Thesis for the Degree of Master of Fisheries

Behaviour of Pacific Cod (*Gadus macrocephalous*) and Environmental Parameters during Winter in Jinhae Bay by Acoustic Telemetry

by

Anthony Appiah

KOICA-PKNU International Graduate Program of Fisheries Science

The Graduate School

Pukyong National University

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음향 텔레메트리 기법을 이용한 동계 진해만에서의 태평양 대구의 행동연구

Advisor: Prof. Hyeon-Ok Shin

by

Anthony Appiah

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by

Anthony Appiah

Approved by :

(Chairman) Dr. Kyoungmi Kang

(Member) Dr. Bo-Gyu Hwang

(Member) Prof. Hyeon-Ok Shin

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Abstract

Pacific cod are fished on their spawning grounds, therefore, it is important to evaluate whether particular spawning sources are more critical than others in sustaining the productivity of fished populations. Four wild male cod (WC1 to WC4) were captured by a pound net. The fish were tagged using surgical method with acoustic transmitters including a pressure. Average total length and weight of tagged fish was 62.5cm (±4.36) and 2,152.5g (±129.34), respectively. The four tagged cod were manually tracked for 2-6 hours. The swimming depth of WC1 and 2 were below 5 m, whereas, WC3 and 4 swam close to the seabed. WC2 average swimming speed was 0.60 TL /s and showed high site fidelity. The average swimming speed of WC1, WC3 and WC4 were 1.11, 2.34 and 1.32 TL/s respectively. Total acoustic signal detection for WC2 was 5.1 hr whereas for WC1, 3 and 4 signal ranged from 1.6 hr to 2.2 hr .

In this study the four tagged cod moved south- eastward in the bay near the coast of Geoje-do. Temperature is the main factor in the movement of WC. Optimum temperature and salinity was found to be in the range of 7.8-8.4^{o}C and 33.4-33.6 psu respectively.

1. Introduction

1.1 Background

Determining where, when and why fish move is critical in understanding the distribution and availability of fish for fishing, and forms a basis for the sustainable management of fisheries. Fish move or migrate for several reasons, including spawning, site fidelity, feeding and to avoid unfavorable environmental conditions.

Pacific cod, *Gadus macrocephalus*, is a transoceanic species (Fig.1), occurring at depths from the shoreline to 500 m extending from about 34° N latitude (Santa Monica Bay, California on North American coast and south end of Korean Peninsula on Asian coast) to about 63° N (Bakkala, et al 1984).

Pacific cod are fished on their spawning grounds, therefore, it is important to evaluate whether particular spawning sources are more critical than others in sustaining the productivity of fished populations.

Fig. 1. Distribution of *Gadus macrocephalous* (FAO, 1990).

Pacific cod belong to a large group of fishes in the suborder Gadoidei: the cods and their allies. The family Gadidae, consisting Atlantic cod, Pacific cod, haddock, whiting, walleye pollock, and pollock, is the most derived family in the suborder Gadoidei.

As indiscriminate predators Pacific cod appear to feed upon dominant food organisms present. They evidently feed very little when close to spawning. The diet of adults includes fish (pollock, smelt, and herring as well as flounders, cottids, salmon and sardines), octopuses, crustacea such as the clams, crab and shrimps. In turn, they are eaten by halibut and marine mammals.

The cod in the eastern coastal areas of the Korean peninsula spawn in November–February, peaking in January (Cha et al., 2007; Lee et al., 2007). Fecundity in Pacific cod has been estimated between 225,000 and 5 million eggs per spawning female, also they are oviparous and have external fertilization (Palsson, 1990). They are single-batch spawners, releasing all ripe eggs in a single spawning event in a few minutes time (Sakurai and Hattori, 1996). Their eggs are demersal and slightly adhesive, hatching in 8–12 days at about 5–12 °C water temperatures (Lee et al., 2007). Jinhae bay is considered as the most important and largest spawning ground of Pacific cod in the Korean Peninsula (Park and Gwak, 2009). Pacific cod are known to have some site fidelity in regards to spawning (Shimada and Kimura, 1994). Half of females are mature by 3 years and 55 cm, and half of males are mature by 2 years and 45 cm (Dunn and Matarese 1987).

1.2 Fishery and Economic Importance of Pacific Cod

Pacific cod is currently fished throughout much of its historical range using a variety of gear: trawl, jig, pot, long-line and set net (Ueda et al., 2004; Thompson et al., 2006). The largest fisheries in 2004 were the United States, Russia, Japan, South Korea and Canada, resulting in a cumulative world catch of 373,617 mt (Cohen et al., 1990).

Pacific cod have been traditionally important commercial fish species in Korea (according to the Annals of the Chosun Dynasty: 1392–1910 AD) (National Institute of Korean History, 2007). They are currently distributed and caught in eastern, western and southern coastal waters off the Korean peninsula. Recruitment to Korean coastal waters seemed to become lower from the 1950s to the 1990s, because catch levels were lower compared with the 1920–1940s. Since 1998, however, catch has continued to increase from 0.5×10^3 metric tons in 1998 to 7.2×10^3 tons in 2007, reaching a record high (due to stock enhancement programmes), making a consensus among policy makers and fishermen that fisheries management plans should be developed to preserve cod stocks.

For developing fisheries management plans, there is the need to determine the fine scale migratory pattern by acoustic telemetry to understand stock assessment of Pacific cod in Korean waters.

1.3 Conventional, Radio and Acoustic Tagging

Advancements in remote animal tracking (biotelemetry) technology have provided researchers a unique and powerful tool to gather information on fish movements, activity, behavior, and habitat use that would otherwise be unattainable in the wild (Shin et al., 2004, Perry et al. 2001). Traditional mark and recapture methods generally involved capturing and handling the fish at both the 'mark' and 'recapture' events, which has the potential to adversely affect the survival, growth, or behavior of the captured individuals . In addition, no information is collected between the capture and recapture events, so limited data are collected. Electronic transmitters, such as radio and acoustic tags, only require handling during the initial tagging event and can subsequently provide data throughout the life of the transmitter.

The use of radio and acoustic tags is similar in many respects; each technique utilizes a transmitter attached to the fish, a hydrophone (acoustic) or antenna (radio) for signal detection, and a receiver for amplifying, filtering, and decoding signals. Tracking techniques are also similar: (1) tagged individuals within range of a remote station are logged with the time and code of the tags, (2) tagged individuals are followed continuously, generally from a boat, and (3) tagged individuals are located periodically from boats. Many tracking studies use a combination of these techniques. In addition to detecting fish location, radio and acoustic transmitters can be optionally outfitted with sensors to determine depth, temperature, light levels, or other parameters (Kang and Shin, 2006).

Acoustic tags were first developed for use in fisheries research because, their low-frequency, long-wave acoustic signals travel well through water and are not substantially affected by conductivity, which allows them to be effective in estuarine and ocean environments (Murphy et al. 1996). In contrast, even relatively low conductivity levels and increasing depth attenuate radio signals. Consequently, radio tags are poorly suited for estuarine or ocean studies but have characteristics suitable for many shallow freshwater studies. This distinguishing characteristic makes acoustics tag the choice for studying movement pattern of Pacific cod in Jinhae bay.

Typical information acquired from these studies includes travel routes and speed. The questions being asked have relatively short time scales (e.g., hours to several weeks) and variable spatial scales that range from a few hundred meters to tens of kilometres. These are questions for which fish tracking studies are particularly suited because of the amount and type of detailed information that can be acquired from each study subject.

