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Movement pattern of red seabream *Pagrus major* and yellowtail *Seriola quinqueradiata* around Offshore Wind Turbine and the neighboring habitats in the waters near Goto Islands, Japan

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ABSTRACT

We investigated movement pattern of commercial important fish around Offshore Wind Turbine (OWT) and neighboring habitats in Goto Islands. We tagged 55 individuals of 2 fish species and released around the OWT in 2017. (27 *Pagrus major* from 1st Feb 2017 to 16th Mar 2017 (winter), 8 *P. major* and 20 *Seriola quinqueradiata* from 13th July 2017 to 13th Oct 2017 (summer)). Acoustic receivers were deployed at OWT, south artificial reef (AS), trapnet (TN), north FAD (F1) and south FAD (F2) in winter and two more receivers were deployed at north artificial reef (AN) and natural reef (NR) in summer. We observed 12 *P. major* at OWT for a day after released in winter, majority of fish (13 individuals) were detected at TN. In summer, 7 *P. major* were observed at OWT, 1 visited TN within the day, but others disappeared. Ten *S. quinqueradiata* stayed at OWT longer than *P. major* after released and disappeared within 2 days. They mostly moved around AS, AN, NR. Residence time from K-M curve was 10 days for *P. major* in winter, a day in summer and 3 days for *S. quinqueradiata*. Both species showed low affinity for OWT as recorded low residency index despite the season.

1. Introduction

An enhanced demand for green energy resources has stimulated the implementation of wind farms at sea. Hence the establishment of Offshore Wind Turbine (OWT) facilities is increasing worldwide in efforts to increase the supply of renewable energy (Wilhelmsson, Malm, & Öhman, 2006). Japan is one of the nations moving towards diversification of its energy being a country surrounded by oceans with rich potential for ocean energy (Fujisawa, 2017). Goto Islands, Nagasaki, Japan was selected for the demonstration project due to suitability of the wind and energy transmission infrastructure that had already been established in the area as the "Offshore Renewable Energy Test Site" by the Japanese government in July 2014 and the OWT has been in operation since March 2016. The OWT is known to induce changes in the marine environment, which may influence local biodiversity and ecosystem functioning (Andersson, Berggren, Wilhelmsson, & Öhman, 2009). Consequently, the OWTs have some environmental costs and benefits in fish (Langhamer, Wilhelmsson, & Engström, 2009) including habitat alteration, changes in sediment characteristics, electromagnetic fields, underwater noise and hydrodynamics. All these ecosystem changes interact with the colonization by epi-fouling organisms, community composition of soft substrate macro and epibenthos, spatio-temporal distribution and migration routes of fish, seabirds and marine mammals (Degraer, Brabant, & Rumes, 2012; Mikkelsen, Mouritsen, Dahl, Teilmann, & Tougaard, 2013; Reubens, Pasotti, Degraer, & Vincx, 2013; Wilhelmsson et al., 2006). Among those knowledges, studies on fish distributions around the OWT showed that several species, such as pouting *Trisopterus luscus* and Atlantic cod *Gadus morhua* can reside in high densities at distances of meters to tens of meters from the turbines (Bergström et al., 2014; Reubens et al., 2013,

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2011). We aimed to study this kind of fish behavior for two commercial and indigenous fish species i.e. red seabream *Pagrus major* and yellowtail *Seriola quinqueradiata* around the OWT in Goto Islands by using acoustic telemetry technique. According to previous studies the *P. major* is a groundfish that is most commonly found at a depth of 35–110 m in the East China Sea (Yamada, Tokimura, Horikawa, & Nakabo, 2007) and is known to be attracted to marine facilities (e.g. Wang et al., 2014). The second species, *S. quinqueradiata* is a migratory fish commonly observed in the shallow water less than 100 m (Riede, 2004) and is known to aggregate on topographic features such as seamounts, natural reefs (Ito & Yoshida, 2013; Takagi, Hasuo, Hanai, & Kimura, 2001). These species accounted for 1% and 5% of annual catch amount of Nagasaki Prefecture in 2014 respectively (Nagasaki Prefectural Government, 2019).

The main objective of the study was to gain a better understanding on the effect of OWT and the neighboring habitats. The specific objectives were to identify individual (1) movements around the OWT and the neighboring habitats (fish aggregating devices, artificial and natural habitats) (2) fish residency and (3) Seasonality in occurrence of the fish within the OWT and the neighboring artificial and natural reefs (winter and summer seasons).

2. Materials and methods

2.1. Study sites

The study was conducted between Feb and Oct 2017 around the OWT and neighboring habitats. The OWT is situated approximately 100 m deep, 5 km off Fukue Island, south end of Goto Islands. Its total spar length is 172 m (total length submerged is 76 m and rotor diameter is 80 m). The other neighboring habitats included artificial reefs that are installed at the northern part about 98 m deep approximately 1.6 km from the OWT and at southern part about 75 m deep approximately 3.0 km from the OWT (to be referred to as AN and AS respectively). Forty 4m-cube reefs were placed at AN in 1993 while 120 hemispherical reefs were set at AS in 2015. There is also a natural reef of depth range 56–59 m approximately 1.9 km at the southern part of the OWT (also referred to as NR) and a large-scale trapnet set approximately 4.2 km western side of the OWT about 47 m deep (also referred to as TN) (Fig. 1). Two Fish Aggregating Devices (FADs) are anchored around Kabashima Island approximately 11 km north from the OWT. Northern FAD (F1) is situated in the waters of 70 m deep while southern FAD (F2) is 100 m deep. Those FADs are cylindrical in shape made of fiber-reinforced plastic with 1.5 m diameter and 7 m length.

