American Journal of Marine Science, 2021, Vol. 9, No. 1, 16-25
Available online at http://pubs.sciepub.com/marine/9/1/4
Published by Science and Education Publishing
DOI:10.12691/marine-9-1-4

Quantitative Relationships between Autumn Catches of Swordtip Squid (*Uroteuthis edulis*) and Oceanic Conditions to the East of Tsushima Islands, Japan

Tadanori Yamaguchi[1,*], Katsumi Takayama[2], Naoki Hirose[2]

[1]Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, Kasuga 816-8580, Japan
[2]Research Institute for Applied Mechanics, Kyushu University, Kasuga 816-8580, Japan
*Corresponding author: tadanoriyama@riam.kyushu-u.ac.jp

Received October 11, 2021; Revised November 13, 2021; Accepted November 26, 2021

Abstract Although the behavior of swordtip squid (*Uroteuthis edulis*) caught in the southern Japan Sea and eastern channel of the Tsushima Strait in autumn have been estimated, it needed to be improved in scientific and fishery benefits, which were a harvest scenario and the reason for serious poor catches in the autumn of 2019. This study aimed to identify oceanic conditions affecting autumn catches using a numerical ocean model. To determine the effects of eddies that occurred in the waters to the east of the Tsushima Islands, Lagrangian tracers were released and the number of tracers remaining in the waters, where the squid of the autumn migrating group are supposed to grow in summer, were counted regularly. Quantitative results in the tracer experiments supported and improved the hypothesis of the migratory behavior of the autumn group. The regression expression was obtained with 0.851 of correlation coefficient between the catch per unit effort (CPUE) in autumn and the index composed from the number of the remaining tracers in summer and the CPUE of May. In the summer of 2019, a U-shaped current occurred from the north to the east of the islands, which perhaps accounted for the poor catches in the autumn.

Keywords: *data assimilation model, Lagrangian tracer experiment, current, eddy, CPUE*

Cite This Article: Tadanori Yamaguchi, Katsumi Takayama, and Naoki Hirose, “Quantitative Relationships between Autumn Catches of Swordtip Squid (*Uroteuthis edulis*) and Oceanic Conditions to the East of Tsushima Islands, Japan.” *American Journal of Marine Science*, vol. 9, no. 1 (2021): 16-25. doi: 10.12691/marine-9-1-4.

1. Introduction

The swordtip squid is a neritic species that is widely distributed in the western Pacific, from northern waters (southern Japan Sea and the East and South China Seas) to the tropical seas (Java Sea and coastal waters of Indonesia, Malaysia, and Thailand), and to northern Australia [1]. This species is particularly abundant in the East China Sea and the Tsushima Strait, which is divided by the Tsushima Islands into the eastern and western channels, where it has become an important source of revenue for many fishermen [2] (Figure 1). The spring, summer, and autumn migrating groups of *U. edulis*, which are caught between April and June, July and September, and October and December, respectively, in the southern Japan Sea and the eastern channel, differ in body shape and size at maturity [3]. Individuals of the autumn group are characterized by thick bodies with large clubs, long tentacles, and large suckers [1]. Catches of the autumn group of *U. edulis* fluctuate considerably, with 2019 being the year with the lowest records so far. Although researchers have suggested that catches of the squid might be related to water temperatures and/or the salinity of fishing grounds, the reasoning behind it remains unidentified [4,5].

It was suggested that fishing grounds in the Tsushima Strait can be studied by analyzing the current velocity field rather than the water temperature, using nighttime light satellite imagery [6]. Furthermore, statolith analyses and Lagrangian tracer experiments have been used to analyze the migratory behavior of *U. edulis* from the southern East China Sea to the fishing grounds through currents surrounding Japan. The squid in the spring and summer migrating groups would be caught when they approach the Tsushima Strait and southern Japan Sea from the East China Sea [7,8,9], whereas those in the autumn group would interestingly need another step to enter the fishing grounds [10] (Figure 2). After moving to the Tsushima Strait from the southern East China Sea, the squid becomes trapped in a pair of clockwise and counterclockwise eddies in the east of the Tsushima Islands, which are caused by the Tsushima Warm Current [11]. These animals become confined in limited layers of the southern Japan Sea, at a probable depth of 30–50 m, due to the thermoclines, until vertical mixing occurs in the autumn, because the empirical water temperatures of the squid were estimated to be ~21°C in the spring and after through the statolith analyses [10]. Thereafter, the distribution of the squid extends to fishing grounds in the southern Japan Sea and then to the Tsushima Strait.

Understanding the ocean dynamics that affect the swordtip squid is important for the establishment of programs seeking to reestablish its population, not only because of the economic importance of this species, but also because of its ecological relevance to the local environment. Therefore, the overall purpose of this study was to reveal quantitative relationships between the catches of *U. edulis* in the autumn migrating group and the oceanic conditions in the east of the Tsushima Islands, to model a harvest scenario before the autumn fishing season, and to identify unusual oceanic conditions that might have caused poor catches of the squid in the southern Japan Sea and eastern channel of the Tsushima Strait in the autumn of 2019.