Most studies also collect information regarding the environmental conditions experienced by fish including water temperature, salinity, water flow, tidal current and direction, time of day, and habitat features; water depth and other characteristics (Hwang and Shin, 2010). When the biological and physical data are merged, a new understanding of the relationship between the movements and behaviors of marine organisms and oceanographic processes will become apparent (Lucas and Baras, 2000).

1.4 Objectives

Despite Jinhae bay being the largest and the most important spawning ground of Pacific cod in the Korean Peninsula, it is difficult to find the researches of behaviour of Pacific cod in Jinhae bay. It is necessary to investigate behaviour of Pacific cod to protect spawning grounds, habitats and migration routes in the bay. Thus, this study aims at analyzing behaviour of Pacific cod in Jinhae bay during winter and finding the escaping routes from the bay.

2. Materials and Methods

2.1 Study Site

Jinhae Bay is semi-enclosed embayment about 400 km^2 (Fig. 2). The seabed of Jinhae bay is generally flat, with water depths of 15-40 m, and it is covered with mud that comprise approximately equal amounts of silt and clay (Park and Lee, 1996). There is the submarine tunnel connecting Gadeok-do to Geoje-do in the mouth of Jinhae bay.

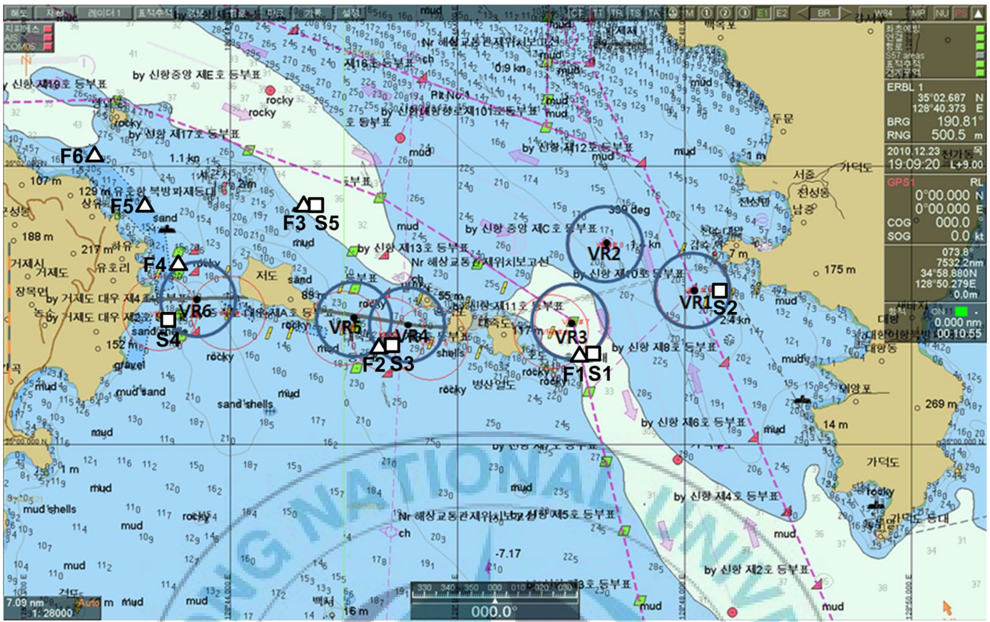


Fig. 2. Arrangement of acoustic receivers (VR1 to VR6) in the study site. Triangle marks (Δ, F1 to F6) and square marks (□, S1 to S5) indicate the observation points on 27 January and 13 February, 2012.

2.2 Observation of Environmental parameters

Observation of environmental parameters (temperature, salinity, conductivity by depths) was conducted in the Jinhae bay on 20 November, 2011, 27 January and 13 February, 2012. Each parameter was measured by CTD recorder (304, Idronaut Srl, Italy) to determine the horizontal and vertical variation at the study site. The recorder was lowered by hand from the surface to the seabed with a descent rate of approximately 1 ms^{-1}. The parameters were recorded automatically and continuously, and used to calculate salinity. Sampling interval was 250 ms.

2.3 Acoustic transmitter attachment and release

Four wild male cod (WC1 to WC4) were captured by a pound net. The fish were tagged using surgical tagging method with acoustic transmitters including a pressure sensor (V16P-4H, Vemco Ltd., Canada). The frequency and the battery life of the transmitter was 69.0 kHz and 715 days, and the source level was 158 dB (re 1μPa at 1 m). It transmitted a signal (including identification number, date, time and depth) once every 40–80 sec. Its size was 16 mm in diameter and 71 mm in length with a mass of 24 g in water (26 g in air). On average, the transmitter was 0.51% of the fish body mass.

The fish were anaesthetized using MS-222 (100 ppm) dissolved in sea water to reduce trauma and struggle during the surgical tagging. They were weighed and measured after fully anaesthetizing. Average weight and total length (TL) of the four was 2,513 g (±129.3) and 62.5 cm (±4.4) respectively (Table 1).

Table 1. Summary of total length (TL) and weight of tagged fish (WC1 to WC4) and tracking duration in the study site from 5 January to 13 February, 2012

Fish	Tag ID	TL (cm)	Weight (g)	Sex	Released		Tracking (hr)
					Date	Time	
WC1	44560	60.0	2,024	male	2012-01-05	12:21	3.7
WC2	44561	60.0	2,150	male	2012-01-16	10:37	6.0
WC3	44562	61.0	2,330	male	2012-01-27	12:15	3.0
WC4	44563	69.0	2,106	male	2012-02-13	12:12	4.6

The fish was placed ventral side up into a V-shaped support adjusted to their morphology (Fig. 3b), and the whole body except the ventral side stayed in the wet towel to avoid dehydration and to blindfold the fish.
Incision (under 2 cm) was made along the ventral of the fish between the pelvic fins and vent. The transmitter was gently inserted into the abdominal cavity (Fig. 3b). Incision was sutured closed with monofilament and iodine was applied to aid and prevent infection (Fig. 3c and 3d). After the surgery, the tagged fish were kept in a tank (1000 L in volume) in the vessel at the study area for an average of 16 hr to observe any negative effects of the

operation (Fig. 3e). The tagged fish showed no observable effect of the surgery on their swimming behaviour. The surgical tagging was completed within 6 min. tagging and Release were carried out 4 times, and each tagged fish was released near or at the capture point.



(a) anesthesia (b) insertion (c) suture



(d) disinfection (e) recovery (f) release

Fig. 3. Tagging procedure in the study.

2.4 Deployment of acoustic receivers and tracking

Six acoustic receivers (VR2; VEMCO Ltd, Canada) were moored in the study site (Fig. 2) on January 4, 2012. Three VR2 receivers each were installed to buoys at eastern and the south-eastern part of the bay. Acoustic receiver recorded the transmitter signal when the tagged fish appeared within its effective range (approximately a 500-m radius). The 6 m rope of the receiver below the surface had additional weight and drag provided by a 2 kg iron weight attached to reduce vertical movement.

Manual tracking was conducted from the vessel equipped with two types of tracking system with a directional hydrophone (VR28 tracking system and VR100 receiver, VEMCO Ltd, Canada). VR28 tracking system consisted of a Laptop computer, a four channel receiver and a quad hydrophone mounted on the VFIN depressor. The hydrophone was towed on the part side of the vessel at 3 to 4 m depth later below the sea surface. VR100 receiver consisted of a sing channel receiver. Its hydrophone was installed on the starboard side of the vessel. Tracking speed ranged from 2.0 to 4.2 kn, and tracking duration was from 3.0 to 6.0 hours after individual release (Table 1).

