Impacts of the 2011 Mega-earthquake and Tsunami on Ezo Abalone *Haliotis discus hannai* at Iwaisaki, Miyagi, Japan

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Abstract

On 11 March 2011, a massive tsunami generated by a mega-earthquake hit a wide area of the Pacific coast of northeast Japan. We have analysed the effects of the tsunami on Ezo abalone *Haliotis discus hannai* population at Iwaisaki in Miyagi, Japan. Ezo abalone is among the most economically valuable fisheries resources, so assessments are needed to evaluate the effects of the disaster on this important species. Before the tsunami, algal forests dominated by the brown macroalga *Eisenia bicyclis* had developed in the survey area, where large juvenile and adult abalone >30 mm in shell length (SL) inhabited. Juvenile abalone <30 mm SL inhabited the area dominated by crustose coralline algae (CCA). After the tsunami, no apparent decrease was observed in the density of large juvenile and adult abalone inhabited in the algal forests. The impact of the tsunami was more profound in the CCA area than in the algal forests. Just before the tsunami, the intensive recruitment of zero-year-old juveniles was observed, but individuals of this year class were not detected after the event. The distribution pattern of juveniles could be a cause of the marked decrease, because most of them inhabited the CCA area where the disturbance by the massive water movement was not reduced by the effects of the macro algal forest. Since the age at first capture of abalone is at 4–5 years old, the future commercial catch may considerably decrease for at least 4–5 years after the tsunami.

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1 Introduction

On 11 March 2011, the Great East Japan Earthquake occurred off the Pacific coast of the northeastern part of Honshu Island, Japan, with a moment magnitude of 9.0 at a depth of 24 km. The massive tsunami generated by this earthquake severely impacted the coast of northeastern

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Honshu Island and resulted in the loss of nearly 19,000 people and devastated many towns in the coastal areas of this region. Fisheries are one of the most important industries in the coastal area impacted by the tsunami. Assessments are needed to evaluate the effects of the earthquake and tsunami on coastal populations of fishery resource organisms for the future fishery and stock enhancement.

On the Pacific coast of northeastern Honshu Island, which was severely disturbed by the massive tsunami, Ezo abalone *Haliotis discus hannai* is one of the most valuable fisheries resources and also play an important role in the food web of the rocky shore ecosystem (Won et al. 2011). The main objective of this study is to examine the effects of the earthquake and subsequent tsunami on the abalone populations. Data on the abalone population before the earthquake and tsunami event are essential to allow comparison and clarify the scale of impacts. Before March 2011, we regularly carried out quantitative analyses on the population of this fisheries resources at Iwaisaki, Miyagi Prefecture. To assess the impacts of the earthquake and tsunami by before and after comparisons, we carried out the survey using the same method after the earthquake and tsunami, in order to compare the results with the data collected before the event.

2 Materials and Methods

2.1 Study Site

This study was done in the rocky subtidal habitats at Iwaisaki located near the mouth of Kesennuma Bay (Fig. 1). As the site faces an open ocean, waves impact this area directly. We selected four stations of 10 m × 10 m each (named A, D, E, G) in the study site. Station A was dominated by crustose coralline alga (CCA) *Lithophyllum yessoense* and the other stations were included in kelp beds (KB) dominated by the brown macroalga *Eisenia bicyclis*. A detailed information of these stations was described in Table 1. All fisheries were closed in the study site after the earthquake at least until June 2011 when the last survey was carried out in this study.

