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Population dynamics of the northern sea urchin Mesocentrotus nudus in Southwestern Hokkaido, Sea of Japan

Dinamika populasi bulu babi *Mesocentrotus nudus* di Hokkaido Barat Daya, Laut Jepang

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ABSTRACT

Kelp bed degradation due to environmental changes and overgrazing by herbivores such as sea urchins has raised concerns about the sustainability of coastal ecosystems and fisheries in northern Japan. Over a 35-year period (1985–2020), population dynamics of the northern sea urchin *Mesocentrotus nudus* were monitored in Shimamaki Village, southwestern Hokkaido, focusing on age-specific density fluctuations. First-year juvenile recruitment varied substantially, while adult density showed smaller fluctuations but a long-term declining trend. No significant correlation was found between juvenile recruitment and adult density, or between adult density and catch volume. Field data were collected through annual scuba surveys using 1 m^2 quadrats, and age was determined by test diameter and genital plate rings. Statistical relationships were assessed using Spearman's rank correlation. The weak correlation suggests that post-recruit mortality, food limitation due to kelp loss, and harvesting pressure may decouple recruitment from adult population size. These findings imply that sustainable sea urchin fisheries require more than just enhancing recruitment; ecosystem-based management including macroalgal restoration is essential. Understanding the role of Isoyake in reducing kelp availability provides critical insight into population stability and fishery yields in northern Japan.

Keywords: age, density, growth, recruit, sea urchin, yearly fluctuation

1. Introduction

The northern sea urchin, *Mesocentrotus nudus*, inhabits rocky shores along the Korean Peninsula, Primorsky in mainland Russia, and Northern Japan, with test diameters reaching up to 7 cm. Their life cycle begins with spawning in the autumn season, followed by a planktonic stage lasting approximately 1–2 months. After settling on the surface of boulders in rocky shores, benthic juveniles begin feeding on sea algae, with the kelp Saccharina japonica being an important food source (Agatsuma, 2014). The gonads of the northern sea urchin are edible and commercially significant for coastal fisheries, being consumed in Asia (China, Korea, and Japan) (Agatsuma, 2014). Considerable research has been conducted on the basic biology of *Mesocentrotus nudus* to facilitate sustainable utilization of their stock. Studies have examined aspects such as the size of first maturity (Fuji, 1960b), reproductive cycle (Fuji, 1960a, c), occurrence dynamics of planktonic larvae (Agatsuma, et al., 1998), distribution on fisheries grounds (Nabata et al., 1992), growth of test diameter (Kawamura, 1966), the influence of wave and water movement on feeding pressure (Kawamata, 1997; 1998), chemical inducers on larval settlement and metamorphosis (Taniguchi et