The study sites locate in the shelf region (Goto-nada Sea) between the mainland Kyushu and the Goto Islands. The Goto-nada Sea is influenced both by the Tsushima Warm Current and coastal waters (Yamamoto, Nakata, & Mizuta, 1999). Surface water temperature of the Goto-nada Sea in 2017 published by the Japan Meteorological Agency (Japan Meteorological Agency, 2019) was around 18.0 °C on 1st January and continued to decrease to the lowest (15.2 °C) at the beginning of March. Then it started to increase up to 28.3 °C at the beginning of August and it was around 24 °C in October. Thus, acoustic monitoring was conducted in the coldest period in winter in the study sites while acoustic monitoring in summer was done to coincide the season when the study sites became the hottest.

Seven acoustic monitoring receivers (Vemco VR2W, Halifax, Canada, diameter of 60 mm, 340 mm length, a weight under water 300 g and a battery life of about 450 days) were used to monitor the presence of pulse coded acoustic transmitters within their detection range. The transmitters used that emitted fish IDs were V9 (Vemco, Halifax, Canada, 9 mm in diameter, 21 mm in length, power output 145 dB re 1 μPa @ 1 m, 180–300 s repeat rate) and V13(Vemco, 13 mm in diameter, 36 mm in length, power output 153 dB re 1 μPa @ 1 m, 35–65 s repeat rate). Receivers record date, time and fish ID when detect the acoustic signal. It is known that the detection range of the receiver is influenced by differences in geography, deployed depth, seasons, weather and even in a day(day/night) (Kessel et al., 2014). The probability of signal reception by a receiver that decreases as the distance between a receiver and a transmitter increases is referred to as detection probability (Claisse et al., 2011; Topping & Szedlmayer, 2011). This study assumed the detection ranges of 450 m (V9) and 700 m (V13) respectively based on web-based software “Seawater Range Calculator” (VEMCO, 2019).

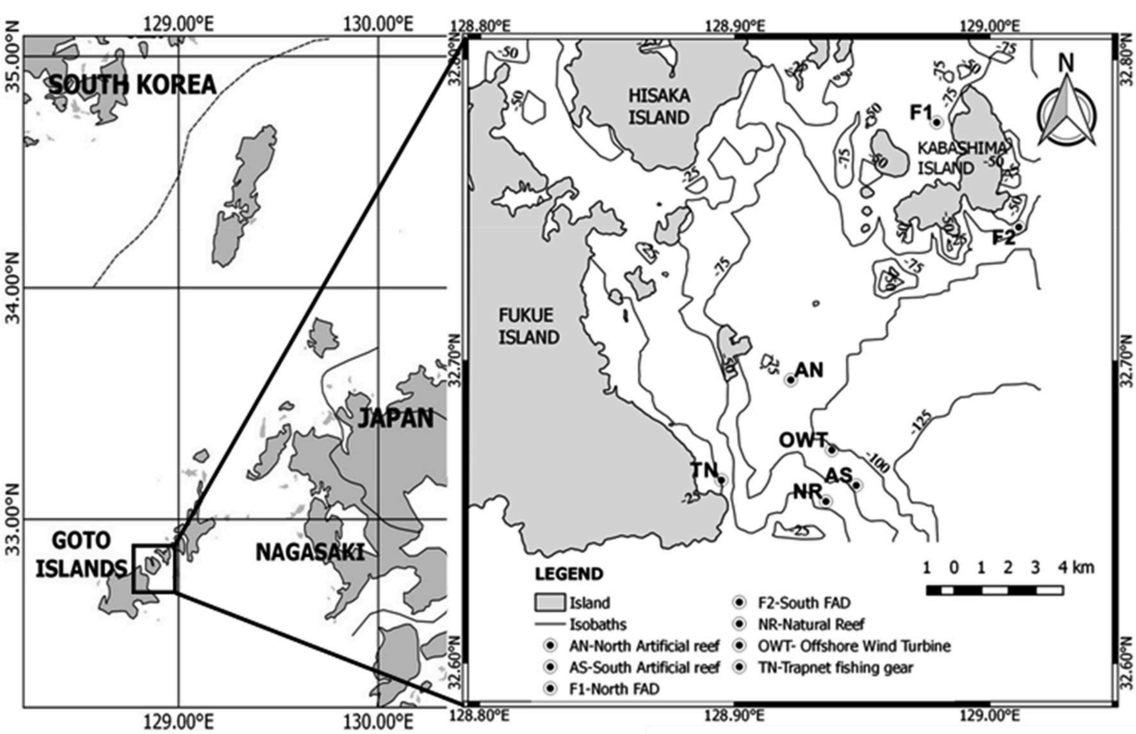

Fig. 1. A map of the study sites in Goto Islands including the locations of the deployed monitoring receivers including Offshore Wind Turbine (OWT), north artificial reef (AN), south artificial reef (AS), natural reef (NR), trapnet (TN), north FAD (F1) and south FAD (F2).

The acoustic receivers were deployed at OWT, AS, TN, F1 and F2 in winter and two more receivers were deployed at AN and NR in summer. Detailed summary of monitoring durations including the deployment date, recovered date, days deployed, the exact positions of the receivers and the scale of various habitats is shown in Table 1. At the OWT, one receiver was attached on the surface approximately 10 m under the sea surface, three receivers were deployed on AN, AS and NR moored with anchors attached to a rope approximately 10 m above the seabed, which was connected to a subsurface buoy. Two receivers were deployed on F1 and F2, and one other receiver was deployed at TN suspended 5 m from the sea surface.

