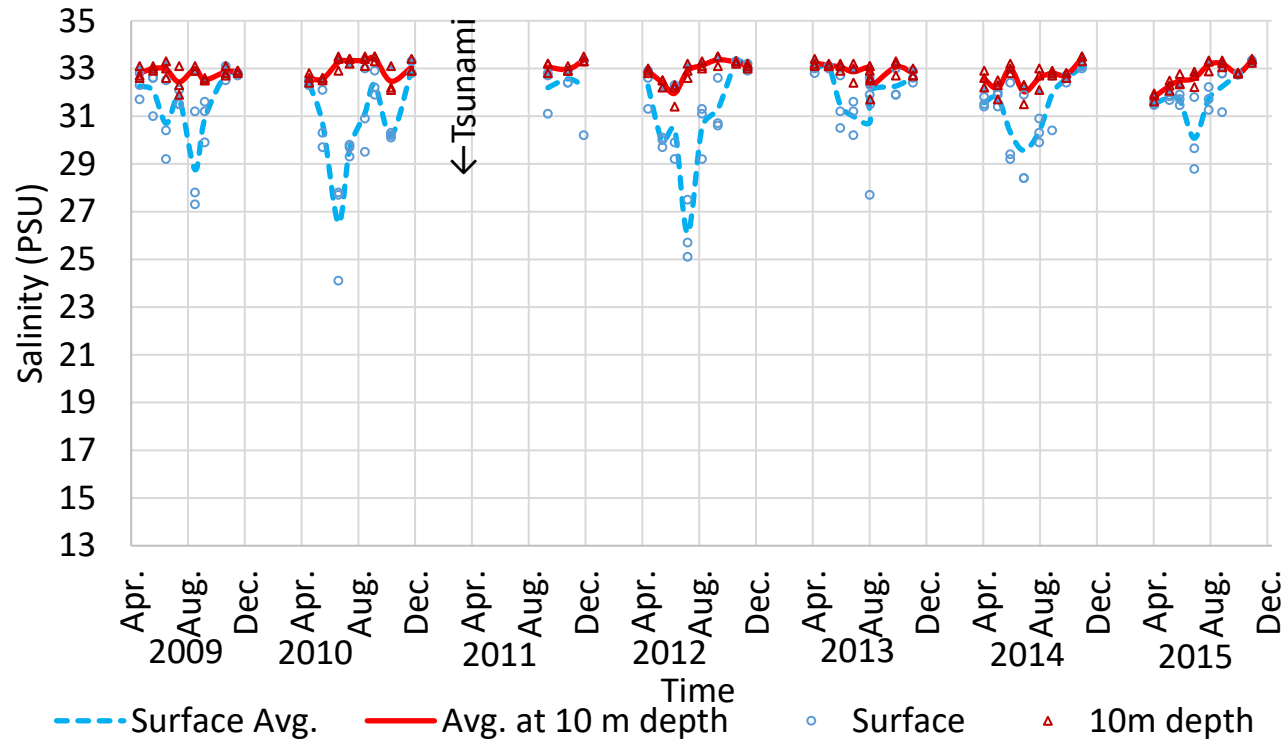


Fig. 7a

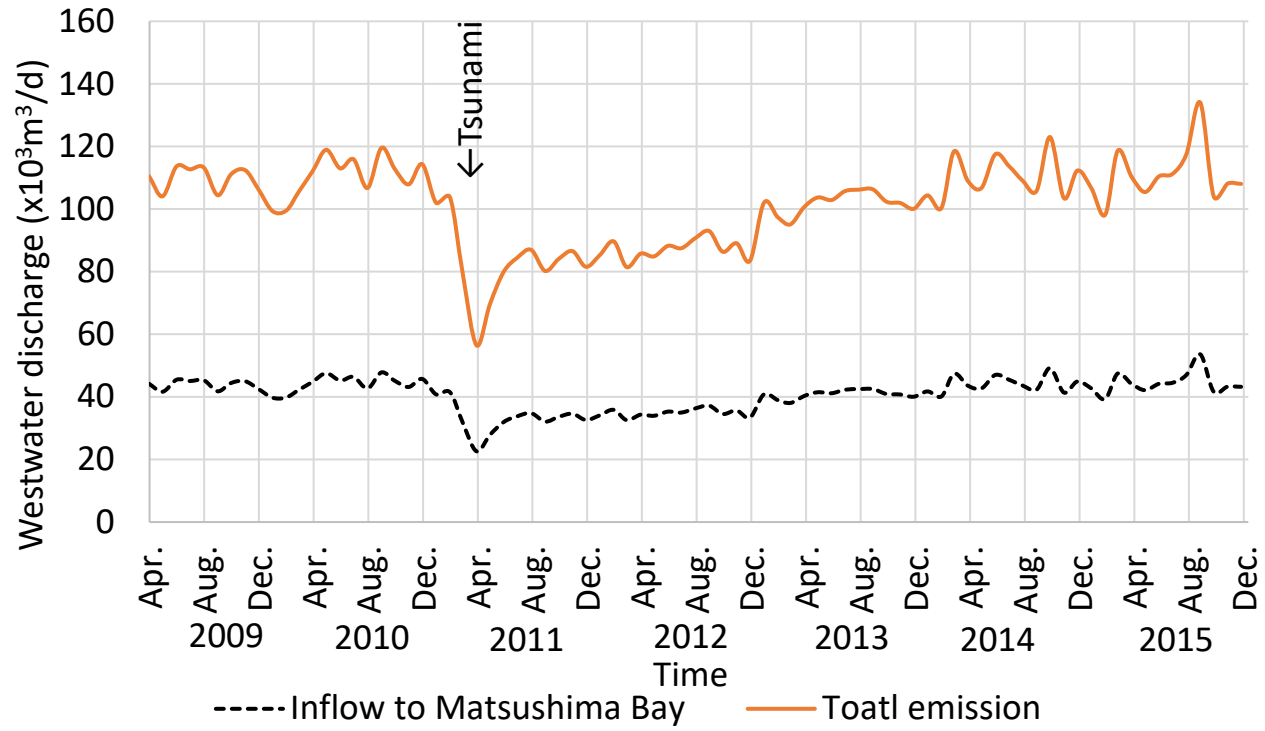