3. Results

3.1 Temperature and salinity in the study site

Temperature distribution at surface (1 m) and a depth of 20 m in the study site is shown as Figure 4 and 5. It was known that Pacific cod did not migrate into Jinhae Bay in November. Average of temperature was 16.7 °C (S.E. = ± 0.14) at a depth of 1 m and 16.9 °C (± 0.11) at a depth of 20 m on 20 November, 2011. Average of salinity at a depth of 1 m and 20 m was 32.3 psu (± 0.22) and 33.1 psu(± 0.52), respectively. It has no significant differences of temperature and salinity between a depth of 1 m and 20 m in the study site during the preparatory experiment.

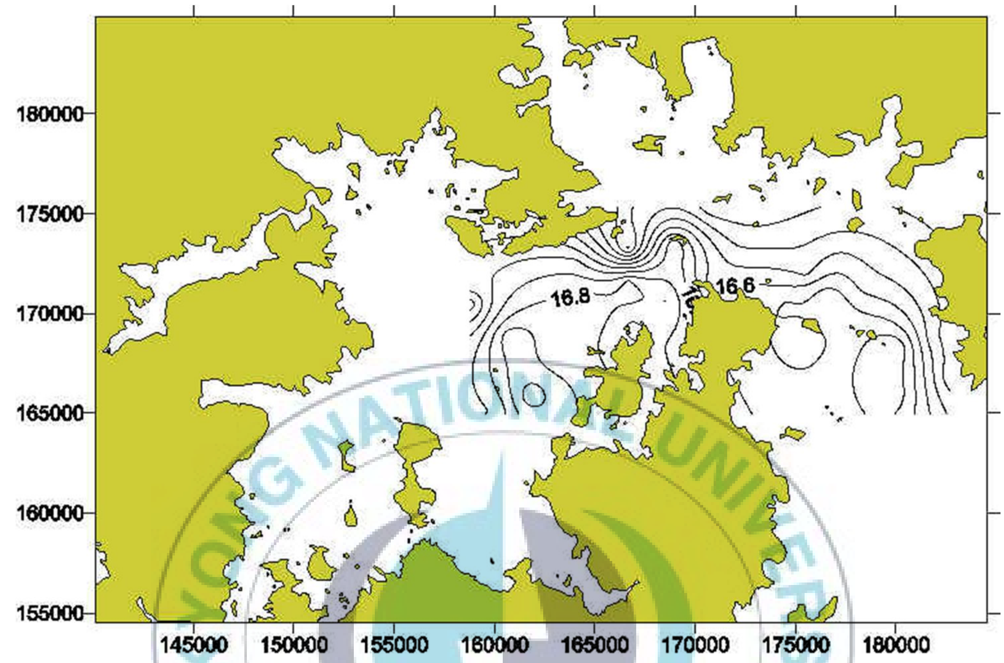


Fig. 4. Temperature distribution at a depth of 1 m in the study site on 20 November, 2011.

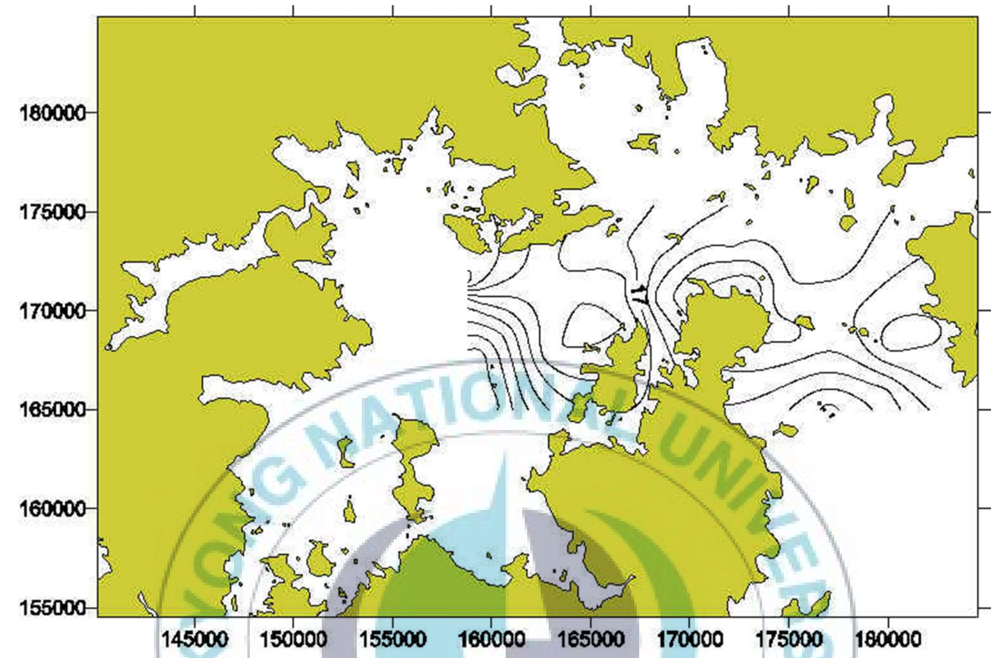


Fig. 5. Temperature distribution at a depth of 20 m in the study site on 20 November, 2011.

In January and February, the result of temperature and salinity in the study site is shown as Figure 6 and 7. Temperature and salinity were measured near the submarine tunnel in the mouth of Jinhae bay (Fig. 2). Maximum temperature and salinity at a depth of 1 m and 20 m in January were 10.1°C (F1) and 33.8 psu (F6), and 10.0°C (F1) and 33.8 psu (F2), respectively. Minimum temperature and salinity at a depth of 1 m and 20 m in January were 7.8°C (F3) and 33.4 psu (F4), and 7.7°C (F4) and 33.4 psu (F4), respectively (Fig. 6). It has a significant difference of temperature at each point. Temperature difference was over 2.0°C between F1 and F4 (Fig. 6a). F1 was deeper than other points (maximum depth: 37 m). F4 was located near the coast of Geoje-do, and shallower than others (maximum depth: 20 m).

In the study site, salinity between F1 and F6 (average salinity: 33.8 psu) (Fig. 6b) were similar. However, salinity of F3, F4 and F5 was lower than other points. Salinity difference was over 0.4 psu between F1 and F4 (Fig. 6b).

It has the same pattern as variation of temperature at the points. Thus, there is possibility that variation of temperature and salinity in the study site was affected by depth.