2.2. Fish tagging

We tagged 27 *P. major* on 1st Feb 2017 (winter), 8 *P. major* on 13th July 2017 and 20 *S. quinqueradiata* on 14th July (summer). Tagged fish were monitored during winter season from 1st Feb to 16th Mar and summer season from 13th July to 13th Oct 2017. The fish were collected using hook and line fishing in winter in the water off Fukue Islands near the study sites by local fishers in Goto Islands. Fish in summer tagging were captured by the large-scale trapnet (TN), one of the study sites. After capture, the individual fish were kept for one or two days in an aerated water tank for *P. major* used in winter or a net cage for *P. major* and *S. quinqueradiata* used in summer before surgical implantation of the acoustic transmitter (i.e. tagging). The fish were lightly anaesthetized in seawater containing dissolved 2-phenoxyethanol at a concentration of 0.3–0.4 mg/L. Then the total lengths were measured to the nearest 1 cm. The size ranged from 35 to 46 cm for *P. major* (in winter and summer, approx. 5–8 years old according to Tojima (2000)) and *S. quinqueradiata* was from 75 to 92 cm (approx. 3–6 years old according to Shiraishi, Ohshimo, & Yukami (2011)). The fish were then transferred onto a "V" shaped tagging table whereby seawater was supplied to the fish mouths to oxygenate the gills. The transmitters were surgically implanted into the fish following standard tag implantation techniques (Fujioka et al., 2010; Meyer, Holland, Wetherbee, & Lowe, 2000). An incision of 1–2 cm was made in the abdominal musculature by a scalpel, approximately 2–3 cm proximal to the anus where the transmitter was inserted into the peritoneal cavity and the incision was closed with two independent sutures. The entire implantation procedure generally took less than 2 min. To facilitate identification of the fish in the case of recaptures, all fish were tagged with external plastic dart tags or T-bar anchor tags inserted through the pterygiophores of the second dorsal fin for external recognition if recaptured. After full recovery up to 2 h' observation for survival, the fish were then released around the OWT.

2.3. Data analysis

To determine the site preference of tagged fish, we used the detection rate as an index. The detection rate is defined as a number of detections recorded in each receiver divided by a number of days detected by that receiver because the deployment durations of receivers were different by winter and summer. We calculated the detection rate only if that fish was present in the study sites on a given day at least twice on that day (Meyer, Ecol, Holland, Ser, & Papastamatiou, 2007; Reubens et al., 2013).

We further quantify the residency of each tagged fish at the different sites using residency index. Residency index was calculated by the number of days that the tagged fish was detected divided by the days at liberty (Abecasis & Erzini, 2008). Days at liberty is defined as the number of days between the date of release and the date of last detection for each tagged fish. The residency index ranges between 0 (completely absent in the site) and 1 (permanently present in the site).

We evaluated the site preference of fish and residency of tagged fish by the detection rate and residency index respectively for each site, but as shown in Fig. 1, the study sites were located within 5 km distance from OWT except for two sites (i.e. F1 and F2). We therefore considered those sites (OWT, AN, AS, NR and TN) as the complex of habitats. We evaluated the residence time of tagged fish in this complex of habitats by species and seasons, defined as the number of days from fish released to the loss of the signal detection, independent of how the loss occurred, by using the product limit method of Kaplan and Meier (1958). This was achieved by estimation of the cumulative residual rate for the two species in the different seasons. The package "OISurv" (2.42) in R (ver 3.5.0) was used to estimate the Kaplan-Meier (K-M) survival function (Fujioka et al., 2010; Ohta & Kakuma, 2005). This analysis estimated residence to the complex of habitats at t days assuming fish tagged in different seasons were released on the same day and examined the entire distribution of emigration of tagged fish from the habitat by species and seasons. The K-M product estimator $\widehat{S}_{(t)}$, which shows the probability that residence of fish in the complex of habitats is longer than t, was calculated for each fish species tagged in different seasons by using the following formula:

$$\widehat{S}_{(t)} = \prod_{k:t_k \le t} \left(1 - \frac{d_k}{r_k}\right)$$

where t_k is a number of days when at least one tagged fish emigrated, d_k represents the number of tagged fish that emigrated from the complex of habitats and r_k, the number of tagged fish stayed in the complex of habitats up to time t_k (Kaplan & Meier, 1958). Median residence time is the number of days when 50% of respective two fish stayed in the complex of habitats in this study.

Table 1
Receivers' deployment information by habitats from Feb to Nov 2017

Habitat name	Deployment location	Deployment date (Start)	Recovered date (End)	Days deployed	Bottom depth (m)	Characteristics
Offshore Wind Turbine (OWT)	32° 40′ 13.98″ N, 128° 56′ 17.04″ E	1st Feb, 22nd June	16th Mar, 11th Oct	44, 112	100	Off Fukue Island
North FAD (F1)	32° 44′ 40.02″ N, 129° 00′ 40.98″ E	1st Feb	12th Oct	254	70	11.8 km northwest of the OWT
South FAD (F2)	32° 46′ 16.98″ N, 128° 58′ 45.00″ E	1st Feb	12th Oct	254	100	10.7 km northwest of the OWT
North artificial reef (AN)	32° 39′ 31.80″ N, 128° 56′ 51.42″ E	13th July	13th Oct	93	98	1.6 km north of the OWT
South artificial reef (AS)	32° 41′ 37.62″ N, 128° 55′ 19.02″ E	1st Feb, 27th June	17th Mar, 13th Oct	45, 109	75	3.0 km south of the OWT
Natural reef (NR)	32° 39′ 12.66″ N, 128° 56′ 08.76″ E	13th July	13th Oct	93	56–59	1.9 km south of the OWT
Trapnet fishing gear (TN)	32° 39′ 37.44″ N, 128° 53′ 41.16″ E	1st Feb	14th Nov	287	47	4.2 km west of the OWT

3. Results

3.1. Movement pattern of the tagged fish

During study periods, 20 (74%) *P. major* were detected for 1 day up to 20 days in the winter (Table 2). In summer, 7 (70%) *P. major* were only detected within 1 day (Table 3) and 15 (75%) *S. quinqueradiata* were detected for 1 day up to 8 days in the summer (Table 4).

