Note

Effect of the 2011 Great East Japan tsunami on water quality in cultivation sites of Sanriku-Town area, southern Iwate Prefecture, Japan

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Abstract: Seven water quality parameters (pH, COD, DO, DO% saturation, TN, transparency and oil film) were monitored in cultivation sites of the Sanriku-Town area, southern Iwate Prefecture, Japan before and after the 2011 Great East Japan tsunami (summer 2008 to winter 2014). The pH, COD, DO and TN ranged within the highest level of water quality in the “Environmental Quality Standards for Conservation of the Living Environment” established by the Ministry of the Environment of Japan, except for the surface DO in the summer of post-tsunami period. The transparency after the tsunami fluctuated at a slightly high level in comparison with that before the tsunami. The DO% saturation retained close to saturation or supersaturation state, and no oil film was detected over the period of this study. In addition to these water quality studies, Undaria pinnatifida sporophytes from the same strain were cultured using the same method in pre- and post-tsunami periods. Their thallus density, length and wet weight did not differ between the two periods. These findings show that the high level of water quality in the cultivation sites of the Sanriku-Town area was maintained after the tsunami.

Key words: Undaria pinnatifida; Sanriku-Town area; The 2011 Great East Japan tsunami; Water quality

The 2011 Great East Japan earthquake and tsunami hit the Pacific coast of the Tohoku and Kanto Region, including Aomori, Iwate, Miyagi, Fukushima, Ibaraki, and Chiba Prefectures. Due to this tsunami, the coastal environments changed remarkably (Kutsumi et al. 2013; Murakami et al. 2013); moreover, huge numbers of buildings and infrastructures were destroyed with a large amount of disaster debris (Inui et al. 2012; Ogasawara and Sakai 2012). The tsunami also utterly destroyed the cultivation facilities in the southern coast of Iwate Prefecture, including Sanriku-Town area. Prior to the tsunami, this coastal area was among the major cultivation fields of Undaria pinnatifida (Harvey) Suringar, and the annual harvest of this species accounted for approximately 14% (7,400 t) of its production in Japan. Other commercially harvested species included Mizuhopecten yessoensis Jay and Halocynthia roretzi Drasche, and their annual harvests were 3,200 t and 860 t, respectively (Ministry of Agriculture, Forestry and Fisheries of Japan 2010).

In the Sanriku-Town area, U. pinnatifida cultivation resumed at the end of 2011, and most of the cultivation facilities were restored in 2013 (City of Ofunato 2014). To this day, however, it has not yet been revealed whether...
the tsunami had a significant effect on water quality in this area. In the present study, seven water quality parameters [pH, chemical oxygen demand (COD), dissolved oxygen (DO), DO% saturation, total nitrogen (TN), transparency and oil film] were monitored in cultivation sites of the Sanriku-Town area over a period of six summer and winter months (September 2008 to February 2014), and these parameters were compared between pre- and post-tsunami periods. To determine the level of water quality in this area, the monitored pH, COD, DO and TN were applied to the “Environmental Quality Standards for Conservation of the Living Environment (EQSs)” relating to water pollution for the fishing grounds (Ministry of the Environment of Japan 1971). In addition to these water quality studies, _U. pinnatifida_ sporophytes were cultured in post-tsunami period to investigate the effect of the tsunami on their growth.

**Materials and Methods**

**Water quality**

Field observations were conducted at eleven monitoring stations (15–90 m in depth), located in four cultivation sites (Yoshihama Bay, Okirai Bay, Ryori Bay and open sea) of the Sanriku-Town area (Fig. 1), in the summer and winter of pre-tsunami (September 2008 to February 2011) and post-tsunami periods (September 2011 to February 2014). At each station, the surface water was sampled on board a boat using plastic bottles, while bottom water samples were collected using a Niskin bottle. These samples were used to analyze pH as an indicator of acidic and alkaline pollution, and COD, DO, DO% saturation and TN relating to organic pollution. The pH was measured with a pH meter (Model IQ240, IQ Scientific Instruments) or a pH/Ion meter (S220, Mettler-Toledo International, Inc.). The COD was determined using acidic potassium permanganate method with a portable analyzer (TNP-10, DKK-TOA Corporation). The DO and DO% saturation were recorded using a LDO probe with portable meter (HD30d, Hach Company) or a RINKO-Profiler ASTD unit (ASTD102, JFE Advantech Co., Ltd.). For the TN, water samples were digested with a potassium persulfate solution in an autoclave and subsequently analyzed using the copper-coated cadmium reduction procedure followed by the colorimetric method (Wood et al. 1967; Parsons et al. 1984). In addition to the five parameters, transparency as an indicator of water turbidity was measured with a 30 cm diameter Secchi disk and, the presence of oil film floating on the water surface was checked visually.