Fig. 7b

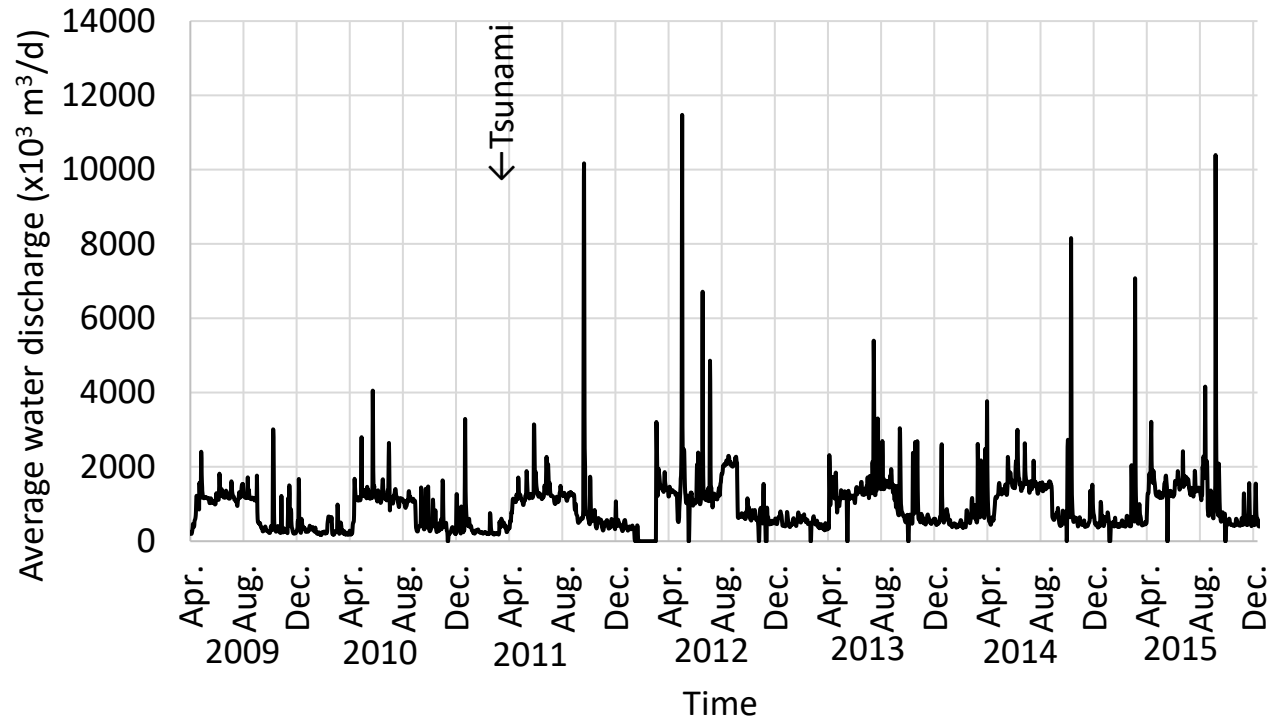


Fig. 7c