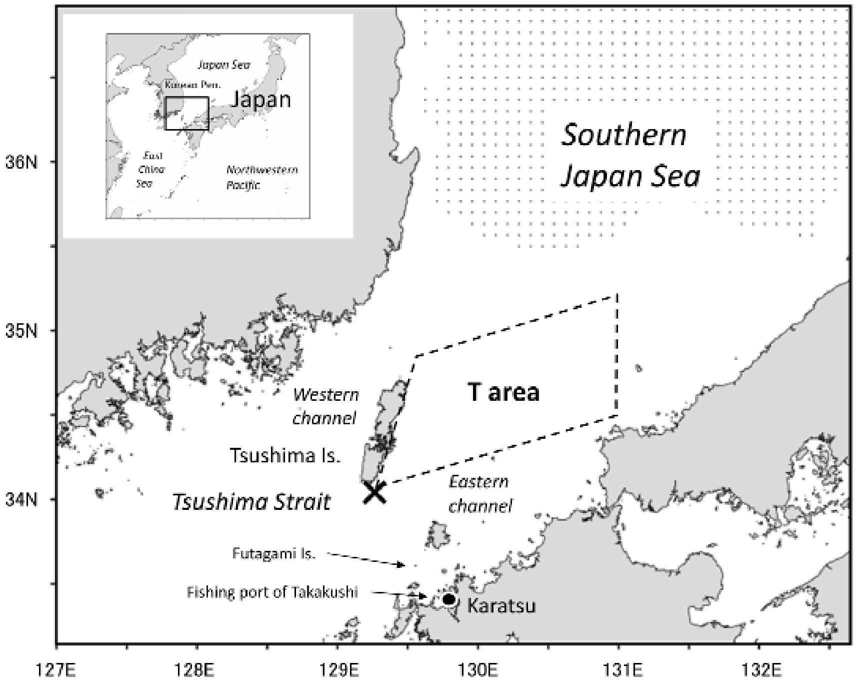

Figure 1. Map of the study area. The X marks the spot where Lagrangian tracers were released, and a broken square (T area) marks the area where individuals in the autumn group potentially spend the summer, at depths of 30–50 m

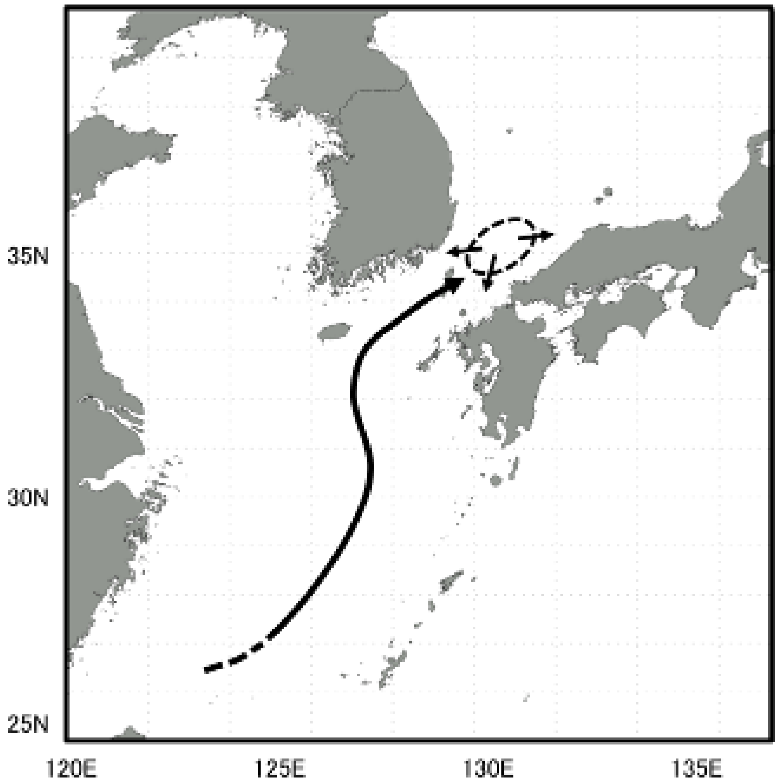

Figure 2. Estimated migratory route of the autumn migrating group of *Uroteuthis edulis* [10]. The broken ellipse shows the area where individuals in this group potentially spend the summer, at depths of 30–50 m

2. Materials and Methods

2.1. Catches of Uroteuthis Edulis

To evaluate relationships between oceanic conditions and catches of *U. edulis* in the southern Japan Sea and eastern channel of the Tsushima Strait, we used monthly catch data of this squid landed at the fishing port of Takakushi in Karatsu, Japan, from 2010 to 2019, as a cross section for catches of squid from the southern Japan Sea and eastern channel because the catch per unit effort (CPUE) was available. All the fishers who landed the squid at the fishing port of Takakushi usually operated in the waters around Futagami Island (33°36′N, 129°33′E; Figure 1), which is located to the northwest of Karatsu. The efficiency of the cross section was validated by using yearly catch data of the specified fishing waters, which were published by the Fisheries Agency (http://www.abchan.fra.go.jp/digests2020/index.html, retrieved on August 3, 2021). We then expressed the abundance of *U. edulis* that migrated to the fishing waters with the CPUE of every month in spring (April to June), summer (July to September) and autumn (October to December).

2.2. Lagrangian Tracer Experiments

The ocean environment was inferred using the high-resolution data assimilation output of water temperature and currents [12]. In addition, Lagrangian tracer experiments were conducted using the Japan Sea Data Assimilation Experiment ver.2 dataset [8]. From 2010 to 2019, on the first day of every month between May and November, 10,000 Lagrangian tracers were released into the eastern channel of the Tsushima Strait (34°00′N, 129°12′E) at depths of 10 m, 30 m, and 50 m (Figure 1) because the empirical water temperatures of the squid were estimated to be ~21 °C in the waters to the east of the Tsushima Islands, where a probable depth was generally 30-50 m from July to October. The area extending from the southern Japan Sea to the east of the Tsushima Islands (the T area: the area where individuals in the autumn migrating group potentially spend the summer, 34°48′N, 129°30′E; 35°18′N, 131°00′E; 34°30′N, 131°00′E; and 34°00′N, 129°12′E, clockwise, Figure 1) is critical to the growth of the autumn migrating group of *Uroteuthis edulis* during the summer after they are trapped in a pair of clockwise and anticlockwise eddies in the east of the islands [10]. Moreover, it was reported that *U. edulis* caught in offshore waters, including those of the T area, from August to October were smaller than those caught in coastal waters [8]. The reason for this is that the former move through a fast current from the East China Sea, but the latter move slowly through a littoral current. The small squid in the T area grow during the summer and join an autumn migrating group when they are larger. Tracers' advection and diffusion were calculated using the method of [13]. In fact, many squids vertically migrate and probably stay at the seafloor or depth of the layer whose water temperature is lowest to survive in the daytime. However, there is little information on how long or how deep this species dives into the sea. In this study, the advection speed was reduced to 50% of the original to simulate the ocean conditions experienced by migrating squid, because velocity usually decreases with depth and the results of Lagrangian tracer experiments with the advection speed reduced to 50% suggested the migratory routes of the squid appropriately [8,9,14].