In winter, movement of tagged fish can be explained from the detection history of acoustic receivers (Fig. 2). Twelve *P. major* (IDs 1, 5, 8, 10, 11, 12, 13, 15, 16, 18, 19, 20) were present at OWT on the released day. Out of which, 7 fish (IDs 1, 5, 10, 12, 15, 16, 18) then moved to TN and stayed for several days (longest duration recorded was 7 days by ID 10). One fish (ID 5) then moved to F2 on 17th Feb for a day then disappeared. Out of the 5 fish (IDs 8, 11, 13, 19, 20) that were only detected at OWT on the released day, 1 fish (ID 13) returned around OWT after a month and stay for 1 day then disappeared. Six *P. major* (IDs 2, 9, 21, 22, 23, 25) moved directly to TN without any detection at OWT. Thus, 13 fish moved to TN between 1st Feb and 6th Mar 2017. In addition, one fish (ID 2) then moved to OWT after one or so months on 13th Mar. Another *P. major* (ID 26) was only detected at F1 for a day on 16th Feb, which was about 16 days after released. One other fish (ID 27) only stayed at AS for about 20 days during the study period.

In summer, 7 *P. major* were detected at OWT within the released day (Fig. 3). Out of which one fish (ID 29) moved to TN on the same day then disappeared. Despite additional monitoring receivers deployed in two more sites (AN and NR) around OWT, the *P. major* was only detected within a day in summer.

Most *S. quinqueradiata* were detected in all habitats a few days after released day in summer as shown in Fig. 4a and b. Whereby 10 *S. quinqueradiata* (IDs 36, 37, 38, 39, 41, 42, 47, 49, 50, 51) were detected at the OWT within 2 days after released but 4 fish (IDs 36, 38, 41, 49) disappeared after the first day. While two fish (IDs 39, 51) were detected on the second day and disappeared within the same day. Moreover, three fish (ID 37, 42, 50) were detected at the OWT for 1–3 days. IDs 37 and 42 then moved and used multiple sites (AS, NR, F1, F2 for ID 37 and NR, AS, F1 for ID42) before they disappeared. ID 37 recoded the longest detection at NR for 6 days while ID 42 recorded the longest detection at AS for 5 days. ID 47 was detected at the OWT and then detected at TN after 10days. Other 5 fish (IDs 40, 43, 44, 45, 46) were not detected at the OWT but at other sites. ID 40 was detected at AN after released then moved to NR after 10 days where it was detected for a day and disappeared. ID 43 was only detected at AS for 8 days after released. IDs 44 and 46 were only detected at the TN after released. However, ID 46 then moved to F1 on 26th Aug (more than a month after released) and stayed there for a day. Moreover, ID 45 was detected on the second day after released at NR and stayed at the site for 5 days. Then moved and stayed at AS for 2 days and was lastly detected at F1 on 7th Oct (85 days after released) for a day then disappeared.

3.2. Habitat usage of the tagged fish

The detection rate and number of fish detected at each site are shown in Fig. 5. In winter, the detection rate for *P. major* was highest at TN (244/day) used by 13 fish, followed by the OWT (78/day) used by 13 fish, AS (19/day) by 1 fish, F2 (15/day) by 1 fish and the least used site

Table 2

Summary of acoustic monitoring data for 27 *P. major* tagged in winter "0" indicated the days at liberty and days detected was within the released date and disappeared completely thus residency index was 0. "-" indicated the fish ID was only detected once hence omitted in the analysis.

Winter							
P. major (N = 27)							
Fish ID	Total length (cm)	Tag type	Date released	Sites detected	Days at liberty	Days detected	Residency index
1	37	V9	2017/2/1	OWT	0	0	0.00
1				TN	0	0	0.00
2	39	V9	2017/2/1	OWT	41	1	0.02
2				TN	41	1	0.02
3	39	V9	2017/2/1	Not detected	–	–	–
4	36	V9	2017/2/1	Not detected	–	–	–
5	37	V9	2017/2/1	OWT	18	1	0.06
5				TN	18	1	0.06
5				F2	18	1	0.06
6	36	V9	2017/2/1	Not detected	–	–	–
7	37	V9	2017/2/1	Not detected	–	–	–
8	35	V9	2017/2/1	OWT	41	1	0.02
9	36	V9	2017/2/1	TN	7	6	0.86
10	36	V9	2017/2/1	OWT	8	1	0.13
10				TN	8	7	0.88
11	35	V9	2017/2/1	OWT	0	0	0.00
12	36	V9	2017/2/1	OWT	10	1	0.10
12				TN	10	2	0.20
13	38	V9	2017/2/1	OWT	29	2	0.07
14	38	V9	2017/2/1	Not detected	–	–	–
15	42	V9	2017/2/1	OWT	10	1	0.10
15				TN	10	1	0.10
16	40	V9	2017/2/1	OWT	9	1	0.11
16				TN	9	1	0.11
17	43	V9	2017/2/1	Not detected	–	–	–
18	41	V13	2017/2/1	OWT	2	1	0.50
18				TN	2	1	0.50
19	42	V13	2017/2/1	OWT	0	0	0.00
20	37	V13	2017/2/1	OWT	0	0	0.00
21	46	V13	2017/2/1	TN	34	1	0.03
22	45	V13	2017/2/1	TN	4	1	0.25
23	38	V13	2017/2/1	TN	13	2	0.15
24	41	V13	2017/2/1	Not detected	–	–	–
25	40	V9	2017/2/1	TN	41	1	0.02
26	38	V9	2017/2/1	F1	17	1	0.06
27	41	V9	2017/2/2	AS	41	20	0.49

Table 3
Summary of acoustic monitoring data for 8 *P. major* tagged in summer. "0" indicated the days at liberty and days detected was within the released date and disappeared completely thus residency index was 0. "-" indicated the fish ID was only detected once hence omitted in the analysis.