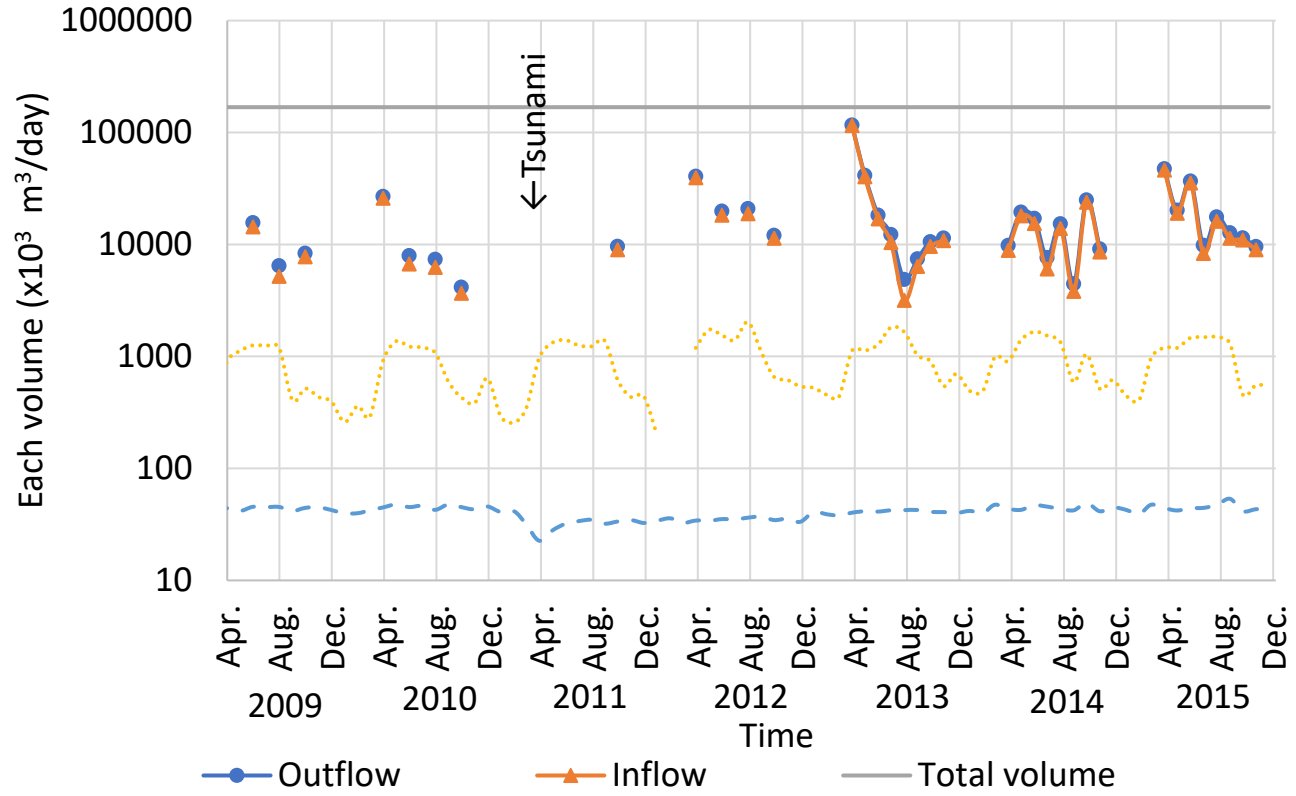


Fig. 8a

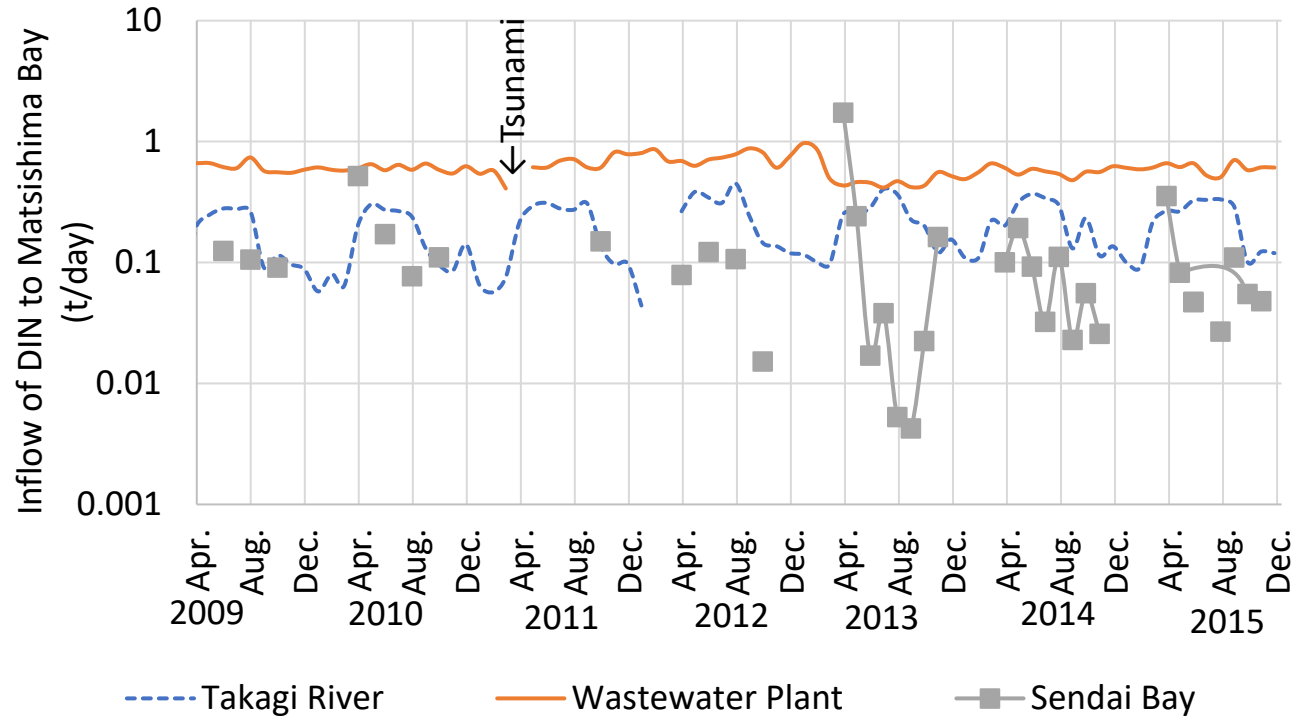




Fig. 8b