Statistical differences in the pH, COD, DO, DO% saturation, TN and transparency among monitored years were separately analyzed in each season, depth and cultivation site by one-way analysis of variance (ANOVA), that is, the 88 monitored cases (16 cases in the five former parameters, and 8 cases in the transparency) were tested using a series of one-way ANOVA (Table 1). Replicates were monitoring stations in each cultivation site (n = 3 in Yoshihama Bay, Okirai Bay and Ryori Bay, and 2 in the open sea). Furthermore, the pH, COD, DO and TN were applied to the EQSs divided into three classes: “Fishery class 1” (7.8 ≤ pH ≤ 8.3, COD ≤ 2 mg/l, DO ≥ 7.5 mg/l, TN ≤ 0.3 mg/l), “Fishery class 2” (7.8 ≤ pH ≤ 8.3, COD ≤ 3 mg/l, DO ≥ 5 mg/l, TN ≤ 0.6 mg/l), and “Fishery class 3” (TN ≤ 1 mg/l) (Ministry of the Environment of Japan 1971).

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**Fig. 1.** Location of eleven monitoring stations in four cultivation sites (Yoshihama Bay, St. 1-St. 3; Okirai Bay, St. 4-St. 6; Ryori Bay, St. 7-St. 9; open sea, St. 10-St. 11) of Sanriku-Town area, the southern Iwate Prefecture, Japan. Bottom depth of each station is shown in parenthesis.
Undaria pinnatifida culture

Undaria pinnatifida sporophytes were cultured along a 50-m cultivation rope at St. 5 of Okirai Bay in the Sanriku-Town area in post-tsunami period (December 2013 to April 2014) using the same strain (Taro strain) and the same method as those used for our previous study (Nanba et al. 2013) conducted in the pre-tsunami period (December 2006 to April 2007). All sporophytes on six and two locations of the rope (0.3 m of the rope for each place) randomly selected in pre- and post-tsunami periods, respectively, were collected at the end of culture. After determining thallus density, thallus length and wet weight were measured for the ten longer sporophytes on each location. Their thallus density, length and wet weight were statistically compared with those in the previous study (Nanba et al. 2013) by unpaired t-tests with Welch’s correction. Replicates of thallus density were locations on the rope in the pre-tsunami (n = 6) and post-tsunami periods (n = 2), and those of thallus length and wet weight were the sporophytes in pre-tsunami [n = 60 (10 in each location)] and post-tsunami periods [n = 20 (10 in each location)].

In the present study, homogeneity of variance was tested using Bartlett’s test, before the one-way ANOVAs. If the variance homogeneity test failed, Kruskal-Wallis test was used. Probability values less than 0.05 were considered statistically significant.

Results

Water quality

In the Sanriku-Town area, mean pH, COD, DO, DO% saturation, TN and transparency were between 7.8-8.2, 0.5-1.6 mg/l, 7.5-10.5 mg/l, 97-115%, 0.07-0.20 mg/l, and 9-21 m during the pre-tsunami period, and between 7.8-8.2, 0.5-1.7 mg/l, 7.2-10.5 mg/l, 97-109%, 0.08-0.23 mg/l, and 10-23 m during the post-tsunami period (Fig. 2). During this study, the pH, COD, DO, DO% saturation, TN and transparency did not differ significantly among monitored years in 37 (4-10 cases in the five former parameters and 3 cases in the transparency) of the 88 monitored cases, and varied significantly within their limits before the tsunami in the 22 cases (2-7 cases in the five former parameters and 2 cases in the transparency) (Fig. 2; Table 1). In addition, the pH, COD, DO and TN ranged within the limits of the “Fishery class 1” in the EQSs, except for the DO applied to the “Fishery class 2” in the summer of post-tsunami period (7.2-7.4 mg/l of surface DO in Yoshihama Bay and Ryori Bay in 2011, in Okirai Bay, Ryori Bay and the open sea in 2012, and in all cultivation sites in 2013, and bottom DO in Yoshihama Bay, Ryori Bay and the open sea in

Fig. 2. Summer and winter pH (A, B), COD (C, D), DO (E, F), DO% saturation (G, H) and TN (I, J) in the surface and bottom waters, and summer and winter transparency (K, L) in the four cultivation sites of the Sanriku-Town area during pre- and post-tsunami periods. Data are shown as means ± SD (n = 3 in Yoshihama Bay, Okirai Bay and Ryori Bay, and 2 in open sea). Symbols connected by solid and dashed lines indicate the surface and bottom waters, respectively; solid circles, Yoshihama Bay; open circles, Okirai Bay; solid triangles, Ryori Bay; open triangles, open sea.
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2013; Fig. 2E). The DO% saturation was above 97% over the period of this study (Fig. 2G, 2H). The transparency in post-tsunami period fluctuated at a slightly high level compared with that in pre-tsunami period (Fig. 2K, 2L), and no oil film was detected during the two periods.