The tracers exiting the area were identified every day for 240 days and counted on the first day of every month. The tracers were released on the first day of a month and the number of tracers remaining in the T area until the first day of the next month indicated the retention of tracers by the eddies for one month or more, which is called the tracer retention index (TRI). Moreover, when TRI (X to Y) is shown, X is the month in which tracers were released and Y is the month in which tracers remaining in the T area were counted. To factor the biomass of squid migrating to the eastern channel into the calculation, we used another index and multiplied the TRI by the monthly CPUE, which is referred to as the corrected TRI by the CPUE of the month.

3. Results

3.1. Changes in CPUE of *Uroteuthis edulis*

A strong positive correlation (r = 0.91, p < 0.001, r: correlation coefficient, p: probability value) was shown between yearly catches of *U. edulis* landed at the fishing port of Takakushi and those at all the fishing ports along the coast of the southern Japan Sea and eastern channel of the Tsushima Strait from 2010 to 2019 (Figure 3). The change in monthly CPUE means (±SDs, SD: standard deviation) of the squid landed at the fishing port of Takakushi are shown in Figure 4. The means remained unchanged at ~17.5 kg/day/boat from April to June before increasing gradually from July to December. The CPUE means in September and December were ~30 kg/day/boat. The change in seasonal CPUE means (±SDs) of the squid landed at the fishing port are shown in Figure 5. All the seasonal CPUEs generally decreased by half over 10 years, and in particular, the autumn CPUEs dropped from 25.8 kg/day/boat in 2017 to 18.8 kg/day/boat in 2018, and then further dropped to 11.6 kg/day/boat in 2019. The correlation coefficients between the autumn CPUEs and monthly CPUEs from April to September for 10 years are shown in Figure 6. The correlation coefficients between the autumn CPUEs and monthly CPUEs of May, June, July, and September were ~0.55, whereas those between the autumn CPUEs and monthly CPUEs of April and August were 0.05 and 0.28, respectively.

3.2. Changes in Monthly TRIs

All the Lagrangian tracers released at the southmost point of the T area flowed northeast along with the Tsushima Warm Current, but some remained in eddies to the east of the Tsushima Islands (Figure 7 and Figure 8). The changes in means (±SDs) of monthly TRIs between 2010 and 2018 and monthly TRI of 2019 at depths of 10 m, 30 m, and 50 m are shown from May to November (Figure 9). In general, the monthly TRIs increased from May to July, and then decreased to August. The

TRIs at a depth of 50 m showed a smooth and gradual decline from summer to autumn, whereas at depths of 10 m and 30 m some irregular changes were observed. The monthly TRIs from June to September in 2019 appeared significantly lower than means of those for the previous nine years.

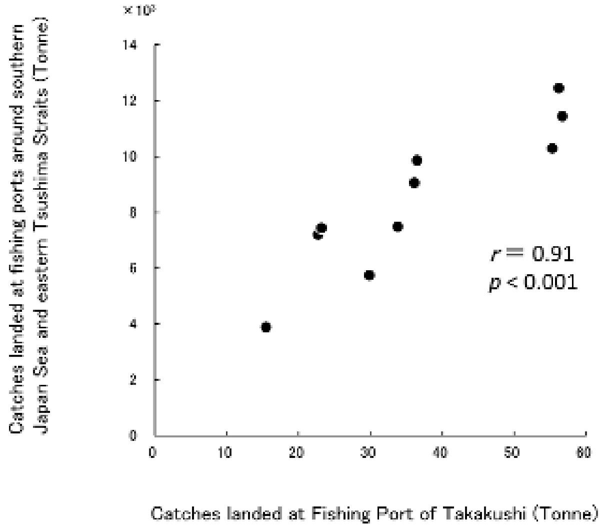

Figure 3. Relationship between the yearly catches of *Uroteuthis edulis* landed at all the fishing ports around the southern Japan Sea and eastern channel of the Tsushima Strait and those at the fishing port of Takakushi

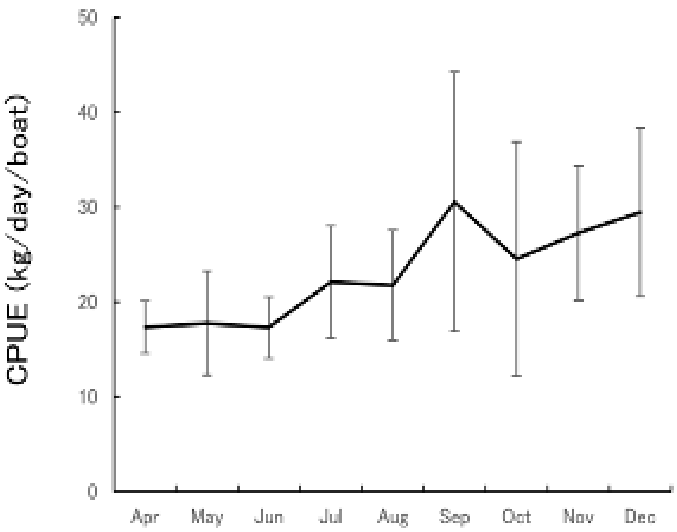

Figure 4. Change in mean (±SD) of monthly catch per unit effort (CPUE) of *Uroteuthis edulis* landed at the fishing port of Takakushi from 2010 to 2019

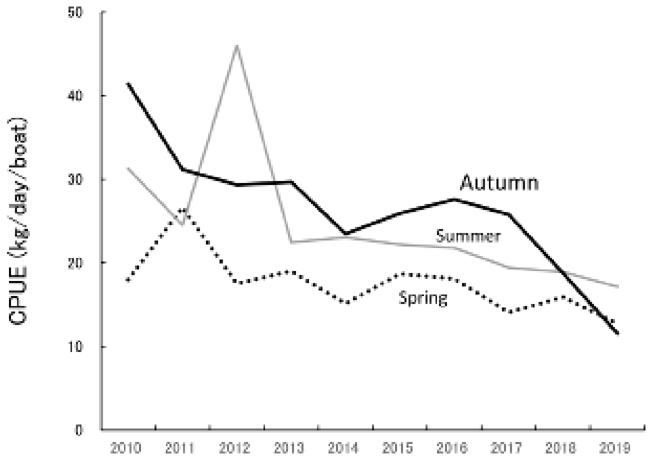

Figure 5. Yearly change in seasonal catch per unit effort (CPUE) of *Uroteuthis edulis* landed at the fishing port of Takakushi. Spring, summer, and autumn represent April to June, July to September, and October to December, respectively