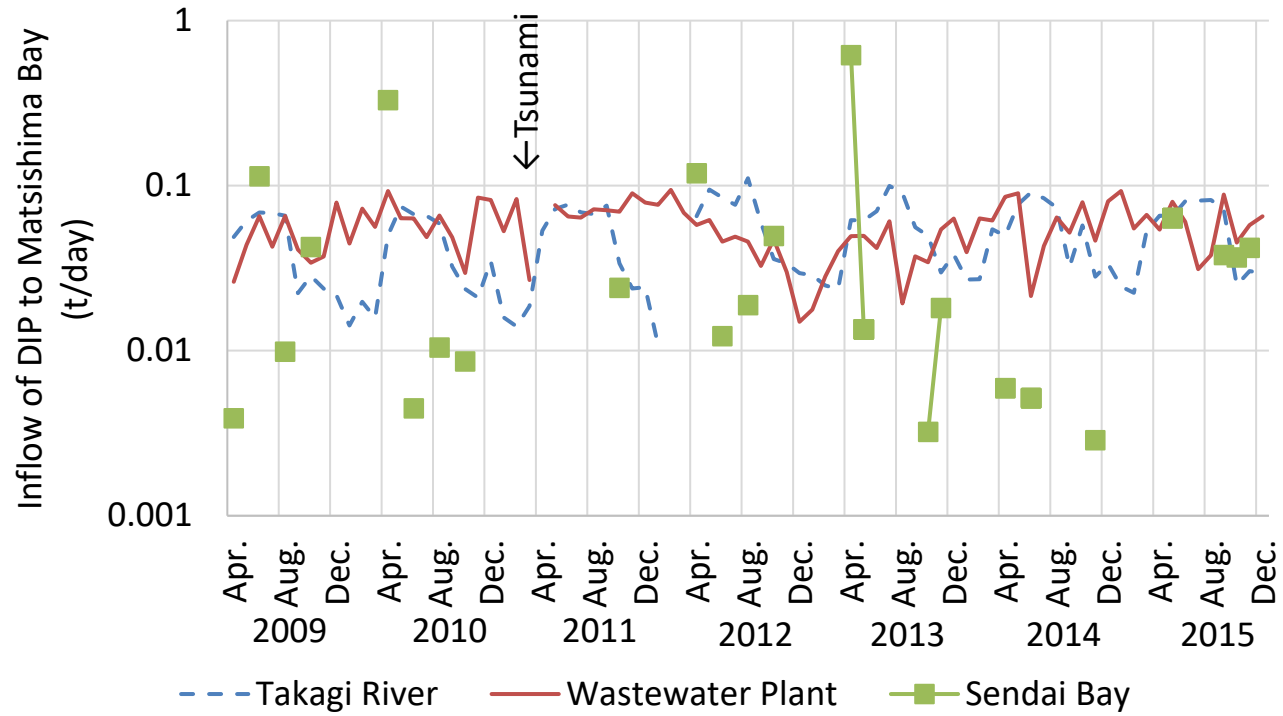
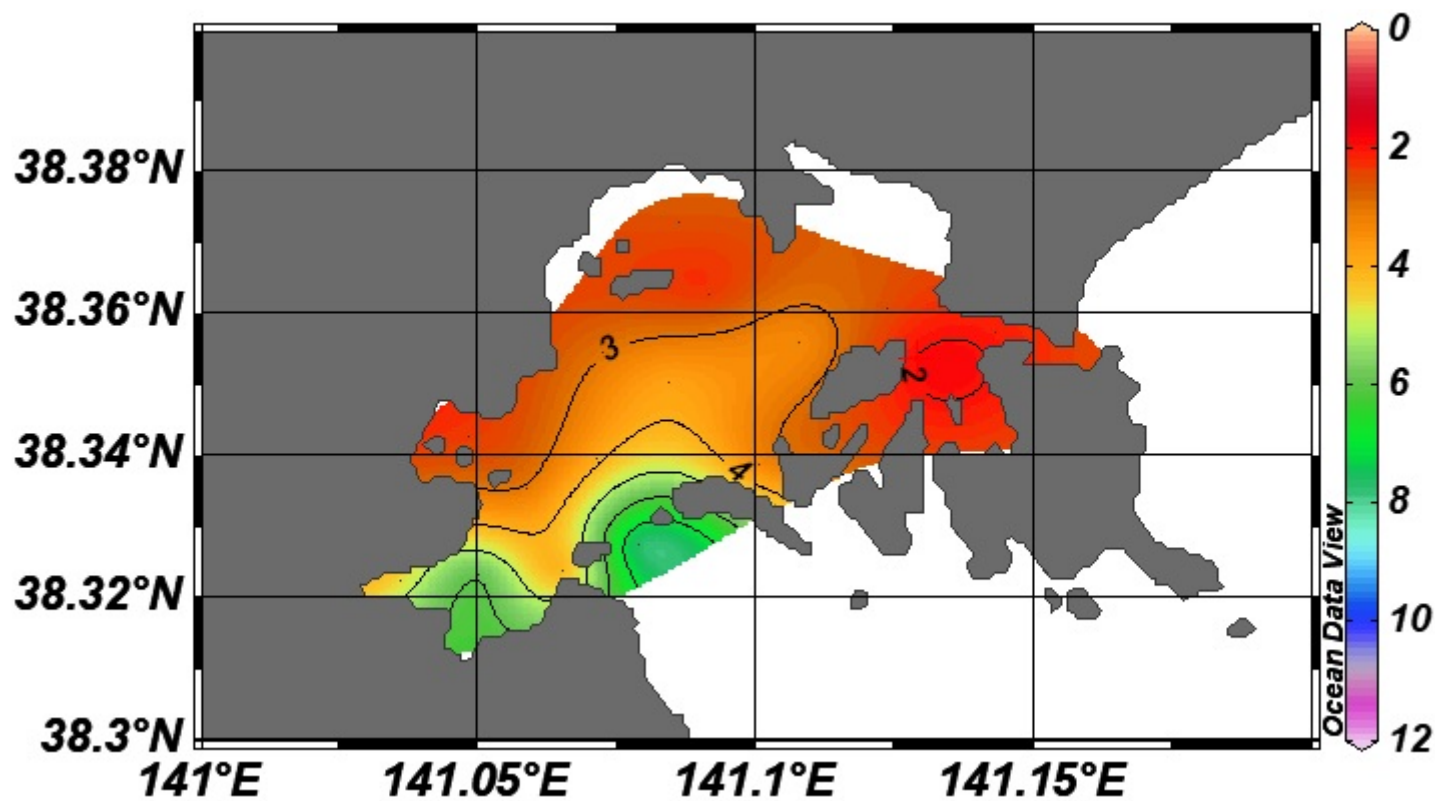