2.2 Sample Collection

The abalone *Haliotis discus hannai* were quantitatively sampled by scuba diving in the mornings of 23 October 2009 (before the earthquake) and 15 June 2011 (after the earthquake) using 2 m×2 m quadrats. In each station, five replicate quadrats were haphazardly located, and all abalone in the quadrats were collected by hand and placed in mesh

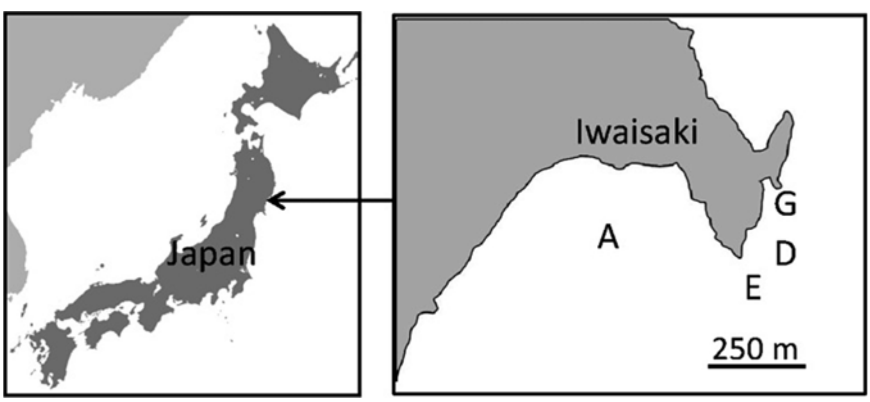

Fig. 1 Location of the study site and stations *A*, *D*, *E*, and *G*

bags before being transported to the boat. The shell length (SL) of abalone was measured to the nearest 1 mm with callipers on the boat, and measured animals were released to their original habitats.

The recruitment process during the juvenile stage of 2008–2010 year classes of abalone was also investigated with the method of Takami et al. (2013) near station A which is located in CCA. Since the distribution of juvenile abalone was too cryptic and patchy to estimate their density by the quadrat sampling, the abundance of juveniles' shell length inferior to 40 mm SL was regularly monitored by intensive visual searching from December 2009 to June 2011. In every survey, the same diver searched for juvenile abalone in every crevice and overhangs by sometimes overturning boulders and removing large *epibiota*, recording each searching time. Juvenile abalone were carefully removed from substrata and transferred to a sampling bottle with fine tweezers. The relative abundance of juvenile abalone was expressed as catch per unit effort (CPUE), accounting for the number of collected juveniles per searching time in hours. The shell length of collected juveniles was measured to the nearest 0.1 mm using a video camera system with an image analyser connected to a dissecting microscope in the laboratory.

2.3 Data Analysis

Changing in abalone densities were tested by a two-way analysis of variance (ANOVA) using date of sampling and type of algal community as fixed factors. Data were transformed in [$\log(n+1)$] in the case of heterogeneous variation.

Table 1 Location and environmental features for each sampling station

Station	Latitude (N)	Longitude (E)	Depth (m)	Dominated algae
A	38°49.673′	141°35.995′	4–5	Crustose coralline algae
D	38°49.622′	141°36.258	4–5	Kelp
E	38°49.573′	141°36.218′	4–5	Kelp
G	38°49.717′	141°36.275′	3–4	Kelp

3 Results and Discussion

After the tsunami, the underwater visibility at the study site was much lower than that before the earthquake and tsunami due to sediment suspension. A remarkable increase in the amount of fine sediments was observed under boulders and in crevices of bedrocks. In stations D, E, and G, although the remaining holdfasts of *E. bicyclis* that lost their fronds were sometimes observed, the biomass of this alga appeared to be undamaged by the event. More severe disturbance was obvious in station A which was located in CCA. Many of the large rocks were cracked and turned over on the seafloor and in consequence bare rocks, which were not covered with any *epibiota* including crustose coralline algae, were exposed in many places.

Abalone density obtained by the quantitative quadrat survey varied significantly among stations and dates of sampling, but there was no significant date by station interaction for the abalone density by the two-way ANOVA (Table 2).

After the tsunami, station A located in CCA indicated the lowest mean densities. In the other stations located in KB, obvious changes in the abalone density were not observed (Fig. 2).

There are no clear trends in the size-frequency distributions of abalone before and after the tsunami. The abalone smaller than 30 mm in shell length was not sampled by quadrat possibly because of the relatively low density and patchy distribution of juveniles (Fig. 3). Juveniles were only detected by intensive visual searching during the recruitment process monitoring which was conducted near station A.