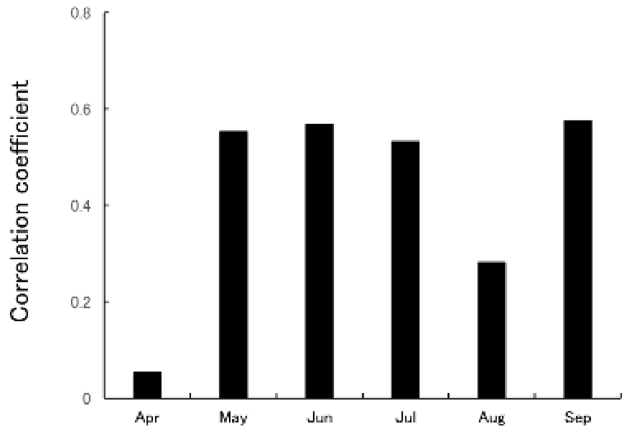

Figure 6. Correlation coefficient between monthly catch per unit effort (CPUE) from April to September and the autumn (October–December) CPUE for 10 years (2010–2019)

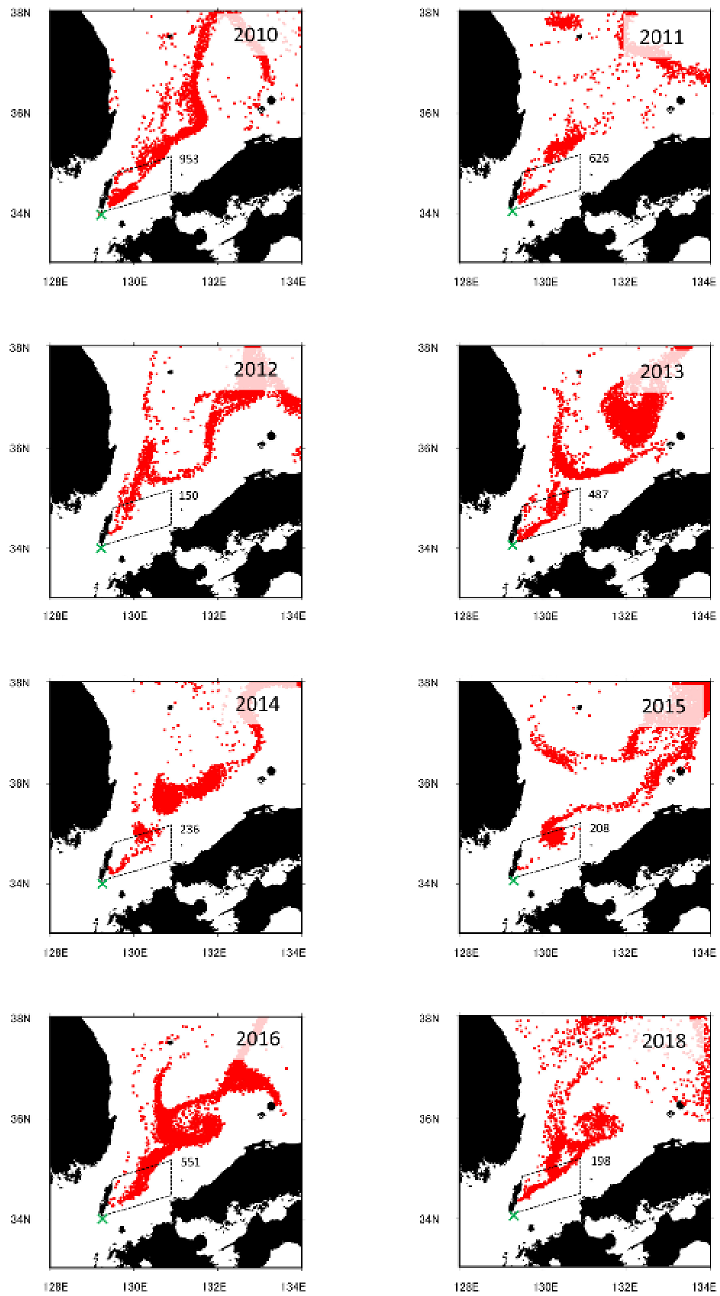

Figure 7. Distribution of Lagrangian tracers on October 1 in 2010–2016 and 2018 when the tracers were released at the X point on July 1 each year at a depth of 30 m. The number of remaining tracers in the T area is shown on the right of each broken square. Those in 2017 and 2019 are shown in Figure 8 (c) and (f), respectively

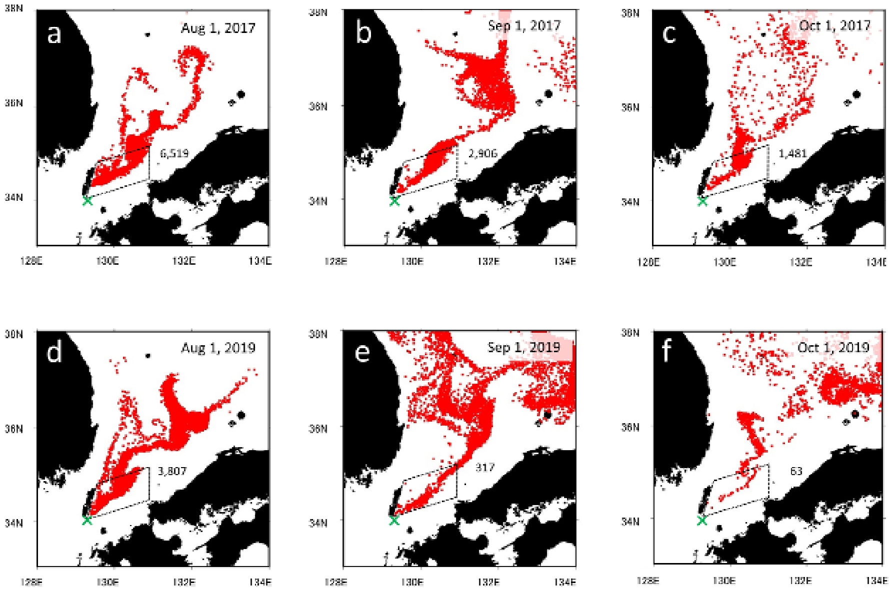

Figure 8. Distribution of Lagrangian tracers on August 1, September 1, and October 1 in 2017 (a, b, and c, respectively) and 2019 (d, e, and f, respectively) when the tracers were released at the X point on July 1 each year at a depth of 30 m. The number of remaining tracers in the T area is shown on the right of each broken square