Table 1 Nutrient concentrations in the Takagi River

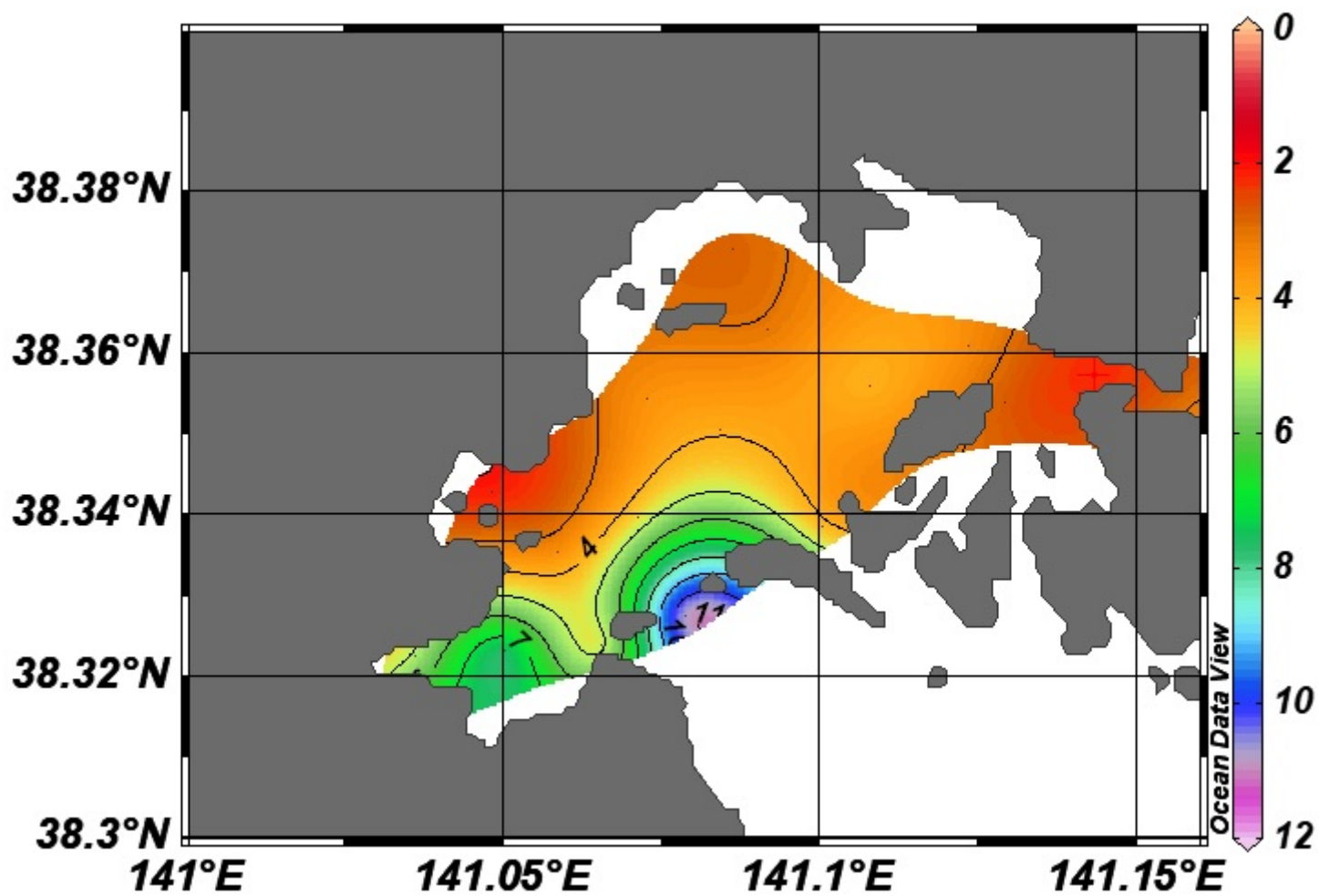
DIN	19.1 ±	15.5 [ $\mu$ mol/L]
PO <sub>4</sub>	1.8 ±	0.6 [ $\mu$ mol/L]

Averages in April, June, August, October, and December 2009; February 2010; and August 2013