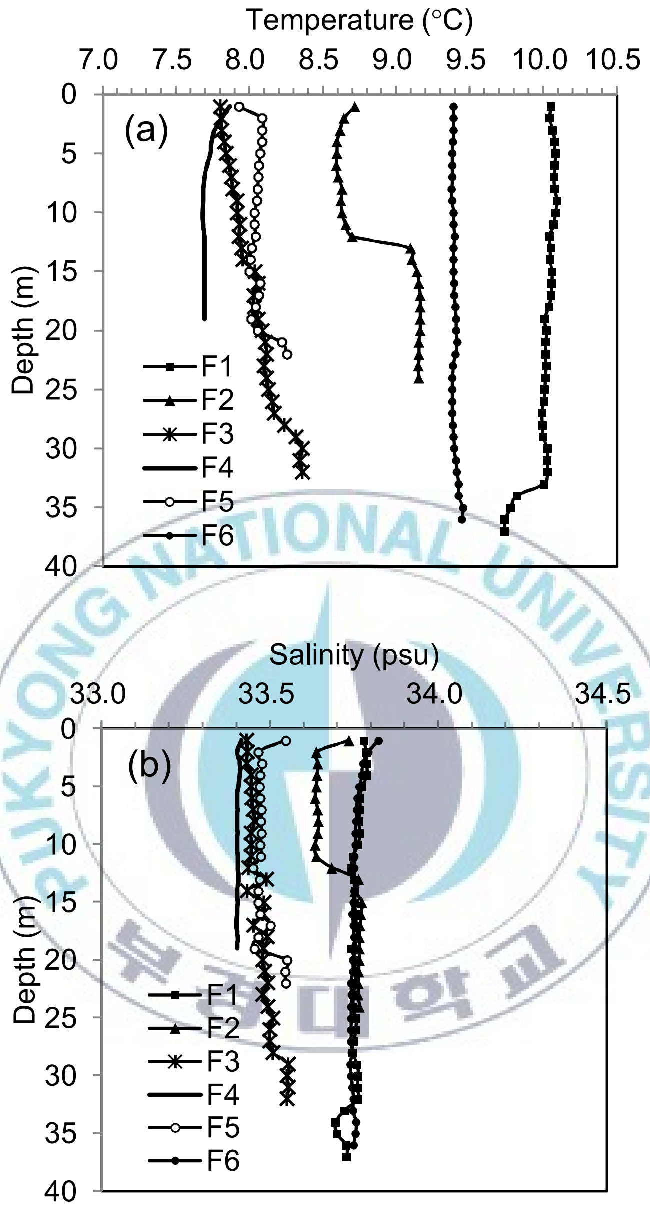
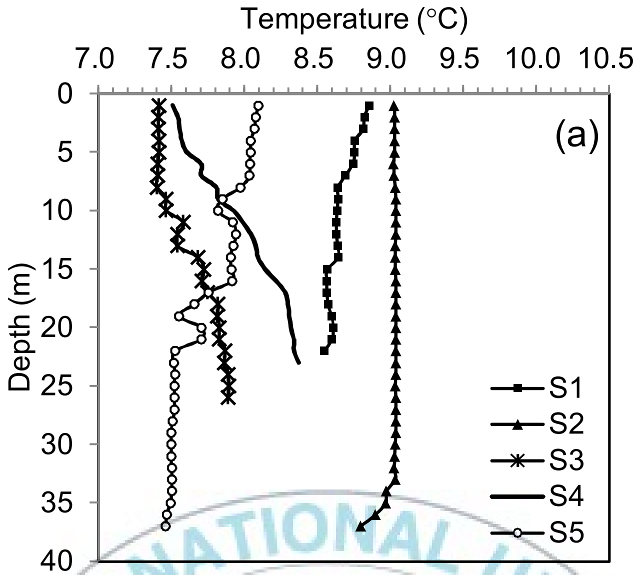


Fig. 6. Variation of temperature and salinity at the observation points in the study site on 27 January, 2012.

Maximum temperature and salinity at a depth of 1 m and 20 m in February were 9.0°C (S2) and 33.9 psu (S2), and 9.0°C (S2) and 34.0 psu (S4), respectively. Minimum temperature and salinity at a depth of 1 m and 20 m in January were 7.8°C (S4) and 33.4 psu (S3), and 7.7°C (S5) and 33.4 psu (S5), respectively (Fig. 7). Although, temperature in January was higher than in February, salinity in January was lower than in February. Temperature difference at depth of 1 m and 20 m decreased than in January, it was below 1.4°C between maximum and minimum. Average salinity and difference at a depth of 1 m and 20 m increased than in January. It was over 0.4 psu between maximum and minimum.



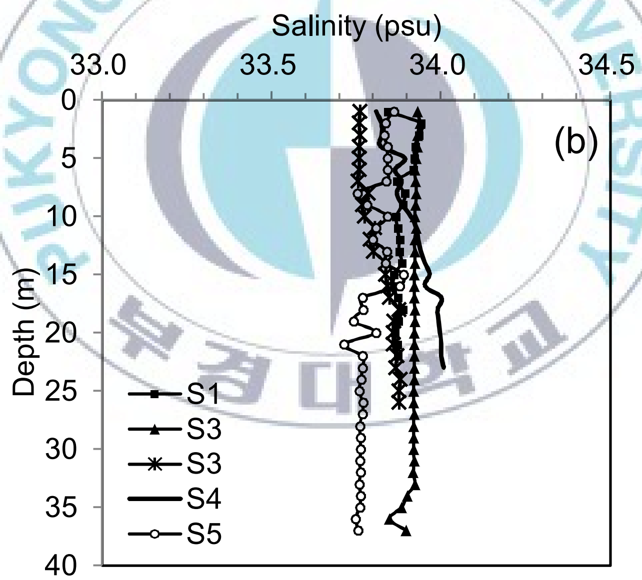


Fig. 7. Variation of temperature and salinity at the observation points in the study site on 13 February, 2012.

3.2 Behaviour of Pacific cod in winter

WC1 was released at a depth of 20 m on 5 January, 2012. The fish moved east about 1.0 km away from the release point by 12:37. Average swimming speed and depth range during the period was 0.6 TL/s and from 1.0 to 5.4 m, respectively. The fish changed movement direction. It moved southward approximately 1.5 km by 13:10, and then it was lost for 41 min. The fish was found 600 m way from the last detected point at 13:51. It changed movement direction again, and moved north about 1.5 km by 14:20. Average swimming speed was 1.0 TL/s. The fish veered to the south-eastward and moved 1.3 km by 14:42. Average swimming speed during the period was 0.9 TL/s. It kept on moving south-eastward (Fig. 8).

During an hour after releasing, the fish moved 1.0 km from the release point. However, hourly movement from the release point was rapidly decreased (Fig. 9).

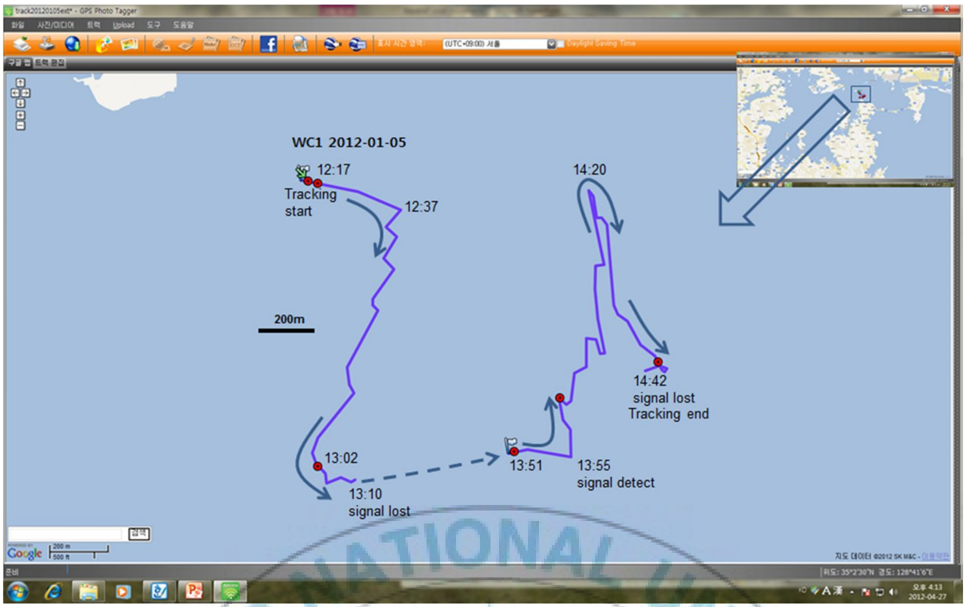


Fig. 8. Movement trcace of tagged fish (WC1) on 5 January, 2012.