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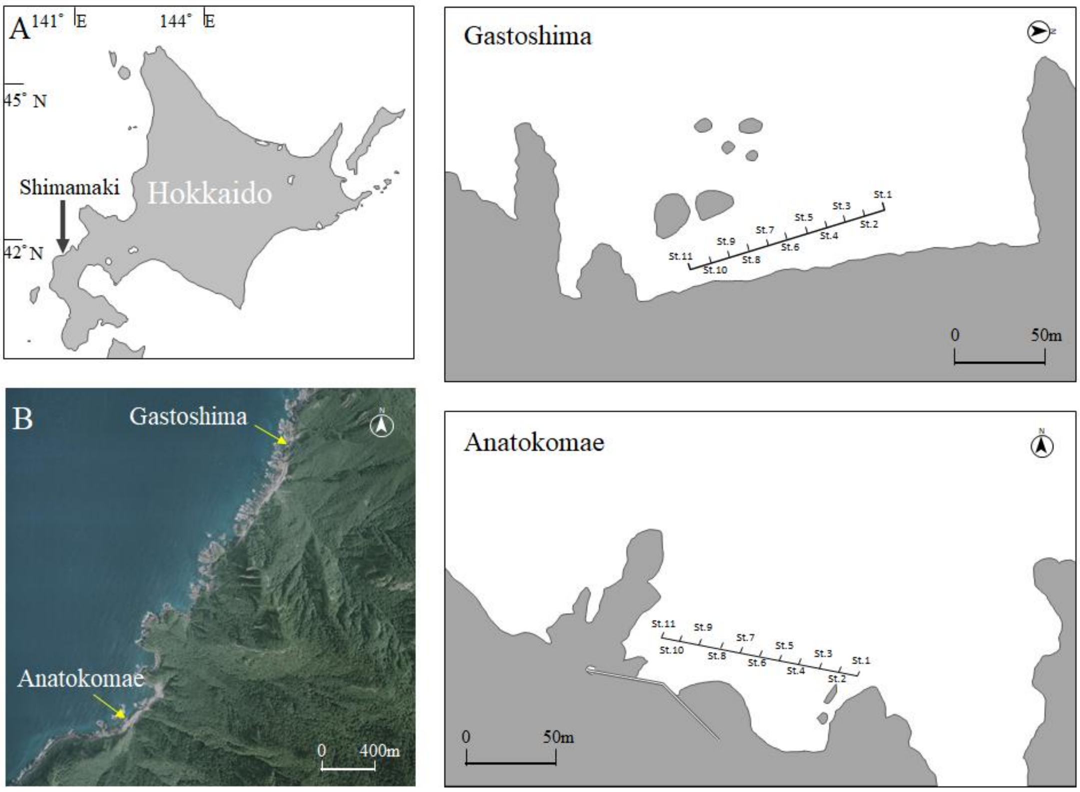
al., 1994), and the role of the Isoyake phenomenon in maintaining higher densities of the species (Agatsuma et al., 2006; Taniguchi, 1991).

Isoyake is defined as the phenomenon of decreased or disappearing beds of upright algae, resulting in poorly vegetated areas on shallow bedrock and stony beds (Ayling, 1981). In shallow subtidal areas, Isoyake has led to the formation of some sea urchin barrens but not stable barren areas such as ones often found offshore of seaweed beds (Fujita, 2010). Long-term studies by Gouda et al. (2017) and Gouda and Agatsuma (2020) have investigated the recruitment of sea urchin Strongylocentrotus intermedius in the Sea of Japan. Agatsuma et al. (1998) demonstrated that the recruitment of juvenile *M. nudus* depends on higher seawater temperatures in the autumn season in Shimamaki Village, as observed through monitoring surveys in the area.

However, few studies have addressed the long-term fluctuations in *M. nudus* recruitment in relation to adult population size, catch trends, and the influence of Isoyake conditions, despite their potential importance for sustainable fisheries management. This knowledge gap limits our ability to predict stock dynamics and to develop effective conservation and harvesting strategies. The present study aims to clarify the long-term population dynamics and recruitment mechanisms of *M. nudus* in Shimamaki Village, addressing the question of how juvenile recruitment relates to adult sea urchin populations and how these populations influence catch volume. To this end, we continued monitoring over 35 years on an annual basis, updating data on recruitment and adult stock, and revealed significant relationships between juvenile recruitment and adult populations, as well as correlations between adult populations and fishery catches. The study also examined the effects of the Isoyake phenomenon on the year-to-year fluctuations of sea urchin stocks.



Panel B is modified from the Geospatial Information Authority of Japan (https://www.gsi.go.jp/tizu-kutyu.html).

Figure 1. Map showing the study sites for the sea urchin *Mesocentrotus nudus*.

2. Methods

2.1. Study Site and Sampling Methods

A diving survey was conducted at 22 sampling sites off Anatokomae and Gastojima in Shimamaki Village, southwestern Hokkaido, Japan, located in the Sea of Japan (Figure 1), during August or September from 1985 to 2020. The substrate at the sampling sites was predominantly bedrock, and water depth increased gradually to 10 m at a distance of 100 m from the shore. Sampling points were positioned at 10 m intervals along a 100 m transect line placed on the seafloor, with depths ranging from 1 to 9 m, extending from the shore to offshore in a fixed direction at both locations. Sea urchins were collected using scuba diving and a 1 m^2 quadrat at each sampling point. The test diameter of each collected sea urchin was measured with a digital caliper. The year-class of the sea urchins was determined by examining the growth rings on their genital plates, following the method of Jensen (1969). The ages determined in September correspond to the spawning season (Sugimoto et al., 1982).