# Online Resource 1a



Online Resource 1b



**Online Resource 2** The monthly mean maximum or minimum of each year in Matsushima Bay

Nutrients	Conc.	Depth	Items	Year						
				2009	2010	2011	2012	2013	2014	2015
DIN	Maximum	Surface	Conc.	<b>7.2</b>	16.4	8.1	<b>20.4</b>	12.3	10.2	14.2
			S.D.	3.2	4	3.4	5.7	2.6	3.8	8.3
			Month	Dec.	Oct.	Oct.	Oct.	Nov.	Nov.	Mar.
		Lower layer	Conc.	<b>7.4</b>	16.6	8.3	<b>20.4</b>	11.9	10.2	10.3
			S.D.	2.3	3.6	3.3	6.1	2.7	3.1	4.5
			Month	Dec.	Oct.	Oct.	Oct.	Nov.	Nov.	Sep.
	Minimum	Surface	Conc.	1.9	2.7	<b>5.9</b>	0.17	<b>0.14</b>	<b>0.14</b>	0.24
			S.D.	0.4	1.5	6.7	0.1	0.06	0.05	0.09
			Month	Aug.	Jun.	Aug.	Aug.	Apr.	Mar.	Aug.
		Lower layer	Conc.	2.3	2.1	<b>5.6</b>	0.65	0.21	<b>0.17</b>	0.91
			S.D.	1.8	1.3	3.5	0.38	0.14	0.08	0.66
			Month	Jun.	Jun.	Aug.	Feb.	Apr.	Mar.	May
DIP	Maximum	Surface	Conc.	<b>0.77</b>	0.88	0.89	<b>1.38</b>	1.27	1.09	0.97
			S.D.	0.22	0.14	0.67	0.25	0.22	0.18	0.12
			Month	Dec.	Oct.	Aug.	Oct.	Nov.	Nov.	Oct.
		Lower layer	Conc.	<b>0.79</b>	0.9	0.82	<b>1.4</b>	1.17	1.12	0.99
			S.D.	0.2	0.16	0.33	0.27	0.2	0.17	0.11
			Month	Dec.	Oct.	Aug.	Oct.	Nov.	Nov.	Oct.
	Minimum	Surface	Conc.	0.23	0.27	<b>0.74</b>	0.05	<b>0.04</b>	0.05	0.1
			S.D.	0.05	0.07	0.21	0.08	0.03	0.06	0.04
			Month	Apr.	Feb.	Oct.	Apr.	Apr.	Jun.	Apr.
		Lower layer	Conc.	2.3	2.1	<b>5.6</b>	0.65	0.21	<b>0.17</b>	0.91
			S.D.	1.8	1.3	3.5	0.38	0.14	0.08	0.66
			Month	Jun.	Jun.	Aug.	Feb.	Apr.	Mar.	May

Red/blue color of bold is the highest/lowest concentration from 2009 to 2015.

**Online Resource 3** Friedman test using nutrient concentrations in the highest or lowest month.

Area	Species	Depth	Concentration	Year	2009	2010	2011	2012	2013	2014	2015	P value
Matsushima Bay	DIN	Surface	Highest	Month	Dec.	Oct.	Oct.	Oct.	Nov.	Nov.	Mar.	3E-08
				Median	6.60	16.1	7.53	19.6	11.7	8.64	11.8	
		Surface	Lowest	Month	Aug.	Jun.	Aug.	Aug.	Apr.	Mar.	Aug.	1E-12
				Median	1.82	2.43	3.21	0.14	0.14	0.14	0.25	
		Lower	Highest	Month	Dec.	Oct.	Oct.	Oct.	Nov.	Nov.	Sep.	2E-11
				Median	6.78	16.5	7.17	19.7	11.1	8.82	11.1	
	Lower	Lowest	Month	Dec.	Oct.	Oct.	Oct.	Nov.	Nov.	Sep.	2E-11	
			Median	6.78	16.5	7.17	19.7	11.1	8.82	11.1		
	DIP	Surface	Highest	Month	Dec.	Oct.	Aug.	Oct.	Nov.	Nov.	Oct.	6E-11
				Median	0.74	0.84	0.71	1.37	1.26	1.05	1.02	
		Surface	Lowest	Month	Apr.	Feb.	Oct.	Apr.	Apr.	Jun.	Apr.	4E-13
				Median	0.23	0.26	0.68	0	0.05	0.03	0.097	
Lower		Highest	Month	Aug.	Dec.	Nov.	Nov.	Oct.	Oct.	Oct.	7E-12	
			Median	0.79	0.81	1.11	1.03	0.89	1.37	1.02		
Lower	Lowest	Month	Apr.	Feb.	Dec.	Apr.	Feb.	Jun.	Apr.	2E-12		
		Median	0.21	0.26	0.73	0.03	0.03	0.06	0.097			
Sendai Bay	DIN	Surface	Highest	Month	Jul.	Apr.	Nov.	Nov.	Apr.	Jun.	Sep.	0.1
				Median	2.71	3.43	1.43	3.93	0.36	0	0.43	1
		Surface	Lowest	Month	Jun.	Sep.	Sep.	May	Sep.	Oct.	Jul.	0.0
				Median	0.57	0.86	0.14	0	0	0.14	0	13
	10m	Highest	Month	Jul.	Nov.	Oct.	Nov.	Apr.	Apr.	Sep.	0.0	
			Median	2.50	3.21	0.71	4.14	0.93	0.71	0.71	28	
	10m	Lowest	Month	Jun.	Aug.	Sep.	May	Sep.	Oct.	Jul.	0.0	
			Median	0.71	0.86	0.43	0	0	0.14	0	10	
	DIP	Surface	Highest	Month	May	Apr.	Nov.	Nov.	Apr.	Jun.	Nov.	0.0
				Median	0.3	0.43	0.17	0.47	0.13	0	0.20	81
		Surface	Lowest	Month	Apr.	Jul.	Oct.	Jun. <sup>1</sup>	Jun. <sup>2</sup>	Apr. <sup>3</sup>	Jun. <sup>4</sup>	0.0
				Median	0	0.07	0.03	0	0	0	0	16
10m	Highest	Month	May	Apr.	Nov.	Nov.	Apr.	Apr.	Nov.	0.0		
		Median	0.33	0.40	0.17	0.47	0.17	0	0.17	13		
10m	Lowest	Month	Apr. <sup>5</sup>	Jun.	Sep.	Jun. <sup>6</sup>	Jun. <sup>2</sup>	May <sup>7</sup>	Apr. <sup>8</sup>	0.3		
		Median	0	0	0	0.03	0	0	0	1		