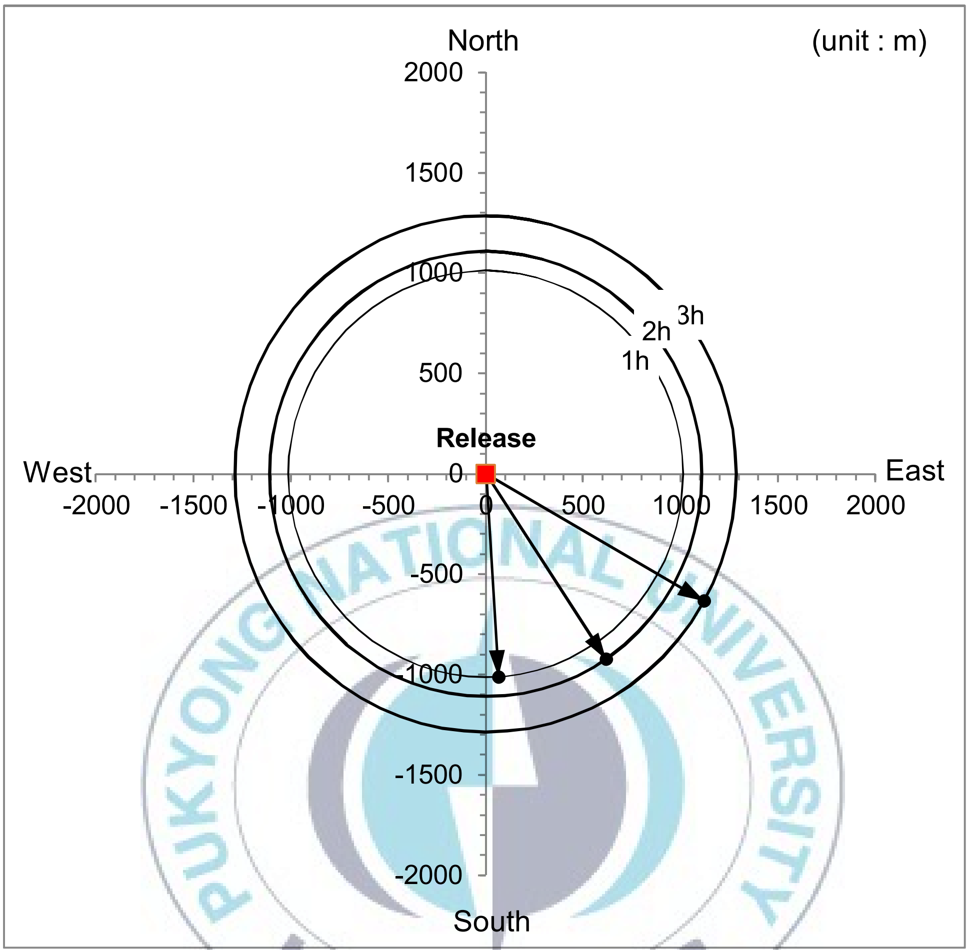


Fig. 9. Hourly movement direction from the release point of tagged fish (WC1) on 5 January, 2012.

WC2 was released at a depth of 20 m on 17 January, 2012. The fish moved north about 1.1 km away from the release point by 11:30, and average swimming speed was 0.6 TL/s. The fish changed movement direction. It moved south-westward about 2.2 km by 11:57, and average swimming speed was 2.2 TL/s. The fish stayed in mid-water at seabed depth of 26-45 m between a small island (Jam-do) and Geoje-do for 4 hr. It went back and forth 1.5 ~ 1.9 km, and average swimming speed was 0.6 TL/s. It was found that the fish was closed to the coast of Geoge-do. Average swimming speed and depth during the period was 0.5 TL/s and 3.8 m, respectively (Fig. 10). WC2 changed movement direction several time during the experiment. It moved north for an hour from releasing, and then changed the direction to south. In the end of the experiment, the fish moved southward from the release point (Fig. 11).

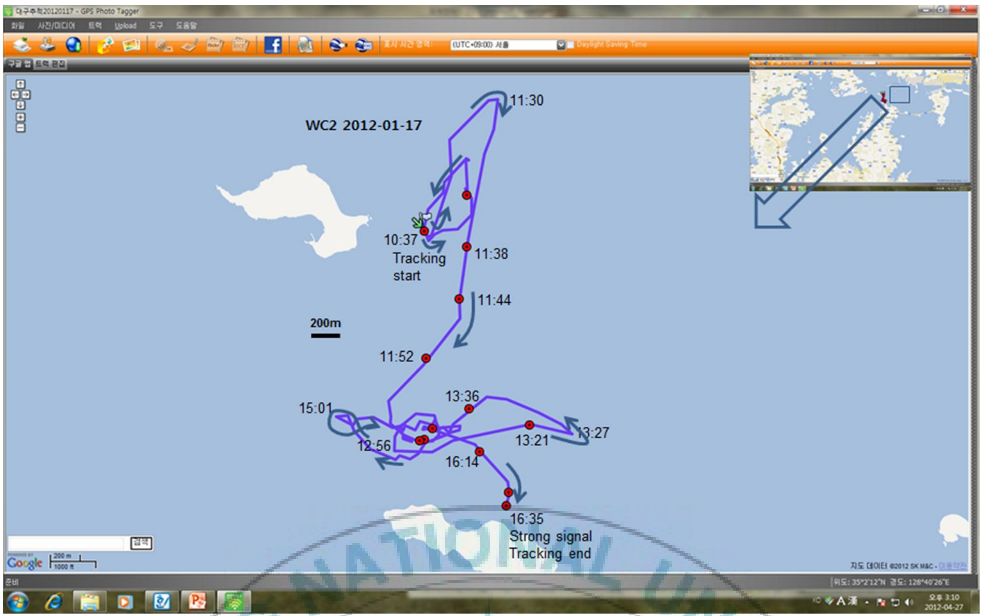


Fig. 10. Movement trcace of tagged fish (WC2) on 17 January, 2012.