The relationship between the mean test diameter of each year class and age was analyzed for these three years. The total number of sea urchins collected from the two transect lines at each site varied between 80 and 451 individuals, depending on the year and sampling location. Additionally, the catch volume of northern sea urchins in Shimamaki Village was obtained from the official report of the Hokkaido Government (http://www.pref.hokkaido.lg.jp/sr/sum/03kanrig/sui-toukei/suitoukei.htm, downloaded on April 1st, 2021). This dataset was used to evaluate the relationship between adult sea urchin density and regional catch.

2.2. Statistical Analysis

Normality of the data was tested using the Shapiro–Wilk test. As the data did not meet the assumption of normality, a non-parametric approach was chosen. The correlation between the density of first-year northern sea urchins and adult sea urchins (4–8 years old) was analyzed using the non-parametric Spearman's rank correlation coefficient, with a significance level set at 5%.

3. Result and Discussion

3.1. Result

3.1.1. Temporal changes in the density of the sea urchin

Figure 2 shows the temporal changes in the density of the sea urchin *Mesocentrotus nudus* from 1985 to 2020. The density of individuals across all age classes (1–8 years) ranged from 3.7 ind./m^2 in 1995 to 20.5 ind./m^2 in 1985 (Figures 2A and 2B). Recruitment of first-year juveniles exhibited significant annual fluctuations (Kruskal–Wallis test, $p < 0.05$), with no recruitment recorded in 1988, 2003, 2006, and 2017. However, higher densities were observed in 1986 (11.1 ind./m^2), 1990 (7.7 ind./m^2), 2008 (11.4 ind./m^2), and 2016 (8.8 ind./m^2).

3.1.2. Size distribution and density of the sea urchin

The test diameter of *M. nudus* in 1990, 2002, and 2018 is shown in Figure 3. Individuals in the 1–3-year age classes did not reach the 5 cm threshold, the minimum size required for harvesting sea urchins in Shimamaki Village. The density of these age classes ranged from 0 ind./m^2in 1988 and 2012 to 17.9 ind./m^2in 1985 (Figure 2C). In contrast, individuals in the 4–8-year age classes reached the harvestable size, with densities ranging from 1.3 ind./m^2in 2000 to 7.9 ind./m^2in 2012 (Figure 2D). The mean density of first-year juveniles decreased from the 1990s to the 2010s (Figure 4). The relationship between the density of first-year juveniles and the density of adult sea urchins in the previous year is shown in Figure 5, with no significant correlation (Spearman's rank correlation with ties, $\rho = -0.110$, $p = 0.319$, $n = 83$) observed. Similarly, Figure 6 presents the relationship between the density of adult sea urchins and the catch volume in Shimamaki Village, indicating no significant correlation (Figure 5: $\rho = -0.110$, $p = 0.319$, $n = 83$; Figure 6: $\rho = -0.074$, $p = 0.054$, $n = 676$).