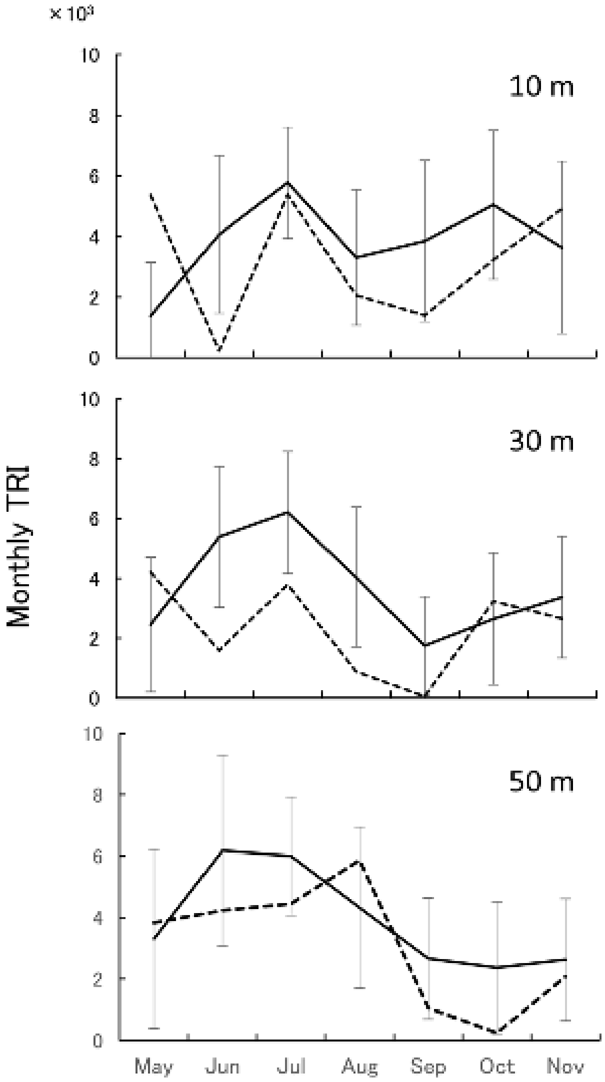

Figure 9. Changes in mean (±SD) of monthly tracer retention index (TRI) for nine years (2010–2018) (solid line) and monthly TRI of 2019 (broken line) from May to November at depths of 10 m, 30 m, and 50 m

3.3. Relationship between CPUEs and TRIs

Table 1 shows correlation coefficients between CPUEs of *Uroteuthis edulis* landed at the fishing port of Takakushi in autumn and the TRIs which varied according to such conditions as release dates, depths and counting dates. More positive correlation coefficients occurred between tracers that were released in June and July than between those released in other months, and between the tracers that were released at a depth of 30 m than between those at other depths. A strong positive correlation (r = 0.846, p < 0.01) was only found between the CPUEs and TRIs (Jul to Sep) at a depth of 30 m. The correlation coefficient between the autumn CPUEs and the corrected TRIs (Jul to Sep) by the CPUEs of May was the highest (r = 0.851, p < 0.01) among between April and December. The correlation coefficient was slightly larger than the original one (r = 0.846, p < 0.01) (Figure 10 and Figure 11).

Table 1. Correlation coefficient between catch per unit effort (CPUE) of *Uroteuthis edulis* landed at the fishing port of Takakushi in autumn (October–December) and the tracer retention index (TRI) counted on the first day of September, October, November, and December after the tracers were released at depths of 10 m, 30 m, and 50 m on the first day of June, July, August, and September from 2010 to 2019. *p < 0.1; **p < 0.05; ***p < 0.01

Release date	Depth	Sep 1	Oct 1	Nov 1	Dec 1
Jun 1	10 m	0.14	0.26	0.29	0.29
	30 m	0.30	0.23	0.49	0.64**
	50 m	0.49	0.19	0.32	0.40
Jul 1	10 m	0.07	0.51	0.21	0.19
	30 m	0.85***	0.50	0.63**	0.50
	50 m	0.33	–0.05	0.25	0.14
Aug 1	10 m	–0.04	0.07	0.17	0.17
	30 m	0.50	0.10	0.35	0.58*
	50 m	0.06	–0.07	0.02	0.27
Sep 1	10 m		0.03	0.12	0.13
	30 m		–0.08	–0.14	–0.21
	50 m		–0.18	0.07	0.02

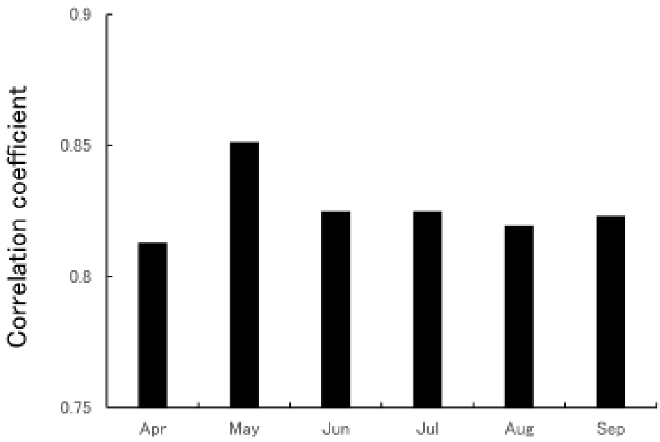

Figure 10. Correlation coefficient between the autumn (October–December) catch per unit effort (CPUE) and corrected tracer retention index for July to September (TRI (Jul to Sep)) by the CPUE of the month from April to September between 2010 and 2019