Depth of Lower is at 50cm above the seabed. 1 is Jun. and Sep.. 2 is Jun., Jul., and Sep..

3 is Apr., May, Jul. Sep., and Oct.. 4 is Jun., and Aug.. 5 is Apr. and Aug..

6 is Jun. and Sep.. 7 is May, and from Jul. to Oct.. 8 is Apr., and from Jun. to Aug..

**Online Resource 4a** Pairwise comparisons using Wilcoxon signed rank test (P value adjustment method is bonferroni), using monthly data of the highest mean DIN values with Sep. 2015 in surface seawater in each year.

	Dec.2009	Oct.2010	Oct.2011	Oct.2012	Nov.2013	Nov.2014
Oct.2010	0.0128	-	-	-	-	-
Oct.2011	1	0.0179	-	-	-	-
Oct.2012	0.0026	1	0.0026	-	-	-
Nov.2013	0.0051	0.2814	0.0051	0.0026	-	-
Nov.2014	0.0051	0.2247	0.0487	0.0026	0.1103	-
Mar.2015	0.6363	1	1	1	1	1

DIN, dissolved inorganic nitrogen

**Online Resource 4b** Pairwise comparisons using Wilcoxon signed rank test (P value adjustment method is bonferroni), using monthly data of the highest mean DIN values at 50cm above the seabed in each year.

	Dec. 2009	Oct. 2010	Oct. 2011	Oct. 2012	Nov. 2013	Nov. 2014
Oct. 2010	0.0026	-	-	-	-	-
Oct. 2011	1	0.0026	-	-	-	-
Oct. 2012	0.0026	1	0.0026	-	-	-
Nov. 2013	0.0026	0.0256	0.0026	0.0026	-	-
Nov. 2014	0.0229	0.0128	0.0846	0.0026	0.3486	-
Sep. 2015	1	0.0051	1	0.0026	1	1

DIN, dissolved inorganic nitrogen

**Online Resource 4c** Pairwise comparisons using Wilcoxon signed rank test (P value adjustment method is bonferroni), using monthly data of the lowest mean DIN values in surface seawater in each year.

	Aug. 2009	Jun. 2010	Aug. 2011	Aug. 2012	Apr. 2013	Mar. 2014
Jun. 2010	1	-	-	-	-	-
Aug. 2011	1	1	-	-	-	-
Aug. 2012	0.0229	0.0349	0.0026	-	-	-
Apr. 2013	0.0223	0.0026	0.0229	1	-	-
Mar. 2014	0.0229	0.0349	0.0026	1	1	-
Aug. 2015	0.0229	0.0026	0.0026	1	0.0792	0.1392

DIN, dissolved inorganic nitrogen

**Online Resource 4d** Pairwise comparisons using Wilcoxon signed rank test (P value adjustment method is bonferroni), using monthly data of the lowest mean DIN values at 50cm above the seabed in each year.

	Jun. 2009	Jun. 2010	Aug. 2011	Feb. 2012	Apr. 2013	Mar. 2014
Jun. 2009	-	-	-	-	-	-
Jun. 2010	1	-	-	-	-	-
Aug. 2011	0.0256	0.0128	-	-	-	-
Feb. 2012	0.0284	0.0229	0.0026	-	-	-
Apr. 2013	0.0227	0.0229	0.0026	0.055	-	-
Mar. 2014	0.0229	0.0229	0.0026	0.0344	1	-
May 2015	0.1455	0.4242	0.0026	1	0.0349	0.0229

DIN, dissolved inorganic nitrogen

**Online Resource 5a** Pairwise comparisons using Wilcoxon signed rank test (P value adjustment method is bonferroni), using monthly data of the highest mean DIP values in surface seawater in each year.

	Dec. 2009	Oct. 2010	Aug. 2011	Oct. 2012	Nov. 2013	Nov. 2014
Oct. 2010		1	-	-	-	-
Aug. 2011		1	1	-	-	-
Oct. 2012	0.0229	0.0229	0.4242	-	-	-
Nov. 2013	0.0227	0.0026	0.5292	1	-	-
Nov. 2014	0.0229	0.1646	1	0.0051	0.0346	-
Oct. 2015	0.357	1	1	0.0229	0.0051	0.6363

DIP, dissolved inorganic phosphate

**Online Resource 5b** Pairwise comparisons using Wilcoxon signed rank test (P value adjustment method is bonferroni), using monthly data of the highest mean DIP values at 50cm above the seabed in each year.