Table 2 Two-way ANOVA for densities of abalone *Haliotis discus hannai* between sampling dates and habitats at Iwaisaki, Japan

	df	MS	F	P
Sampling date	1	0.718	8.562	0.006
Habitats	3	2.806	11.152	0.000
Interaction	3	0.380	1.511	0.231
Residual	32	2.684		

The main spawning season of Ezo abalone at this site is from late August to early October (Nakaie and Takami 2012). In December 2009, small juveniles (4.6–12.5 mm SL) which were reproduced in the 2009 spawning season were observed as the cohort with higher CPUE than the 2008 year class. Then, the CPUE of the 2009 year class did not markedly decrease until June 2010. From December 2010 to February 2011, newly recruited juveniles, which were spawned in 2010, were detected as a single cohort. During the same period, juveniles of the 2009 year class grew to more than 25 mm SL with lower CPUE. In June 2011, 3 months after the tsunami, no individual of the 2010 year class was not observed, whereas the CPUE of the 2009 year class did not change obviously between before (February 2011) and after (June 2011) the tsunami (Fig. 4).

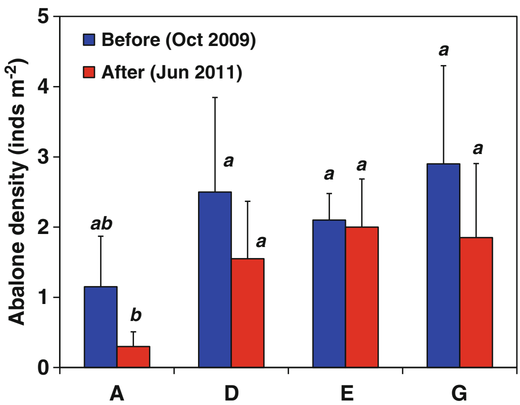

Fig. 2 Changes in density of Ezo abalone *Haliotis discus hannai* collected in stations *A*, *D*, *E*, and *G* between before and after the earthquake and tsunami

From the results of quadrat sampling and CPUE survey on juveniles, it was demonstrated that the impacts of tsunami on Ezo abalone *Haliotis discus hannai* were different among stations and their growth stages. After the tsunami, although significant difference was not marginally detected, abalone densities by quadrat sampling tend to decrease in station A which was dominated by CCA.

Newly recruited juveniles inhabit near station A was more severely affected by the tsunami than older individuals. Juveniles reproduced in 2010 were not detected after the tsunami, and such a collapse of the youngest year class has not been observed before the tsunami. Naylor and McShane (2001) suggest that the wave action caused by even usual storm disturbances is an important contributor to the mortality of new recruits in the New Zealand abalone *H. iris* because of the relatively weaker adhesion of juveniles to substrate than that of adults. Similarly, the much more serious disturbance by the tsunami event could specifically influence the survival of smaller abalone in the present study site. The distribution pattern of juvenile abalone also had significant consequences for their survival. Juveniles mainly inhabit crustose coralline algae, which were more severely disturbed than