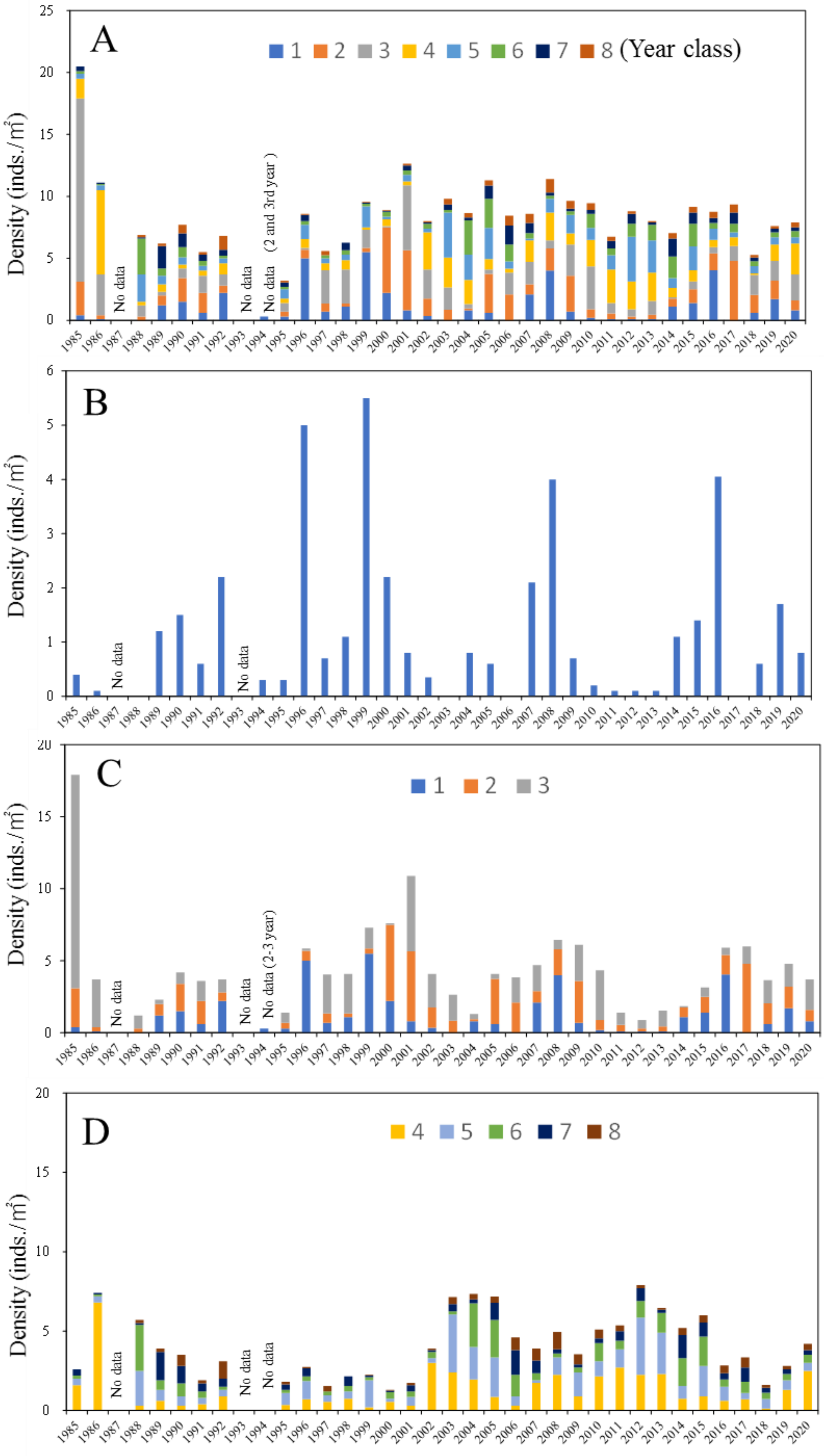
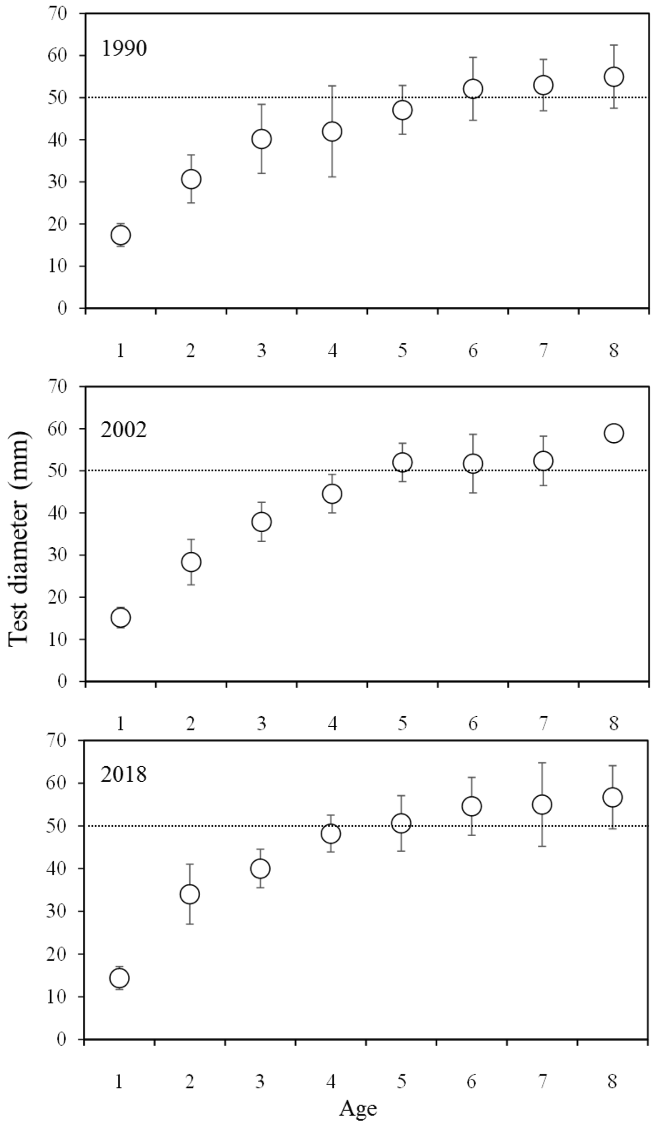