Summer							
P. major (N = 8)							
Fish ID	Total length (cm)	Tag type	Date released	Sites detected	Days at liberty	Days detected	Residency index
28	42	V9	2017/7/13	OWT	0	0	0.00
29	39	V9	2017/7/13	OWT	0	0	0.00
29				TN	0	0	0.00
30	44	V9	2017/7/13	OWT	0	0	0.00
31	43	V9	2017/7/13	OWT	0	0	0.00
32	38	V9	2017/7/13	OWT	0	0	0.00
33	45	V9	2017/7/13	OWT	0	0	0.00
34	46	V9	2017/7/13	Not detected	–	–	–
35	41	V9	2017/7/13	OWT	0	0	0.00

Table 4
Summary of acoustic monitoring data for 20 *S. quinqueradiata* tagged in summer "0" indicated the days at liberty and days detected was within the released date and disappeared completely thus residency index was 0."-" indicated the fish ID was only detected once hence omitted in the analysis.

Summer							
S. quinqueradiata (N = 20)							
Fish ID	Total length (cm)	Tag type	Date released	Sites detected	Days at liberty	Days detected	Residency index
36	87	V13	2017/7/14	OWT	0	0	0.00
37	88	V13	2017/7/14	OWT	75	1	0.01
37				NR	75	6	0.08
37				AS	75	3	0.04
37				F1	75	2	0.03
37				F2	75	3	0.04
38	89	V13	2017/7/14	OWT	0	0	0.00
39	92	V13	2017/7/14	OWT	0	0	0.00
40	81	V13	2017/7/14	AN	11	1	0.09
40				NR	11	1	0.09
41	91	V13	2017/7/14	OWT	0	0	0.00
42	80	V13	2017/7/14	OWT	5	2	0.40
42				NR	5	3	0.60
42				AS	5	4	0.80
42				F1	5	1	0.20
43	82	V13	2017/7/14	AS	24	8	0.33
44	84	V13	2017/7/14	TN	0	0	0.00
45	85	V13	2017/7/14	NR	89	5	0.06
45				AS	89	2	0.02
45				F1	89	1	0.01
46	79	V13	2017/7/14	TN	44	1	0.02
46				F1	44	1	0.02
47	83	V13	2017/7/14	OWT	10	1	0.10
47				TN	10	1	0.10
48	89	V13	2017/7/14	Not detected	–	–	–
49	77	V13	2017/7/14	OWT	0	0	0.00
50	75	V13	2017/7/14	OWT	0	0	0.00
51	77	V9	2017/7/14	OWT	0	0	0.00
52	92	V13	2017/7/14	–	–	–	–
53	74	V13	2017/7/14	–	–	–	–
54	85	V13	2017/7/14	–	–	–	–
55	91	V13	2017/7/14	–	–	–	–

was F1 (1/day) by 1 fish. Thus, TN was the most preferred site for *P. major* in winter. The residency indices of *P. major* for study sites were mostly low because most fish were detected at the site only for a few days (Table 2). However, two fish (IDs 9, 10) recorded high residency indices of 0.86 and 0.88 at OWT and one fish (ID 27) showed 0.49 at AS.

Unlike the results in winter, the detection rate of *P. major* in summer was highest at OWT (54/day) used by 7 fish followed by TN (3/day) by 1 fish. However, no residency was recorded at both sites since all the fish disappeared within the same day when they were released (Table 3). This species tended to stay for shorter duration around the OWT where they were released, then moved to coastal area (TN) and stayed for some time during winter, while most of them moved somewhere out of detection ranges in summer.

The detection rate for *S. quinqueradiata* in summer was highest at the OWT (248/day) used by 10 fish, followed by AS (159/day) used by 4 fish, and NR (96/day) by 5 fish (Fig. 5). However, *S. quinqueradiata* generally showed low residency indices for study sites except AS and NR (Table 4). One fish (ID 42) showed high residency indices both for AS and NR (0.80 and 0.60 respectively), suggesting that this fish moved back and forth between AS and NR. Other fish detected at AS and NR also showed relatively higher residency indices between (0.02–0.33). *S. quinqueradiata* tended to use the OWT longer than *P. major* and frequently used AS and NR located at the southern part of the OWT.

Residence time in the complex of habitats estimated from K-M product limit method varied by seasons and species (Fig. 6). In winter, *P. major* median residence time (when 50% of fish still present) was 10