Thallus density, length and wet weight of Undaria pinnatifida sporophytes

Thallus density, length and wet weight of cultured Undaria pinnatifida sporophytes were 70 thalli/m (SD = 5), 176 cm (SD = 16) and 182 g (SD = 69) in the pre-tsunami period, and 70 thalli/m (SD = 5), 176 cm (SD = 16) and 182 g (SD = 69) in the post-tsunami period (Fig. 3). Their thallus density did not differ significantly between the two periods (unpaired t-test with Welch’s correction, t_{1.919} = 0.000, P = 1.000). No significant differences were found in their thallus length (unpaired t-test with Welch’s correction, t_{50.467} = 1.913, P = 0.062) and thallus wet weight (unpaired t-test with Welch’s correction, t_{29.707} = 0.646, P = 0.523) between the two periods.

Discussion

The 2011 Great East Japan tsunami caused devastating damage to the southern coast of Iwate Prefecture, including the Sanriku-Town area, with distinct change in coastal environments, utter destruction of infrastructures and buildings, and a large amount of disaster debris (Inui et al. 2012; Ogasawara and Sakai 2012; Murakami et al. 2013). In 2012, the M. yessoensis and H. roretzi productions did not recovered because these species take more than three years to be harvest, while the U. pinnatifida production reached approximately 70% of its previous level (Ministry of Agriculture, Forestry and Fisheries of Japan 2010, 2012).

Table 1. Results of one-way ANOVA or Kruskal-Wallis test for the differences in the pH, COD, DO, DO% saturation, TN and transparency among monitored years in the 88 monitored cases (16 cases in the five former parameters, and 8 cases in the transparency) shown in Fig. 2

<table>
<thead>
<tr>
<th>Season</th>
<th>Depth</th>
<th>Cultivation site</th>
<th>pH</th>
<th>COD</th>
<th>DO</th>
<th>DO% saturation</th>
<th>TN</th>
<th>Transparency</th>
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<tbody>
<tr>
<td>Summer</td>
<td>Surface</td>
<td>Yoshihama Bay</td>
<td>4.625</td>
<td>6.221</td>
<td>0.005</td>
<td>16.18</td>
<td>0.006</td>
<td>15.29</td>
</tr>
<tr>
<td></td>
<td>Yoshihama Bay</td>
<td>16.47</td>
<td>0.006</td>
<td>11.32</td>
<td>0.045</td>
<td>16.07</td>
<td>0.007</td>
<td>30.31</td>
</tr>
<tr>
<td></td>
<td>Ryori Bay</td>
<td>15.96</td>
<td>0.007</td>
<td>1.566</td>
<td>0.245</td>
<td>15.43</td>
<td>0.009</td>
<td>81.52</td>
</tr>
<tr>
<td></td>
<td>Open sea</td>
<td>7.333</td>
<td>0.197</td>
<td>5.244</td>
<td>0.387</td>
<td>72.67</td>
<td>0.001</td>
<td>7.255</td>
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<tr>
<td>Bottom</td>
<td>Yoshihama Bay</td>
<td>13.23</td>
<td>0.021</td>
<td>11.96</td>
<td>0.035</td>
<td>4.831</td>
<td>0.012</td>
<td>0.622</td>
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<tr>
<td></td>
<td>Okirai Bay</td>
<td>2.345</td>
<td>0.105</td>
<td>12.22</td>
<td>0.032</td>
<td>3.271</td>
<td>0.043</td>
<td>1.206</td>
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<tr>
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<td>Ryori Bay</td>
<td>16.01</td>
<td>0.007</td>
<td>2.204</td>
<td>0.122</td>
<td>34.88</td>
<td>0.001</td>
<td>14.36</td>
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<td>9.581</td>
<td>0.088</td>
<td>6.484</td>
<td>0.262</td>
<td>7.904</td>
<td>0.158</td>
<td>8.182</td>
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<tr>
<td>Winter</td>
<td>Surface</td>
<td>Yoshihama Bay</td>
<td>13.49</td>
<td>0.019</td>
<td>9.221</td>
<td>0.101</td>
<td>5.014</td>
<td>0.010</td>
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<tr>
<td></td>
<td>Okirai Bay</td>
<td>15.97</td>
<td>0.007</td>
<td>10.59</td>
<td>0.06</td>
<td>4.130</td>
<td>0.021</td>
<td>3.583</td>
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<td>Ryori Bay</td>
<td>15.75</td>
<td>0.006</td>
<td>11.41</td>
<td>0.044</td>
<td>7.151</td>
<td>0.003</td>
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<tr>
<td></td>
<td>Open sea</td>
<td>10.63</td>
<td>0.059</td>
<td>5.832</td>
<td>0.344</td>
<td>1.269</td>
<td>0.385</td>
<td>1.028</td>
</tr>
<tr>
<td>Bottom</td>
<td>Yoshihama Bay</td>
<td>13.97</td>
<td>0.016</td>
<td>10.93</td>
<td>0.053</td>
<td>14.18</td>
<td>0.001</td>
<td>17.85</td>
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<td>Okirai Bay</td>
<td>15.24</td>
<td>0.009</td>
<td>5.000</td>
<td>0.416</td>
<td>5.117</td>
<td>0.010</td>
<td>3.504</td>
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<td>Ryori Bay</td>
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<td>11.47</td>
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<tr>
<td></td>
<td>Open sea</td>
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<td>4.717</td>
<td>0.451</td>
<td>10.48</td>
<td>0.063</td>
<td>5.085</td>
</tr>
</tbody>
</table>