Figure 2. Annual changes in the density of *Mesocentrotus nudus* in Shimamaki Village, southwestern Hokkaido, Sea of Japan. A, Total density of *M. nudus* (1–8 years); B, Density of 1-year-old juvenile *M. nudus*; C, Density of immature *M. nudus* (1–3 years); D, Density of adult *M. nudus* (4–8 years).

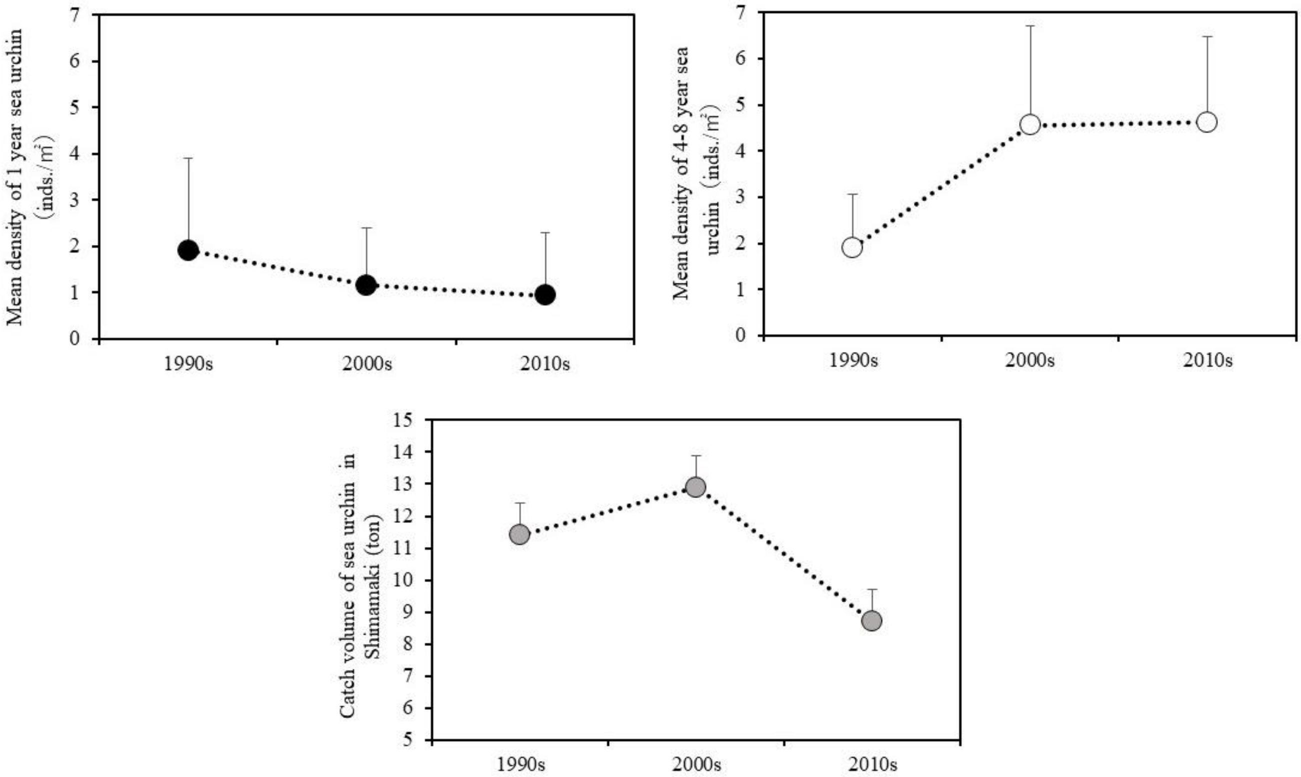
The total density of sea urchins aged 1–8 years showed no statistically significant trend over the 35-year study period (slope = -0.015 ind./m² per year, p = 0.79, linear regression), indicating that the overall population remained relatively stable (Figure 2A). The maximum density, recorded in 1985, was 20.5 ind./m^2, which was6.4 times higher than the minimum density of 3.2 ind./m^2observed in 1995 (Figure 2A). Notably high recruitment of first-year juvenile sea urchins occurred twice in the 1990s, once in the 2000s, and once in the 2010s, potentially contributing to overall density stability.