	Dec. 2009	Oct. 2010	Aug. 2011	Oct. 2012	Nov. 2013	Nov. 2014
Oct. 2010		1	-	-	-	-
Aug. 2011		1	1	-	-	-
Oct. 2012	0.0229	0.0026	0.0349	-	-	-
Nov. 2013	0.0229	0.0286	0.21	0.0344	-	-
Nov. 2014	0.0227	0.0227	0.1455	0.0229	1	-
Oct. 2015	0.1453	0.7539	0.357	0.0229	0.1491	0.4326

DIP, dissolved inorganic phosphate

**Online Resource 5c** Pairwise comparisons using Wilcoxon signed rank test (P value adjustment method is bonferroni), using monthly data of the lowest mean DIP values in surface seawater in each year.

	Apr. 2009	Feb. 2010	Oct. 2011	Apr. 2012	Apr. 2013	Jun. 2014
Feb. 2010		1	-	-	-	-
Oct. 2011	0.023	0.023	-	-	-	-
Apr. 2012	0.044	0.022	0.023	-	-	-
Apr. 2013	0.022	0.023	0.023	1	-	-
Jun. 2014	0.034	0.034	0.023	1	1	-
Apr. 2015	0.035	0.023	0.023	0.451	0.065	0.678

DIP, dissolved inorganic phosphate

**Online Resource 5d** Pairwise comparisons using Wilcoxon signed rank test (P value adjustment method is bonferroni), using monthly data of the lowest mean DIP values at 50cm above the seabed in each year.

	Apr. 2009	Feb. 2010	Dec. 2011	Apr. 2012	Feb. 2013	Jun. 2014
Feb. 2010		1	-	-	-	-
Dec. 2011	0.0229	0.0026	-	-	-	-
Apr. 2012	0.1088	0.0229	0.0227	-	-	-
Feb. 2013	0.022	0.0225	0.0223	1	-	-
Jun. 2014	0.0353	0.0225	0.0229	1	0.5439	-
Apr. 2015	0.0227	0.0229	0.0227	1	0.0638	1

DIP, dissolved inorganic phosphate



**Online Resource 6** The monthly mean maximum or minimum of each year in Sendai Bay

Nutrients	Conc.	Depth	Items	Year						
				2009	2010	2011	2012	2013	2014	2015
DIN	Maximum	Surface	Conc.	2.71	3.74	1.48	<b>4.88</b>	<b>0.55</b>	2.95	<b>0.55</b>
			S.D.	0.41	2.25	0.12	1.66	0.32	4.17	0.17
			Month	Jul.	Apr.	Nov.	Nov.	Apr.	Jun.	Sep.
		10m	Conc.	2.36	3.02	1.19	<b>5</b>	1.07	0.81	<b>0.69</b>
			S.D.	0.31	0.24	0.72	1.47	0.59	0.41	0.09
			Month	Jul.	Nov.	Oct.	Nov.	Apr.	Apr.	Sep.
	Minimum	Surface	Conc.	0.64	<b>1.05</b>	0.31	0.02	<b>0</b>	0.12	<b>0</b>
			S.D.	0.21	0.6	0.29	0.03	0	0.03	0
			Month	Jun.	Sep.	Sep.	May	Sep.	Oct.	Jul.
		10m	Conc.	0.62	<b>0.88</b>	0.55	<b>0</b>	0.05	0.17	<b>0</b>
			S.D.	0.19	0.15	0.28	0	0.07	0.09	0
			Month	Jun.	Aug.	Sep.	May	Sep.	Oct.	Jul.
DIP	Maximum	Surface	Conc.	0.3	0.41	0.16	<b>0.49</b>	<b>0.12</b>	0.42	0.18
			S.D.	0.03	0.03	0.02	0.11	0.02	0.6	0.03
			Month	May	Apr.	Nov.	Nov.	Apr.	Jun.	Nov.
		10m	Conc.	0.32	0.42	0.13	<b>0.45</b>	0.18	<b>0.02</b>	0.16
			S.D.	0.02	0.03	0.05	0.12	0.07	0.03	0.02
			Month	may	Apr.	Nov.	Nov.	Apr.	Apr.	Nov.
	Minimum	Surface	Conc.	<b>0</b>	<b>0.08</b>	0.03	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
			S.D.	0	0.02	0.03	0	0	0	0
			Month	Apr.	Jul.	Oct.	Jun., Sep.	Jun., Jul., Sep.	Apr., May, Jul., Sep., Oct.	Jun., Aug.
		10m	Conc.	<b>0</b>	<b>0.02</b>	0.01	<b>0.02</b>	<b>0</b>	<b>0</b>	<b>0</b>
			S.D.	0	0.03	0.02	0.02	0	0	0
			Month	Apr., Aug.	Jun.	Sep.	Jun, Sep.	Jun., Jul., Sep.	May, Jul., Aug., Sep., Oct.	Apr., Jun., Jul., Aug.

Red/blue color of bold is the highest/lowest concentration from 2009 to 2015.