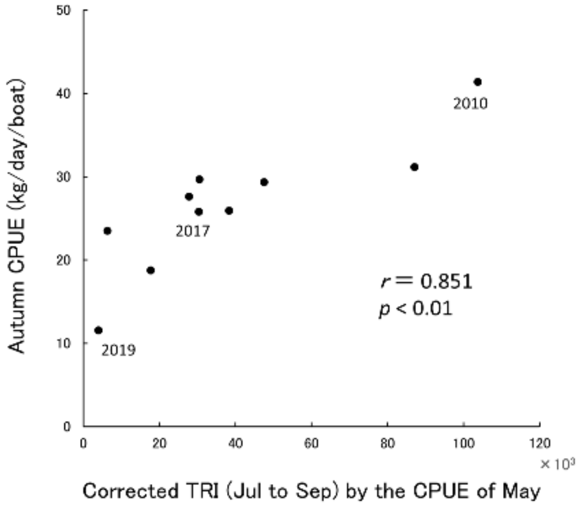

Figure 11. Relationship between the autumn (October–December) catch per unit effort (CPUE) and corrected tracer retention index for July to September (TRI (Jul to Sep)) by the CPUE of May from 2010 to 2019

3.4. Oceanic Conditions in the Western Japan Sea, 2019

Figure 8 shows differences in the distribution of the tracers on the first day of August, September, and October between 2017 and 2019 after the tracers were released on July 1. The autumn CPUE of the squid in 2017 was close to the average for the 10 years from 2010 to 2019, whereas that in 2019 was the lowest (Figure 5). In 2017, the TRI (Jul to Oct) was as half as the TRI (Jul to Sep), and the TRI (Jul to Sep) was as half as the TRI (Jul to Aug), which means the number of the tracers remaining in the T area decreased by half each month (Figure 12). In 2019, however, the number of the tracers decreased to one-tenth of the TRI (Jul to Aug) in September. In the waters to the east of the Tsushima Islands, within the T area, few eddies or currents occurred in summer, but a U-shaped current occurred in the area in the middle of August 2019 (Figure 13). This current flowed to the south and pushed the Tsushima Warm Current southward. Figure 14 shows that the water temperature and current distribution in the T area and the wasters to the east of the Korean Peninsula were different in the two years. In 2019, the southward current occurred between the waters whose water temperatures were high and low off the peninsula.

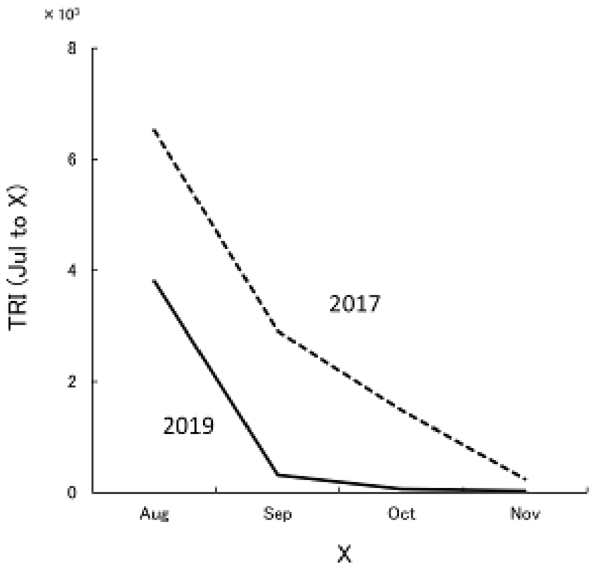

Figure 12. Change in tracer retention index (TRI) for June to August, September, October and November in 2017 and 2019

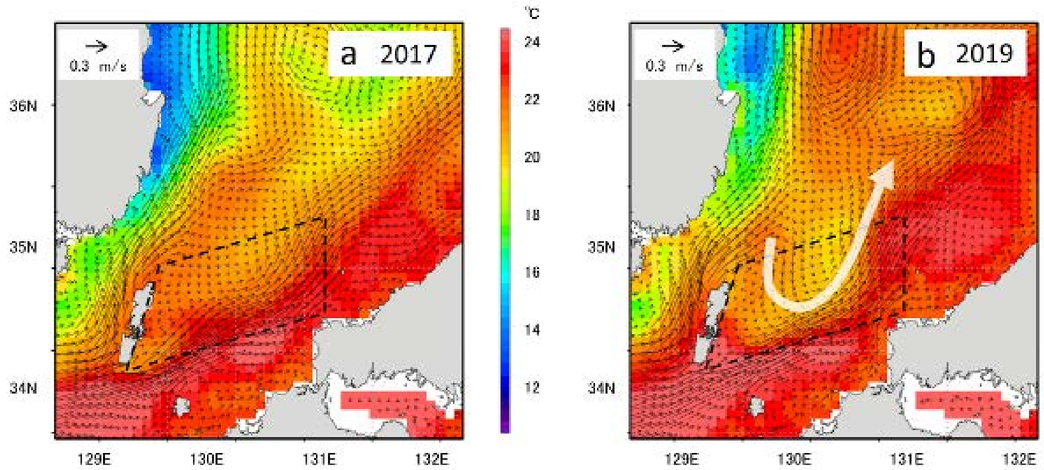

Figure 13. Distribution of sea water temperatures and current vectors in the southern Japan Sea and Tsushima Strait at a depth of 30 m on August 15 in (a) 2017 and (b) 2019. Each black broken square shows the T area. The curved line in (b) indicates the unusual U-shaped current