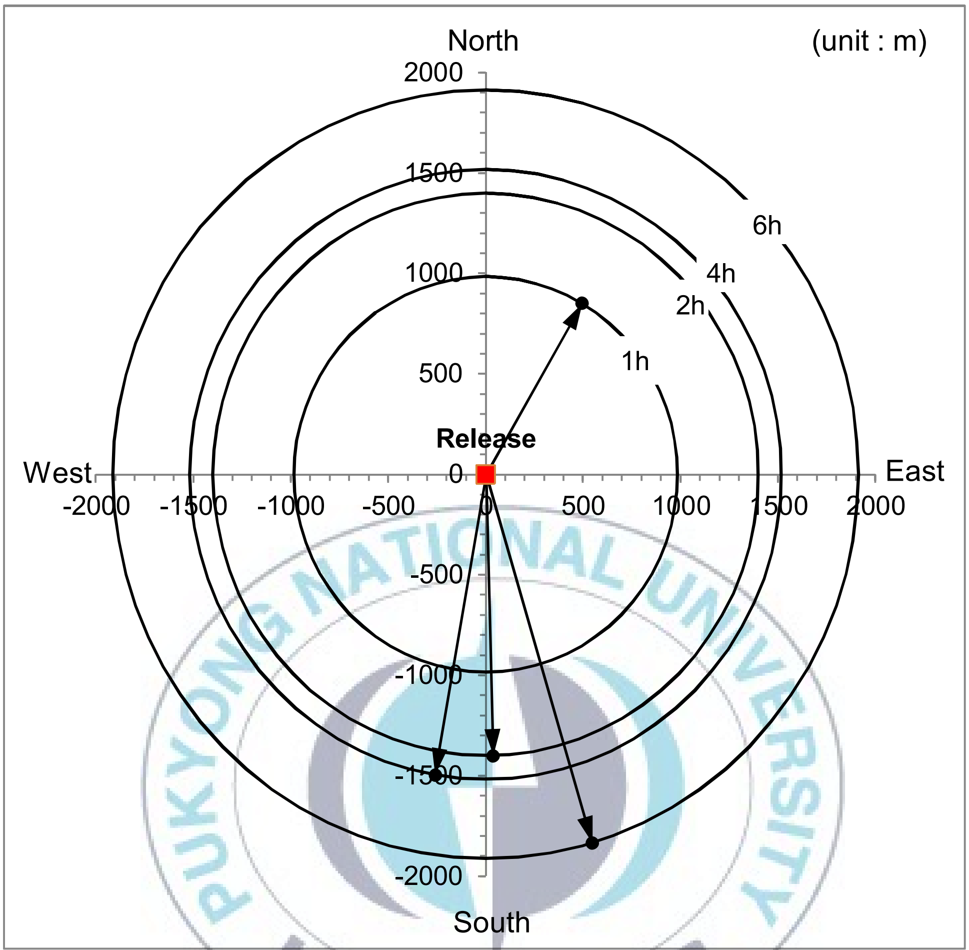


Fig. 11. Hourly movement direction from the release point of tagged fish (WC2) on 17 January, 2012.

WC3 was released in the inner bay (at a depth of 22 m) on 27 January, 2012. Temperature at a depth of 1 m, 10 m and 20 m was 8.0 °C, 8.0 °C and 8.3 °C, respectively. There was no difference of salinity (33.5 psu) by depth. The fish moved north-eastward about 0.3 km away from the release point by 12:30, and average swimming speed was 0.6 TL/s. It kept moving north-eastward about 0.7 km by 12:55. During the period, average swimming speed was 1.2 TL/s. The signal of tagged fish was lost, and the fish was found about 0.4 km away from the last detected point. It started moving south, and swimming speed was 1.1 TL/s (Fig. 12). Totally, the fish was traced for 2.3 hr, and average swimming speed was 0.8 TL/s in the experiment. WC 3 has different behavior than WC 1 and WC2. The fish moved circularly from 12:32 ~ 12:39 (circumference of movement was about 0.4 km). Swimming speed was 1.3 TL/s for 7 min (Fig. 12).

Whereas WC2 stayed at mid-water, WC3 showed benthic characteristics (known of cods) with average swimming layer of 17.85 m (range: 11.7-24 m) at 23.5-24 m seabed. WC3 spent most of the time at 20–24.5 m layer.

The fish showed complex movement routes during the experiment. It moved north-eastward for an hour from releasing, and then veered to the south-east in the end of the experiment (Fig. 13). It was a similar tendency with previous two fish (W1 and W2) (Fig. 16).

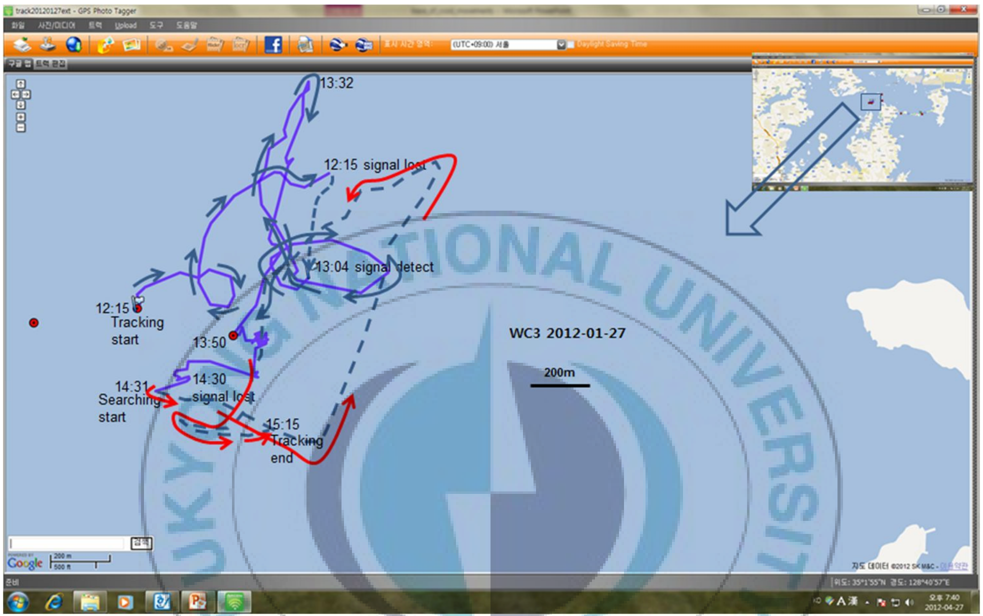


Fig. 12. Movement trcace of tagged fish (WC3) on 27 January, 2012.

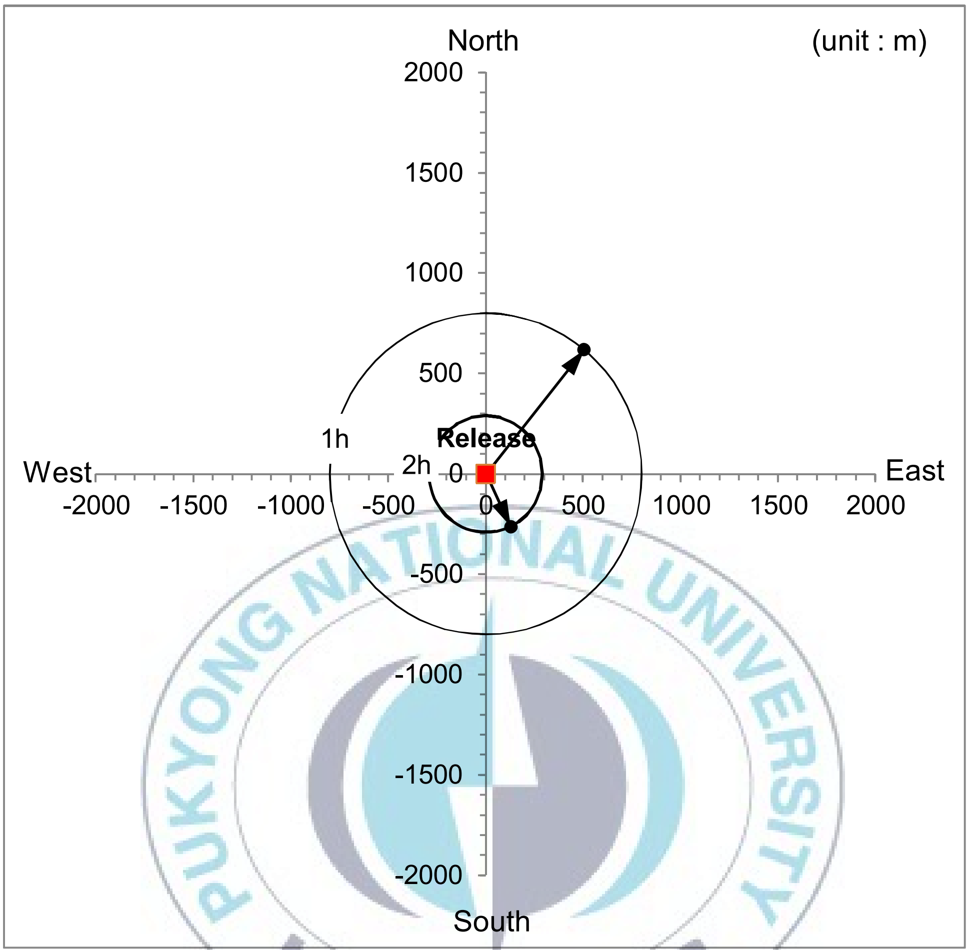


Fig. 13. Hourly movement direction from the release point of tagged fish (WC3) on 27 January, 2012.