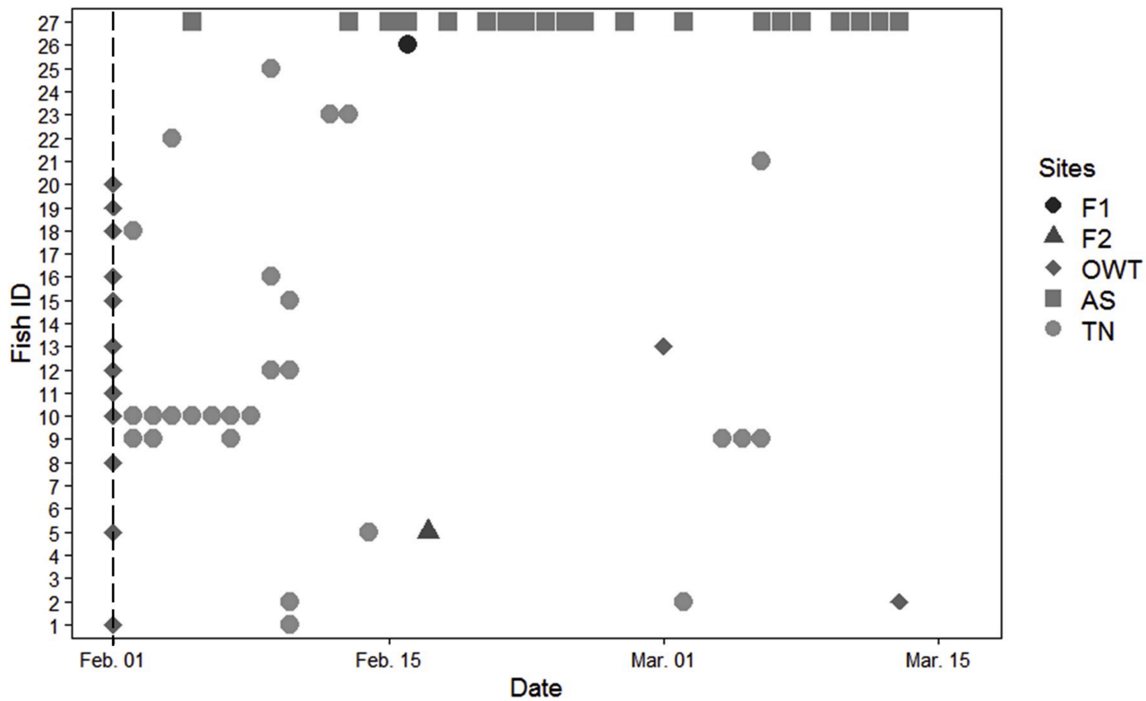

Fig. 2. Detection history of *P. major* tagged in winter. Dotted line indicated the released date. (1st Feb)

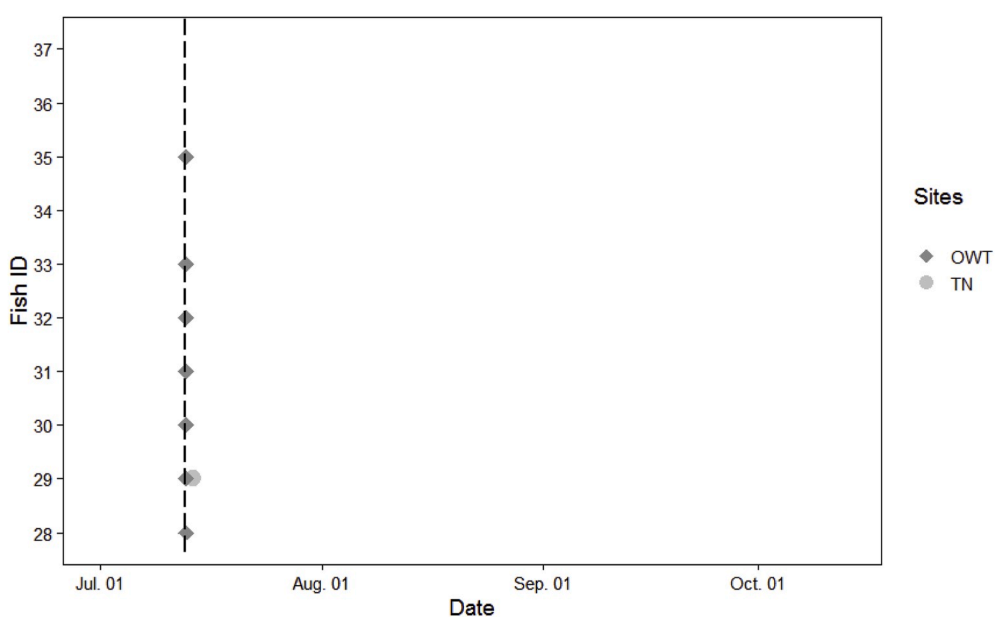

Fig. 3. Detection history of *P. major* tagged in summer. Dotted line indicated the released date. (13th Jul)

days then declined gradually up to 35 days before complete disappearance after 41st day. In summer, it was a day and the *P. major* completely disappeared on the same day. While *S. quinqueradiata* median residence time was 3 days and complete disappearance was on the 25th day.

4. Discussion

This study provides important preliminary evidence concerning the movement pattern of *P. major* and *S. quinqueradiata* around the OWT and the neighboring habitats off Fukue Island in Goto Islands. Unlike previous similar studies in Europe (Bergström et al., 2014; Reubens et al., 2013, 2011), we observed low affinity of *P. major* and *S. quinqueradiata* to OWT in relation to the neighboring habitats. The fish stayed around the OWT not more than three days irrespective of the seasons and moved to other habitats surrounding the OWT (Figs. 2, 3 and 4a and 4b).

P. major tagged in winter were observed at the released site (OWT, 100 m deep) within a day and recorded low residency index, then 13 fish were detected at TN (47 m deep) from 2nd February to 6th Mar 2017. One fish (ID27) used AS (75 m deep) for 20 days and one other fish (ID26) directly moved to the northern part and used (F1, 70 m deep) briefly, this meant that majority of fish moved to the coastal shallower area. It is well known that *P. major* migrate to shallower waters in late spring (Hakuta & Tabeta, 2013; Russell et al., 2014, p. 8235). In addition, this observation was due to the increasing

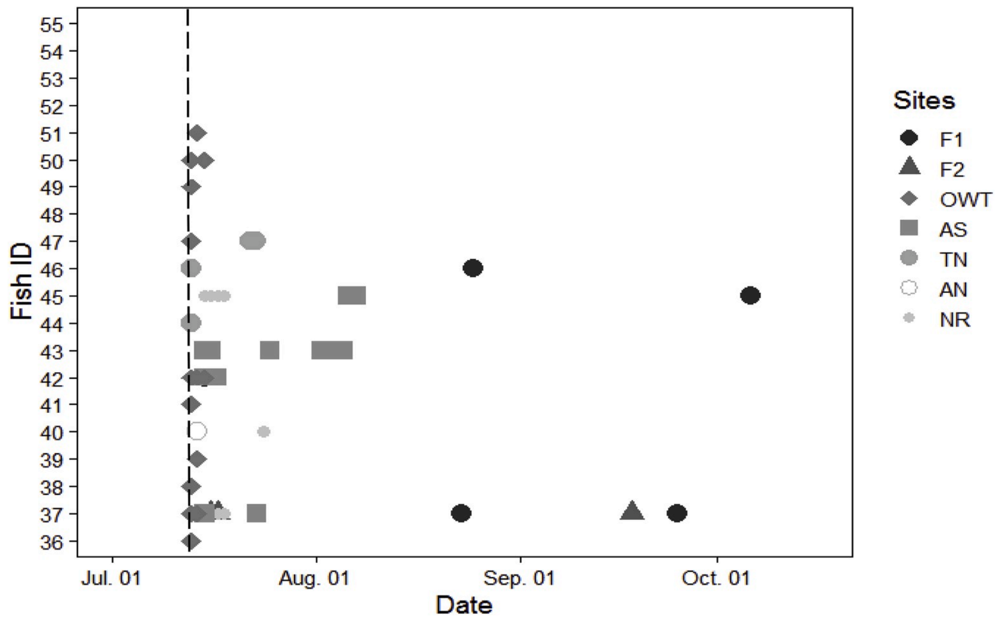

Fig. 4a. Detection history of *S. quinqueradiata* tagged in summer. Dotted line indicated the released date. (14the Jul)