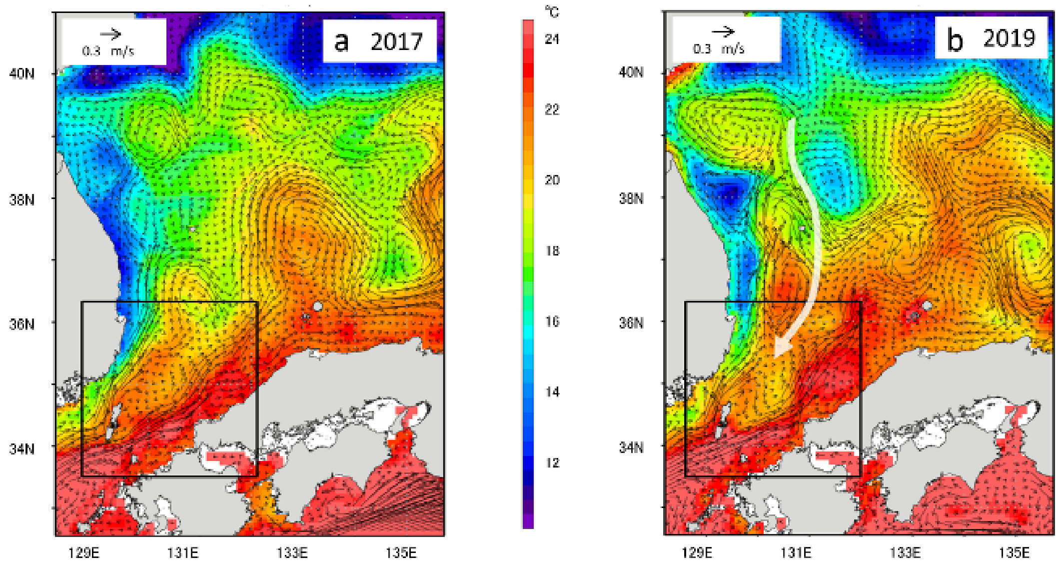

Figure 14. Distribution of sea water temperatures and current vectors in the southern and western Japan Sea and Tsushima Strait at a depth of 30 m on August 15 in (a) 2017 and (b) 2019. The squares in (a) and (b) show (a) and (b) in Figure 13, respectively. The curved line in (b) indicates the unusual southward current

4. Discussion

4.1. Improved Migratory Process of the Autumn Group

Although it was expected that the eddies to the east of the Tsushima Islands would be weaker in October [10], the results of our tracer experiments showed that the retention decreased gradually from summer to autumn (Figure 9). The deeper the tracers were released, the more gradual the decrease in the monthly TRIs. This might be caused by the weakened effect of the wind. If the retention by the eddies accounts for the growth process of the individual squid belonging to the autumn migrating group, July and September would be important because the monthly TRIs decreased sizably from July to September, especially at a depth of 30 m. It was suggested that the squid of the autumn group would migrate into waters with a temperature of ~21°C in summer, and that such a temperature appeared at a depth of ~30 m in the eastern channel of the Tsushima Strait in July [10]. The correlation coefficient between TRIs (Jul to Sep) and autumn CPUEs was larger than that between TRIs (Jul to Oct) and autumn CPUEs (Table 1), indicating that the squid that stayed in the eddies in the T area would spread to the southern Japan Sea and Tsushima Strait in September and begin to be caught in the coastal waters in October. Moreover, the correlation coefficient between the corrected TRIs (Jul to Sep) by the CPUE of May and the autumn CPUEs was the largest (Figure 10), meaning that the migrating group, which included individuals caught in the waters around Futagami Island in May, unexpectedly contributed to the autumn group, even though the CPUE of May was smaller than that of July, August, and September (Figure 4). Thus, some small squid that migrated from the East China Sea to the waters around Futagami Island and/or those to slightly the west of the island in May would reach the T area one or two months later (Figure 2).

4.2. Causes for Poor Catches in Autumn 2019

Figure 13 shows that a U-shaped current occurred in the T area in the middle of August 2019. This unusual current seems to have stopped the tracers from remaining in the T area and moved them out of the area to the Japan Sea. Although the distribution of the tracers cannot be directly applied to the migration of the squid, the power to hold something in the waters to the east of the Tsushima Islands would have been weakened in the August of 2019 by the U-shaped current. Supposing that the improved hypothesis about the migratory behavior of the autumn group above is correct, fewer squid would be trapped in the T area in the summer of 2019 than in the other years. This event can account for the poor catches of the squid in the autumn of 2019. The reason the U-shaped current occurred is yet unknown, however, this might be linked to the southward current caused by high and low water temperature distributions, lying north and south, in the waters off the eastern Korean Peninsula we observed in August (Figure 14). The difference in the water temperature off the northeastern peninsula was more than 10 °C larger than the average year (Figure 15), which probably account for the unusual southward current.

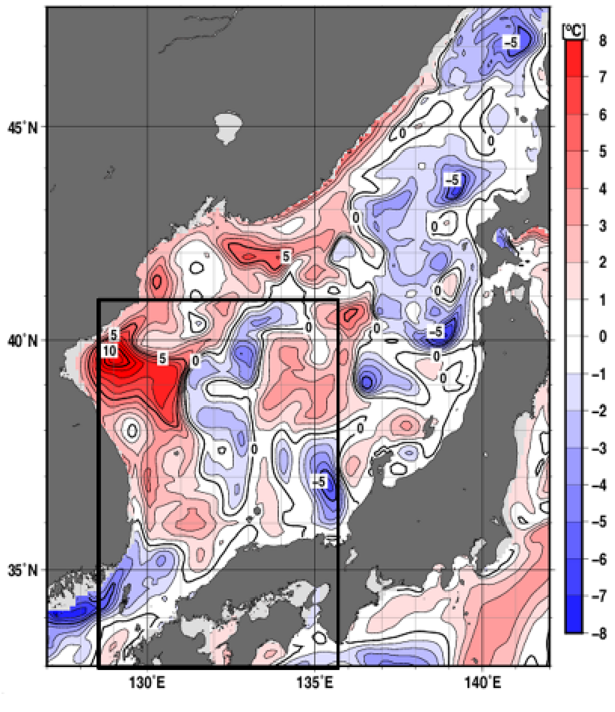

Figure 15. Difference in water temperatures at a depth of 50 m in the Japan Sea in the middle of August between 2019 and average year. The water temperatures in the average year was calculated by using the data between 1993 and 2017. This figure was retrieved from the website of Japan Meteorological Agency (http://www.data.jma.go.jp/kaiyou/shindan/) on August 26, 2021. The square in the figure shows Figure 14 (b)

5. Conclusions

In this study, the quantitative results by using the distribution of Lagrangian tracers released in the eastern channel of the Tsushima Strait not only supported but also improved the hypothesis of the migratory behavior of the autumn migrating group of *Uroteuthis edulis* estimated through the statolith analyses. Thus, Lagrangian tracer experiments would be a powerful tool to know the distribution of not only eggs, larvae and juveniles of fishes and squids but also adults with appropriate experiment conditions for behavior of each creature. However, the T area, where the tracers were counted regularly, was defined in an arbitrary manner because there was little information about the distribution of small *U. edulis* in the waters to the east of the Tsushima Islands as fishermen usually operate in the coastal waters, where large squid are generally distributed in summer [8]. This is why we need to set a more appropriate area, which will enable us to estimate an autumn CPUE more accurately by using a CPUE of May and a TRI (Jul to Sep) before the harvest season.