WC4 was released at a depth of 23 m in the mouth of the bay on 13 February, 2012. The release point was closer to the mouth of the bay than other points. Temperature and salinity at a depth of 1 m, 10 m and 20m was 7.5 °C and 33.8 psu, 7.9 °C and 33.9 psu and 8.4 °C and 34.0 psu, respectively. The fish moved south-eastward about 0.3 km away from the release point by 12:30, and swimming speed was 0.5 TL/s. It changed movement direction to east. The fish moved eastward about 0.3 km by 12:58, and swimming speed was 1.1 TL/s. The fish was lost twice in the experiment at 13:09 and 13:47. It was found about 1.3 km and about 1.4 km way from last detected points, respectively. The fish went back and forth between south and east, and north and west from 13:47 ~ 15:26. It moved about 5.1 km, and average swimming speed was 1.2 TL/s. Totally, the fish was traced about 11.1 km for 4.3hr (Fig. 14).

WC4 also showed complex movement routes during the experiment as WC3. In the end of the experiment, it was headed south-eastward. It was a similar tendency with previous three fish (Fig. 15 and 16).

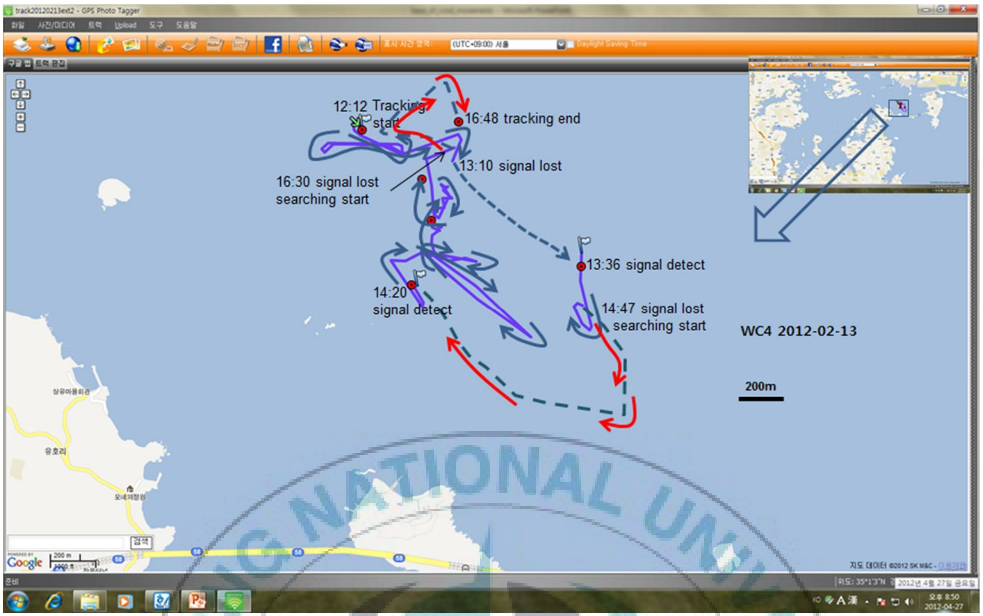


Fig. 14. Movement trcace of tagged fish (WC4) on 13 February, 2012.

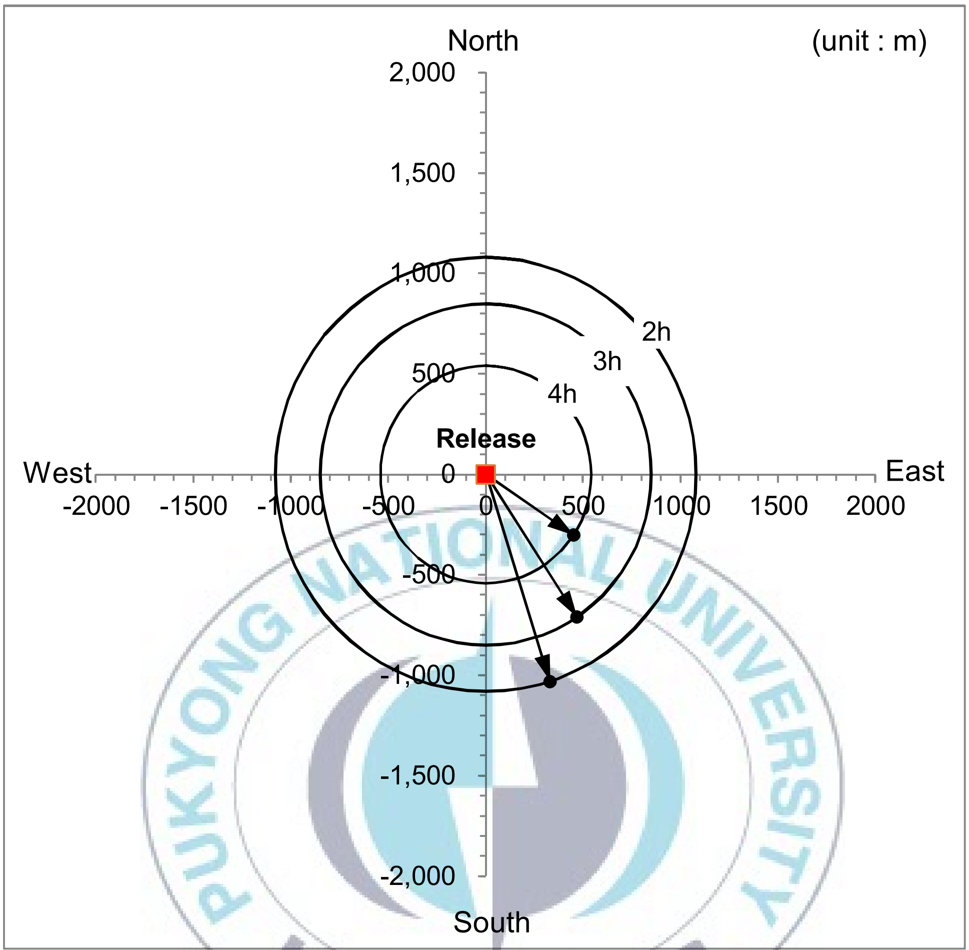


Fig. 15. Hourly movement direction from the release point of tagged fish (WC4) on 13 February, 2012.