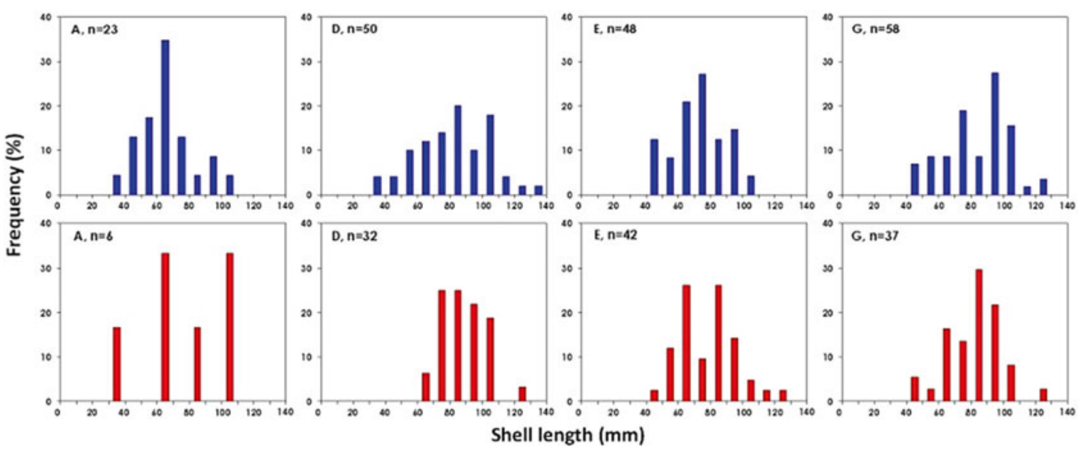

Fig. 3 Changes in size distribution of Ezo abalone *Haliotis discus hannai* collected in stations *A*, *D*, *E*, and *G* between before (October 2009, *upper row*) and after (June 2011, *lower row*) the earthquake and tsunami

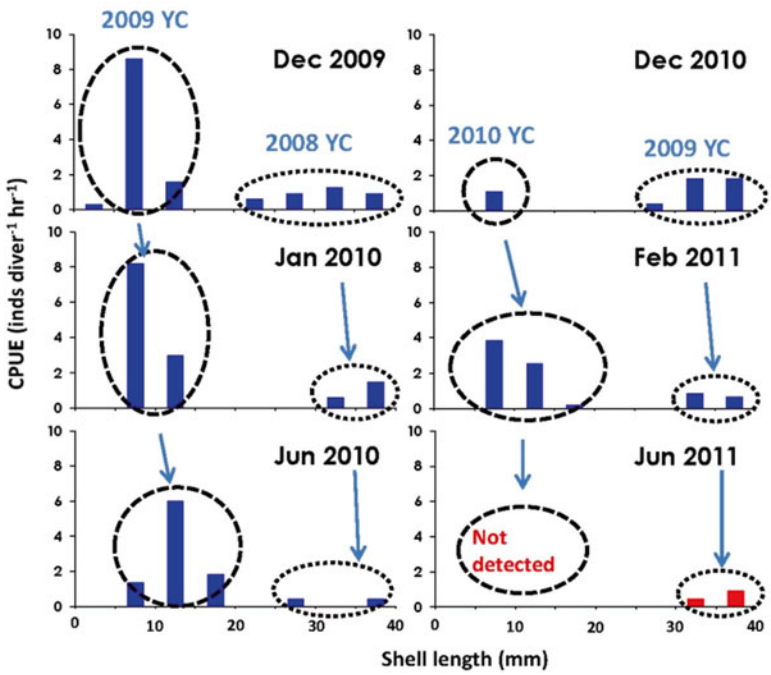

Fig. 4 Changes in CPUE for the number of collected juvenile Ezo abalone *Haliotis discus hannai* per searching time in hours with size distribution between before and after the earthquake and tsunami

in kelp beds. In contrast, the main habitat of adult abalone is kelp beds, where the current velocity of the tsunami might have been partially attenuated by the presence of the algal canopy as observed in the previous tsunami event generated by the Sumatra-Andaman earthquake in 2004 (Whanpetch et al. 2010).

Takami et al. (2013) also reported that young-of-the-year Ezo abalone (2010 year class) were seriously affected by this mega-earthquake and the tsunami at Oshika Peninsula in Miyagi which is located 53 km south from this study point. There is a possibility that the mega-earthquake and tsunami had a negative impact in a wide range in the survival of the smaller juvenile of Ezo abalone. Since the age at first capture of abalone is 4–5 years old (Sasaki 1999), the future commercial catch may considerably decrease at least after 4–5 years from the event. Continuous monitoring of the affected abalone population is needed for effective stock management to avoid collapse of these ecologically and economically important resources.

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