It is still difficult to fully understand the oceanic conditions. In fact, we cannot explain the reason why the U-shaped current occurred in the T area, although the unusual water temperature distribution may have affected the current. Furthermore, it is unclear why the monthly TRIs began to decrease not in October but in August [10] although the thermoclines are usually stable until September. To understand not only these remaining questions but also relationships between currents and the migration of other species, an oceanographic approach is required. The Japan Fisheries Agency (http://www.abchan.fra.go.jp/digests2020/index.html, retrieved on August 3, 2021) reported, for example, serious poor catches of Japanese common squid (*Todarodes pacificus*) in the Japan Sea in the autumn of 2019, which would be caused by the drastically changed distribution of the Tsushima Warm Current because the squid migrated in the Japan Sea from spring to autumn [15]. Additionally, the newly cohort of Chub mackerel (*Scomber japonicus*) and Japanese anchovy (*Engraulis japonicus*), which were manly caught in the southern Japan Sea, decreased in 2019, which might be caused by the unusual currents due to low swimming ability as the small *U. edulis* would. If the currents can be appropriately estimated by using ocean data and a model, the catches of some species will be forecasted in the immediate term.

Acknowledgements

We express our sincere thanks to Japan Fisheries Cooperative SAGA GENKAI for supplying the monthly catch data of *Uroteuthis edulis* landed at the fishing port of Takakush and to Y. Sakurai for the valuable information about the unusual oceanic conditions of the western Japan Sea in 2019.

References

[1] Jereb, P. and Roper, C.F., “Cephalopods of the world. An annotated and illustrated catalogue of cephalopod species known to date”. Volume 2. Myopsid and Oegopsid Squids. FAO, 2010.

[2] Arkhipkin, A.I., Rodhouse, P.G., Pierce, G.J., Sauer, W, Sakai, M., Allcock, L., Arguelles, J., Bower, J.R., Castillo, G., Ceriola, L., et al., “World squid fisheries”. *Reviews in Fisheries Science & Aquaculture*, 23(2):92-252, 2015.

[3] Okutani, T., “Past, present and future studies on cephalopod diversity in tropical West pacific”. *Phuket marine Biology Center Research Bulletin*, 66:39-50, 2005.

[4] Ando, A., Nakata, H. and Ishizaka, J., "Influence of Tsushima Warm Current on the fishing ground formation of swordtip squid (*Photololigo edulis*) in the Sea of Genkai, Japan". *Bulletin of the Japanese Society of Fisheries Oceanography*, 77(2): 83-91, 2013 (in Japanese with English abstract).

[5] Kanamoto, Y. and Shibata, Y., "Investigation of factors affecting CPUE of swordtip squid *Uroteuthis edulis* in coastal waters of Shimane Prefecture and forecast". *Nippon Suisan Gakkaishi*, 86(5):371-385, 2020 (in Japanese with English abstract).

[6] Shimada, Y., "Movement of fishing boats with fishing lights in the Tsushima Strait in summer and fall using nighttime light satellite images". *Journal of Japan Society of Civil Engineers*, 75(2):1025-1030, 2019 (in Japanese with English abstract).

[7] Yamaguchi, T., Kawakami, Y. and Matsuyama, M., "Migratory routes of the swordtip squid *Uroteuthis edulis* inferred from statolith analysis". *Aquatic Biology*, 24:53-60, 2015.

[8] Yamaguchi, T., Takayama, K., Hirose, N. and Matsuyama, M., "Migratory routes of different sized swordtip squid (*Uroteuthis edulis*) caught in the Tsushima Strait". *Fisheries Research*, 209:24-31, 2019.

[9] Yamaguchi, T., Takayama, K., Hirose, N. and Matsuyama, M., "The Sea of Amakusa playing the role of a distributor of swordtip squid (*Uroteuthis edulis*) migrating from the East China Sea to the east and west sides of Japan". *Fisheries Research*, 225:105475, 2020.

[10] Yamaguchi, T., Kawakami, Y. and Matsuyama, M., "Analysis of the hatching site and migratory behaviour of the swordtip squid (*Uroteuthis edulis*) caught in the Japan Sea and Tsushima Strait in autumn estimated by statolith analysis". *Marine Biology Research*, 14(1):105-112, 2017.

[11] Takikawa, T, Yoon, J.H. and Cho, K.D., "The Tsushima warm current through Tsushima Straits estimated from ferryboat ADCP data". *Journal of Physical Oceanography*, 35(6):1154-1168, 2005.

[12] Hirose N, Takayama K, Moon J.H., "Regional data assimilation system extended to the East Asian marginal seas". *Sea and sky*, 89(2): 1-9, 2013.

[13] Kako, Y., Sakai, M., Mmasujima, M., Okazak, M., Igarashi, H., Masuda, S. and Awaji, T., "Effects of hydrographic conditions on the transport of neon flying squid *Ommastrephes bartramii* larvae in the North Pacific Ocean". *Hidrobiológica*, 24(1):33-38, 2014.

[14] Yamaguchi, T., Aketagawa, T., Miyamoto, M., Hirose, N. and Matsuyama, M., "The use of statolith analyses and particle-tracking experiments to reveal the migratory routes of the swordtip squid (*Uroteuthis edulis*) caught on the Pacific side of Japan". *Fisheries Oceanography*, 27:517-524, 2018.

[15] Yamaguchi, T., Hirose, N. and Kim, J., "Annual migration of the Japanese common squid (*Todarodes pacificus*) traced using a data assimilation model". (submitted).