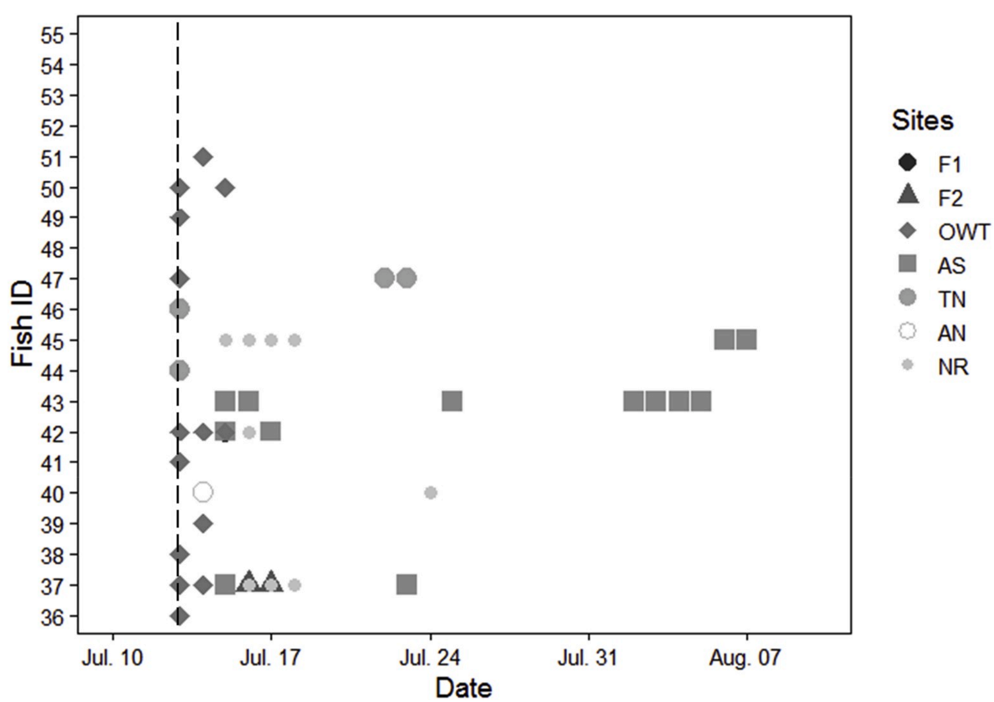

Fig. 4b. Detection history of *S. quinqueradiata* from 10th July to 10th Aug 2017. Dotted line indicated the released date (14th Jul).

temperature that augmented the fish swimming activity and was within the range of habitat temperature for *P. major* (15° ~ 26 °C) (Takeuchi et al., 2016). According to communication from the fishermen operating TN, they stated that they never found any tagged *P. major* in their catches during our monitoring period. With this regards TN can be said to be an artificial reef structure with large volume built in the shallower waters, according to Kakimoto (1998) epibenthic species such as *P. major* preferred bottom habitats including artificial or natural reefs.

On the other hand, *P. major* tagged during summer was only observed at the OWT just after released and one fish then moved to TN within the same day (Fig. 3). Thus, *P. major* were never detected at other sites around the OWT. Hook and Line fishing for *P. major* around the studied area (Fukue Island) is conducted in waters from 50 to 150 m deep between March and June, then the fishing ground moves to waters (40–180 m deep) around the northern parts of Goto Islands from April to December (Nagasaki Prefectural Institute of Fisheries, 1983). These facts on the fishing seasons and grounds for *P. major* support that *P. major* in summer moved to other waters.

Fifteen *S. quinqueradiata* tagged in summer were detected in all the sites for some days. Out of which, 10 fish were only detected at the OWT then disappeared within three days. In addition, 6 fish were observed at plural sites for different number of days. This movement pattern seems to be different from *P. major* in winter and summer