F indicates F-value for one-way ANOVA in the Yoshihama, Okirai and Ryori Bay, and (F) in the open sea.

H represents chi-squared for Kruskal-Wallis test.
P-values in parentheses denote the monitored cases that these parameters after the tsunami fluctuated within their limits before the tsunami.

Fig. 3. Thallus density (A), length (B) and wet weight (C) of Undaria pinnatifida sporophytes at St. 5 of Okirai Bay in the pre- and post-tsunami periods. Data are shown as means ± SD (n = 6 and 2 in A, and 60 and 20 in B and C of pre- and post-tsunami periods, respectively).
In this and our previous studies (Nanba et al. 2013), *U. pinnatifida* sporophytes from the same strain were cultured using the same method in the Sanriku-Town area in the pre- and post-tsunami periods. Their thallus density, length and wet weight did not differ between the two periods. These results show that the *U. pinnatifida* production probably reach its pre-tsunami level.

Moreover, seven water quality parameters (pH, COD, DO, DO% saturation, TN, transparency and oil film) were monitored in the cultivation sites of the Sanriku-Town area during pre- and post-tsunami periods. The monitored pH, COD, DO and TN were applied to the EQSs relating to water pollution for the fishing grounds (Ministry of the Environment of Japan 1971). During the two periods, the pH, COD, DO, DO% saturation, TN and transparency did not vary significantly or fluctuated within their limits before the tsunami in two-third of the monitored cases (four-ninth to three-fourth of the cases in these parameters); moreover, the pH, COD, DO and TN were applied to the class indicating the highest level of water quality in the EQSs, except that the summer waters were slightly lower than the lower limit of this class in post-tsunami period. The DO% saturation retained close to saturation or supersaturation state over the period of this study. In addition to these parameters, the monitored transparency in post-tsunami period fluctuated at a slightly high level in comparison with that in pre-tsunami period, and no oil film was observed during the two periods. These findings show that the high level of water quality in the cultivation sites of the Sanriku-Town area was maintained after the tsunami, with no water turbidity, acidic and alkaline pollution, and organic and oil pollution derived from the tsunami disturbance, the damage of sewage facilities, and the disaster debris. On the other hand, large-scale reconstruction projects in this area have progressed to a full-fledged phase (Reconstruction Agency of Japan 2011); therefore, future monitoring should take account of the effect of terrestrial conditions, river waters in particular, on water quality in the cultivation sites.

**Acknowledgments**

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**References**


岩手県南部三陸町養殖海域の水質に対する東日本大震災の影響

難波信由・加戸隆介・鴨志田絃子・篠塚美佐希

岩手県南部三陸町海域の養殖水質に対する東日本大震災の影響の有無を明らかにするために、震災前後各3年間の夏季と冬季の7つの水質項目（pH, COD, DO, DO饱和度, TN, 透明度, 油膜）を測定、比較した。その結果、DO, TN, pH, COD の4項目は、震災後夏季の DO を除き、環境省が設定した「生活環境の保全に関する環境基準」において最も高い水質を示す範囲であり、DO 鮮和度は測定期間を通じて飽和付近または過飽和な状態であった。そして、震災後も透明度は震災前に比べてわずかに高い範囲で変動し、油膜は測定期間を通じて観察されなかった。さらに、ワカメの養殖実験を震災後に実施して震災前の結果と比較した結果、養殖ワカメの藻体密度、藻長、藻体体重量に差はみられなかった。これらの結果は、三陸町海域の高水準な養殖水質に対して東日本大震災が大きな影響をおよぼしていないことを示していた。