Statistical trend analysis is required However, a gradual decline in juvenile recruitment appears to occur over time (Figure 4). To evaluate this tendency, we conducted a statistical trend analysis. Linear regression analysis indicated a negative slope (−0.49 ind./m² per decade), but the trend was not statistically significant (p = 0.20). Similarly, a non-parametric Mann–Kendall test did not detect a significant monotonic trend (Z = −1.04, p = 0.30). These results suggest that although juvenile density tended to decline from the 1990s to the 2010s, the decrease was not statistically significant.



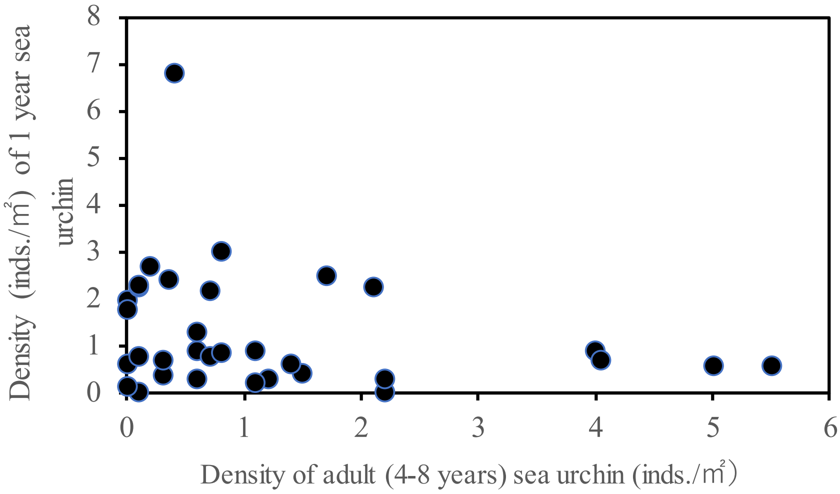
Error bars indicate ± standard deviation. The horizontal dotted line at 50 mm denotes the legal catchable size in the Shimamaki coastal area.

Figure 3. Association between mean test diameter and age of *Mesocentrotus nudus* in Shimamaki Village, southwestern Hokkaido, Sea of Japan.



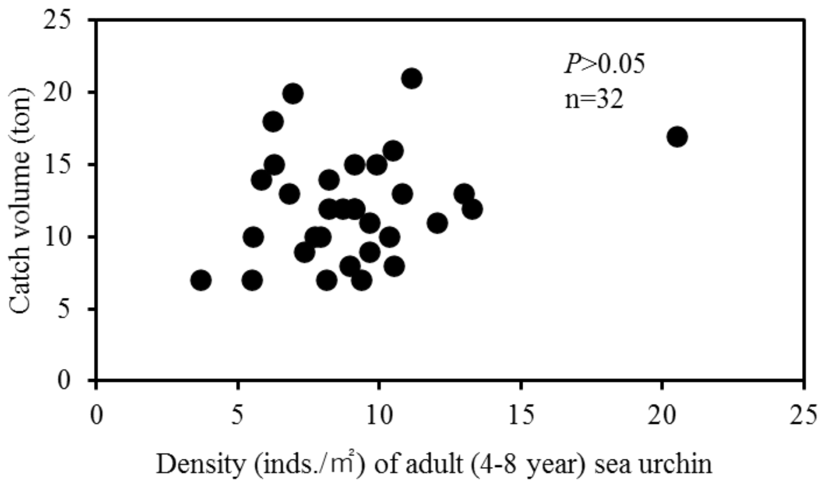
Error bars represent ± standard deviation.