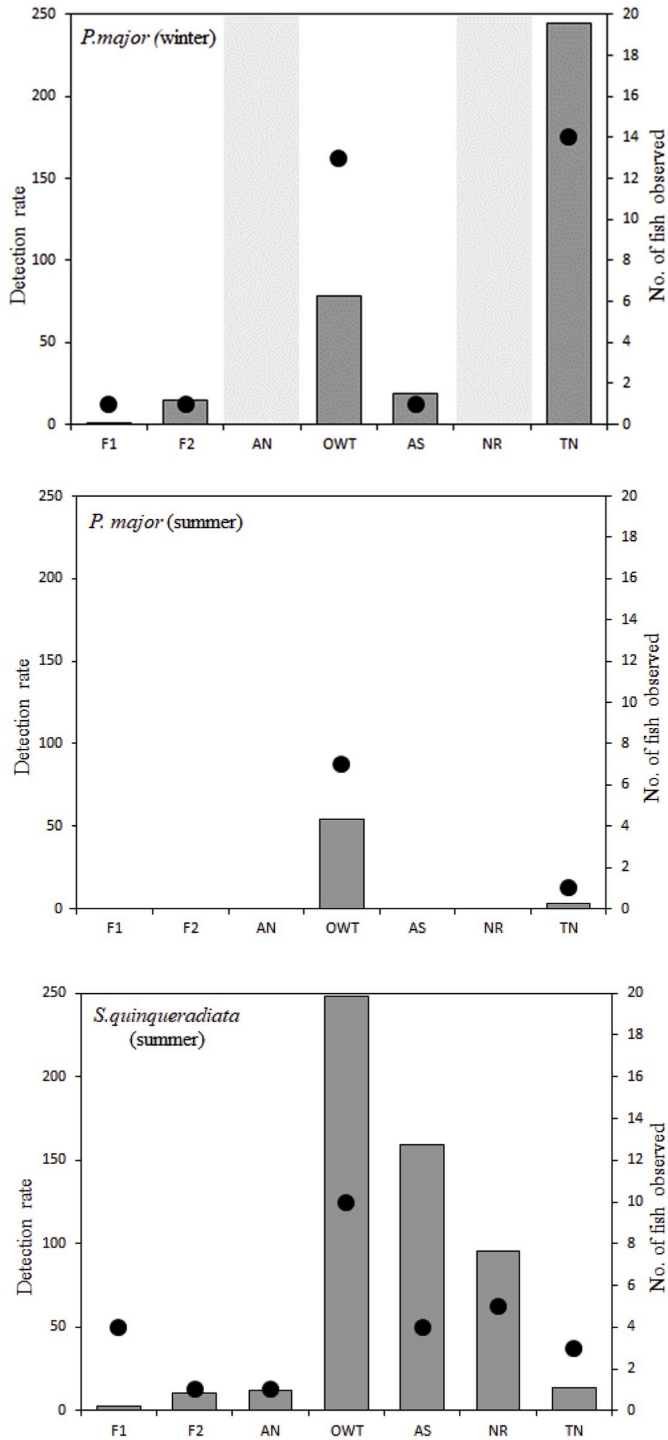

Fig. 5. Detection rate by *P. major* tagged in winter, *P. major* and *S. quinqueradiata* tagged in summer. Vertical bars indicate the detection rate and the dots indicate the number of fish observed. Vertical bars filled with gray shades in the top graph for *P. major* (winter) showed the sites where the receivers were not deployed.

because *S. quinqueradiata* frequently moved in all the habitats including floating objects (OWT, F1, F2) and benthic habitats (NR, AN, AS, TN). They were especially observed at the OWT, AS and NR (Fig. 4a and b). This indicated that *S. quinqueradiata* made extensive migrations in terms of distance and in terms of depths between habitats around the OWT. These results concurred with several studies that pelagic predators such as tunas aggregate around localized seamounts and lumps (Fujioka et al., 2010; Klimley, Jorgensen, Muhlia-melo, & Beavers, 2003). Kasai, Sakuramoto, Mitsunaga, and Yamamoto (2000) also confirmed that yellowtails including *S. quinqueradiata* would stay in some restricted areas during the night, move via the frontal area to another coastal area to feed then return. Our observation suggested a possibility that *S. quinqueradiata* had utilized the OWT and the neighboring habitats as feeding grounds and shelters.

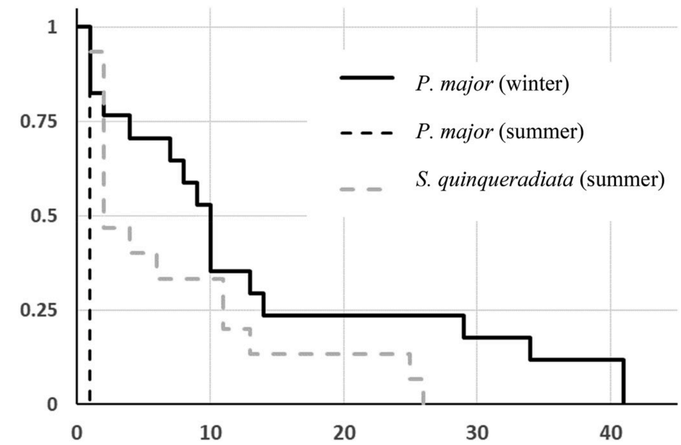

Fig. 6. Residence time estimates of *P. major* and *S. quinqueradiata* from KM analysis during the study from 1st Feb to 16th Mar (winter) and 13th July to 13th Oct (summer).

We can conclude that *P. major* preferred the coastal area including TN in winter while most of them moved out of detection ranges in summer probably the sites were not favorable habitats due to their life history behavior. While some *S. quinqueradiata* stayed around the OWT for longer durations (about 3 days) as compared to *P. major* then moved to the neighboring habitats and were detected in all the sites. As a result, residence time of the complex of habitats around the OWT for *P. major* tagged was 10 days in winter and a day in summer while it was 3 days for *S. quinqueradiata*. These residence times were short which suggest these species moved around the OWT only for a limited time. From our preliminary study, we recommend further investigation on the relationship between fish movement and environmental factors because only a year has passed since the OWT was deployed. It was reported that the fauna of marine sessile animals in the artificial habitats, which is considered important factors for fish attraction, becomes stable after 1.5–2 years in the coastal areas influenced by warm currents in Japan (Kajihara, 1979). Therefore it is necessary to monitor change in the environmental conditions and habitat usage of fish. This will assist in explaining the reasons for our findings in terms of the movement pattern by the two commercial important species around the OWT and neighboring habitats. Such findings can be used to enhance future designs of the artificial structures and their integration with the natural environments to increase their positive effect.

CRediT authorship contribution statement

Khyria Swaleh Karama: Formal analysis, Data curation, Writing - original draft. **Yoshiki Matsushita:** Project administration, Supervision, Writing - original draft, Writing - review & editing. **Masahiro Inoue:** Methodology, Investigation. **Kenta Kojima:** Investigation, Data curation. **Kazuki Tone:** Data curation, Formal analysis. **Itsumi Nakamura:** Resources, Software, Writing - review & editing. **Ryo Kawabe:** Conceptualization, Methodology, Resources, Software, Writing - review & editing.

Declaration of competing interest

None.

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