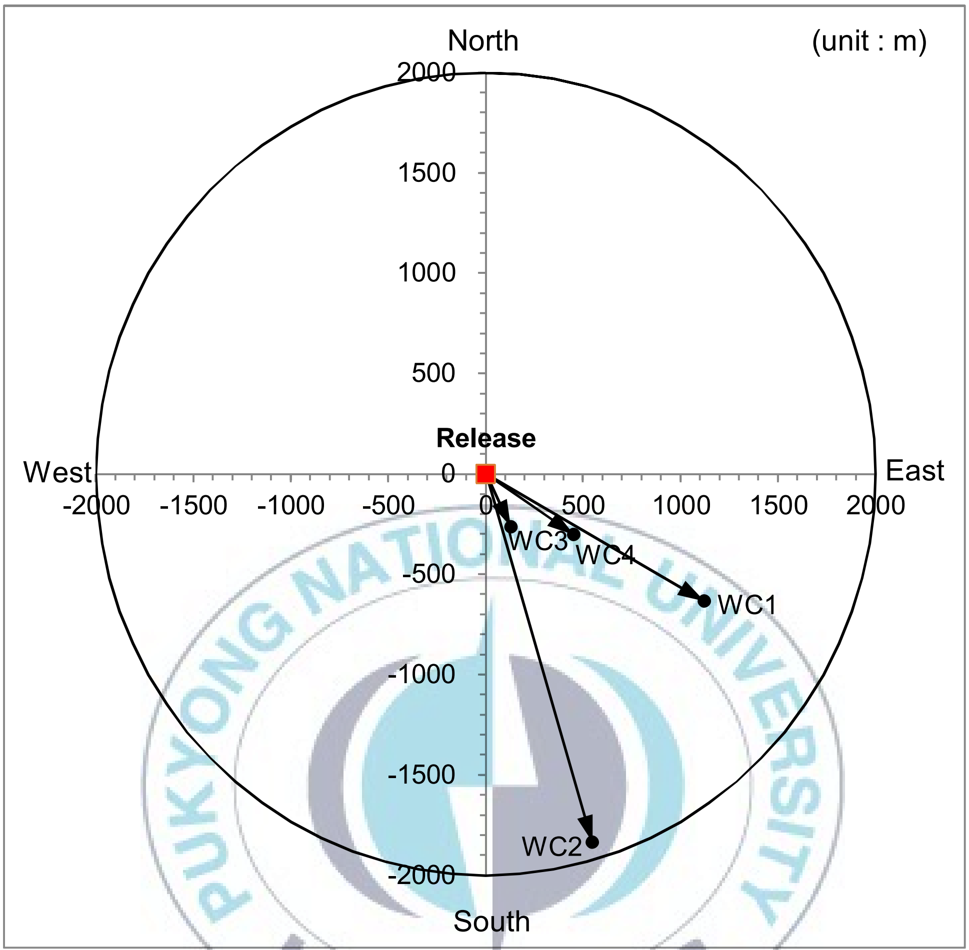


Fig. 16. Movement direction from the release point of tagged fish in the study site.

4. Discussion

Movement records from acoustic telemetry fall into two main types; the short-term movements that fish make daily during foraging, courting and general maintenance, and long-term movements that are on a seasonal or lifetime basis, such as migration and dispersal (Bakar,1978). In this study movement records are considered as short-term as it is within six hours of signal detection. Short-term analysis of movements is typically based on distances, times, speeds, and angles. The highest successful tracking of WC2 for over 5 hr could account for the 1.9 km movement from the release point, as others were tracked on average for only 2 hr and moved within 800 m and 1.3 km from their release points. Increased detections of WC2 may have been related to increased use of the water column and therefore improved detection capability (Olla et al., 1980). The total detection time for WC1-WC4, indicate that the tag had no negative effect on the fish. Buckley & Blankenship, 1990 found that internal tags may have minimal or negligible effect on the behaviour of fishes and also small fish may have problems with relatively large tags but the acoustic used in this study was only 0.51% of the fish body mass. In this study, no difference was found between tagged and untagged fish in terms of behaviour or physiology (Hinch et al., 1996).

All tagged fish moved South-East of the bay. It was expected that acoustic receivers (VR2) shall detect the tagged fish escaping from the mouth of the bay. There was no detection of tagged fish escaping from the mouth of the bay; however, one of the six VR2 receivers was lost.

The wide area traversed by tagged WC1 in the mid-water column, is possibly, because the space was sparse in prey and favourable environmental factors, thus, the faster movement in search of food and better conditions in the initial tracking time. Gentron and Staddon (1984) and Ryer and Olla (1997), found that visual feeders have been shown to decrease their swimming speed when searching for less conspicuous. But, as Pacific cod is top predator, it could have searching for conspicuous prey and therefore the higher TL/s movement. Predation is regarded as negligible. Palsson (1990), reported that adult cod experience low predation risk. Also, no potential predators have been observed in the study site.

The presence of WC1 and 2 at mid-water layer support the finding that, cod feed on a variety of prey, from epibenthic to pelagic (Mattson, 1990), and therefore forage over a wide vertical range, irrespective of water depth.

WC2 had high site fidelity in this location. The swimming speed decreased from the first hour to the time of ending tracking, possibly because, the fish found a more habitable environment from and around the release point.

Fields of site fidelity like this one corresponds to areas where animal find sufficient food or prey and optimum temperature. The high site fidelity and surface swimming of the cod can be regarded as spawning characteristics; January & February are observed to be the peak of spawning activity in the bay. Sakurai & Hottori (1996), found that female Pacific cod released all of her eggs in a single spawning which involved one female and one or more males in the mid-water of the tank. The preference of tagged cod at the site near the coast of Geoje-do, suggest that cod prefer lower temperature and salinity on spawning grounds.

The bathymetry survey (Fig. 2) reveals that the seabed of site fidelity (south-eastern) is sandy and it support the finding by Garrison and Miller (1982) that adult cods are associated with coarse sand and gravel substrates, as, Pacific cod require a suitable bottom type, namely, silt or sand, as well as suitable conditions in the water column (e.g. salinity and temperature) to ensure successful reproduction.

WC3 and 4 were swimming close to the seabed, these cod have been feeding more on benthic organisms using its chemical sensors for feeding.

Movements can be also be a useful index of energy expenditure, which is a fundamental measure in ecology but is generally impractical to measure directly in the field. As indirect indices of energy costs, progress has also been made in telemetric recording of respiration rate or heart rate (Gessamen, 1980; Woakes, 1992). By the average swimming speed and crisscrossing movement trace of WC3 , it can be speculated to had the highest index of energy expenditure. Higher swimming speed will lead to higher energy gain resulting from more frequent prey encounters but higher energy expenditure (Jobling, 1994). However, Soofianni and Priede (1985), found that swimming cost of cod may be relatively low. But in addition to lowering energy cost, decreasing swimming speed could increase the probability of locating prey through the chemical senses. Cod can detect prey visually (Brawn, 1969).

Comparing the movement trace of WC1 and 2 with their respective average speeds, WC2 can be said to have scored the least index of energy expenditure and also the highest site fidelity in this study. The south-eastern part of the study site is an important spawning ground of Pacific cod in the Jinhae bay as all the four tagged fish moved in that direction.

Alderdice and Forrester (1971) found that no spawning occurs below 0°C or above 10-13°C, and the ambient temperatures recorded in this study fall within the values reported for the distribution and thermal range of this species. Pacific cod prefer colder temperatures at spawning grounds in the bay. The optimum for cod in this was 7.8°C. Temperature determines the vertical and horizontal directional movement of cod in the bay. Tyler (1995), found that warmer winter water temperatures also appear to decrease the fecundity of Pacific cod stocks and thus the avoidance of tagged cod beyond the mouth of the bay where temperature was relatively higher.

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