Figure 4. Average density of first-year juvenile *Mesocentrotus nudus* in Shimamaki Village, located in southwestern Hokkaido, Sea of Japan.



No significant correlation was detected (Spearman's rank correlation with ties, $\rho = -0.110$, $p = 0.319$, $n = 83$).

Figure 5. Correlation between the density of first-year juvenile *Mesocentrotus nudus* and the density of adults (4–8 years) in the preceding year in Shimamaki Village, southwestern Hokkaido, Sea of Japan.



Catch volume data were sourced from annual fisheries statistics published by the Hokkaido Government (http://www.pref.hokkaido.lg.jp/sr/sum/03kanrig/sui-toukei/suitoukei.htm; accessed on April 1, 2021).

Figure 6. Relationship between the density of adult *Mesocentrotus nudus* and the corresponding catch volume in Shimamaki Village, southwestern Hokkaido, Sea of Japan. No significant correlation was detected ($\rho = -0.074$, $p = 0.054$, $n = 676$).

3.2. Discussion

No direct relationship was found between the recruitment of first-year juveniles and the density of adult sea urchins (Figure 5). Previous research by Agatsuma *et al*. (1998) identified a significant correlation between juvenile density and the average water temperature in the previous September, suggesting that higher temperatures may shorten the larval period and enhance juvenile recruitment. This aligns with the present study's findings. Previous studies suggested that higher autumn temperatures may shorten the larval period and enhance juvenile recruitment (Agatsuma et al., 1998), which is consistent with our observations. However, recruitment success is likely influenced by multiple processes, and other factors such as larval mortality, post-settlement survival, predation, or stochastic environmental events may also contribute to the observed fluctuations. These potential mechanisms were not directly evaluated in the present study, and further research will be necessary to clarify their relative importance. Although Agatsuma *et al*. (1998) reported that high recruitment years were associated with increased harvest volumes in Shimamaki Village, the present study did not detect a significant relationship between adult sea urchin density and catch volume (Figure 6). This discrepancy may be explained by the fact that catch volume is influenced by gonad weight, which is dependent on the availability of macroalgae—the primary food source for sea urchins (Fuji, 1960a; Agatsuma, 2014; Watanuki, 2014).

The Isoyake phenomenon, which has persisted off the southwestern coast of Hokkaido for the past two decades (Akaike *et al*., 1999; 2002; Hoshikawa *et al*., 2018), has led to the decline of kelp forests—an essential food source for sea urchins (Agatsuma, 2014; Kawai *et al*., 2018). Consequently, many sea urchins may experience insufficient algal intake, resulting in underdeveloped gonads. In Isoyake-affected areas, fishers often avoid harvesting sea urchins with poorly developed gonads. Therefore, the density of adult sea urchins may not directly correspond to catch volume. To achieve the sustainable use of edible sea urchins in Isoyake regions, further research is needed on methods for restoring seaweed forests and improving our understanding of the Isoyake phenomenon.

4. Conclusion

Over the 35-year period, the population density of *Mesocentrotus nudus* in Shimamaki Village remained relatively stable, as shown in our dataset, despite pronounced year-to-year fluctuations in first-year juvenile recruitment and a tendency toward lower recruitment since the 1990s. No significant correlation was detected between juvenile recruitment and adult density, nor between adult density and catch volume. These results indicate that juvenile recruitment alone does not determine adult population dynamics or fishery yield. Beyond recruitment, broader ecosystem conditions, including food availability and habitat status, are likely to shape fishery outcomes, underscoring the importance of ecosystem-based approaches for sustaining sea urchin fisheries in southwestern Hokkaido.

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