Thesis for the Degree of Master of Fisheries Science

Behavioural Characteristics of *Scomber japonicus* in the Sea Cage with Acoustic Telemetry

by

Lotfi Ramdani

KOICA-PKNU International Graduate Program of Fisheries Science

The Graduate School

Pukyong National University

February, 2012

Behavioural Characteristics of *Scomber japonicus* in the Sea Cage with Acoustic Telemetry

음향텔레메트리를 이용한 가두리 내에서 고등어 행동특성 분석

Advisor: Prof. Hyeon-Ok Shin

by

Lotfi Ramdani

A thesis submitted in partial fulfilment of the requirements for the degree of

Master of Fisheries Science

in KOICA-PKNU International Graduate Program of Fisheries Science,

The Graduate School,

Pukyong National University

February, 2012

Behavioural Characteristics of *Scomber japonicus* in the Sea Cage with Acoustic Telemetry

A dissertation

by

Lotfi Ramdani

Approved by :

(Chairman) Dr. Kyoungmi Kang

(Member) Prof. Hyeon-Ok Shin

(Member) Dr. Bo-Gyu Hwang

February 24, 2012

Tables of contents

List of Figures

List of Tables

Behavioural Characteristics of *Scomber japonicus* in the sea cage with acoustic telemetry

Lotfi Ramdani

KOICA-PKNU International Graduate Program of Fisheries Science,

The Graduate School,

Pukyong National University

Abstract

This study was performed in order to investigate fish behavior and to obtain biological characteristics using the acoustic telemetry. The experimental works were conducted in the marine ranching area in Tongyeong, South Korea. The target fish (mackerel, *Scomber japonicus*) was handled with a minimum of trauma, and the implantation of the tag in the abdominal cavity was done by surgery procedure. The study was divided into the neap and the spring tide, from 13 to 14 November 2010 and from 19 to 20 December 2010, respectively. Fish was altered by the light cycle, which is approved by our results of vertical movement where in the neap tide, the average swimming depth was 6.0 m (±0.5) during a daytime and 5.6 m (±0.9) at night and in the spring tide, the average swimming depth was 6.6 m (±0.8) during a daytime and 3.9 m (±1.5) at night. The swimming depth was affected by high current. In this result, sunlight was a main stimulus to affect on the vertical movement in the cage. For the horizontal movement, in the neap tide, the distribution of the positions had a circular shape and was focused in the middle of the net cage, however, The positions were, more scattered along the x-axis in the spring tide than in the neap tide and appeared an ellipsoidal shape. These results have the potential to improve our knowledge of fish behavioral capabilities of temperate species, and advance the capability of biophysical dispersal models to predict the probabilities of dispersal and retention in coastal zones.

Introduction

Behavior of animals is governed by a multitude of internal and external stimuli (Fredrik et al., 2001). When an animal is exposed to a perturbation, the first line of defence is a behavioral one, most often an avoidance behavior, designed to lessen the probability of death or the metabolic costs incurred by maintaining physiological homeostasis (Olla et al., 1980). Such behavioral alterations are very sensitive indicators of a constraint level or stress imposed on fish by the environment (Cooke et al., 2000).

Sea fish cage farming is being globally popularized by the depletion of fisheries resources from over fishing so its importance in fishing industry is increasing over time. The sea cage is installed in shore where the current is not a strong. It is generally close packed with a large amount of fish to improve a spatial efficiency. The net of cage is, however, receives a force by a current at that area. Thus, the volume of living space will decrease by changing the shape of the net. The small living space will act stimuli or stresses on caged fish by obstructing a natural swimming behaviour and be causative of a hurt and a death in extreme cases.

Understanding of fish behaviour in net cage can offer a wide range of possibilities to improve both production and management in marine aquaculture through understanding behaviour or physiology of free-swimming fish inside their culture environment (Baras and Lagardère, 1995). However, it is difficult to observe fish behaviour in the net cage by naked eye because of the deep and turbid sea water. It is why Ultrasonic telemetry using stationary positioning systems represents a new method for studying the behavior of fish which occupy a restricted area as a net cage (Hawkins et al., 1974; Lagardère et al., 1990; Juell & Westerberg, 1993; Lucas & Baras, 2000).

The acoustic telemetry allows the remote sensing of the positions, movements, and aspects of physiological or behavioral variables of an animal (Baras and Lagardère, 1995). It is the useful method to investigate fish behavior and widely used to obtain biological information (Shin et al, 2008; 2010) as well as to analyze the effects of release and spill-out (Kang and Shin, 2006, 2008; Shin et al, 2004, 2005, 2010; Juell and Westerberg, 1993).

The purpose of this study is to analyze an interaction and relationship between the cage-net movement while changing shape by a current speed and direction. The free-swimming behaviour of mackerel (*Scomber japonicus*) in the cage-net was measured in neap tide and spring tide, and current speed and direction were also measured during the experiments. The net movement was monitored to analyze the change of fish behaviour against the net.

Materials and Methods

Acoustic positioning system

It was measured free-swimming fish in a sea net-cage during neap (from 13 to 14 November 2010) and spring tide (from 19 to 20 December 2010) using an acoustic positioning system (VRAP, AMIRIX System Inc., Canada). The system was consisted of three sea stations and a base station, and used LBL method (Long Baseline) to calculate the position of each pinger (Fig. 1). Each sea station (RAP buoy) had an omni-directional hydrophone and receiver for detecting acoustic signals and a VHF modem and an antenna for simultaneous communication to the base station (Table 1). The base station decoded and plotted the detailed position information from the pinger in real-time on a monitor before saving on a hard disk.

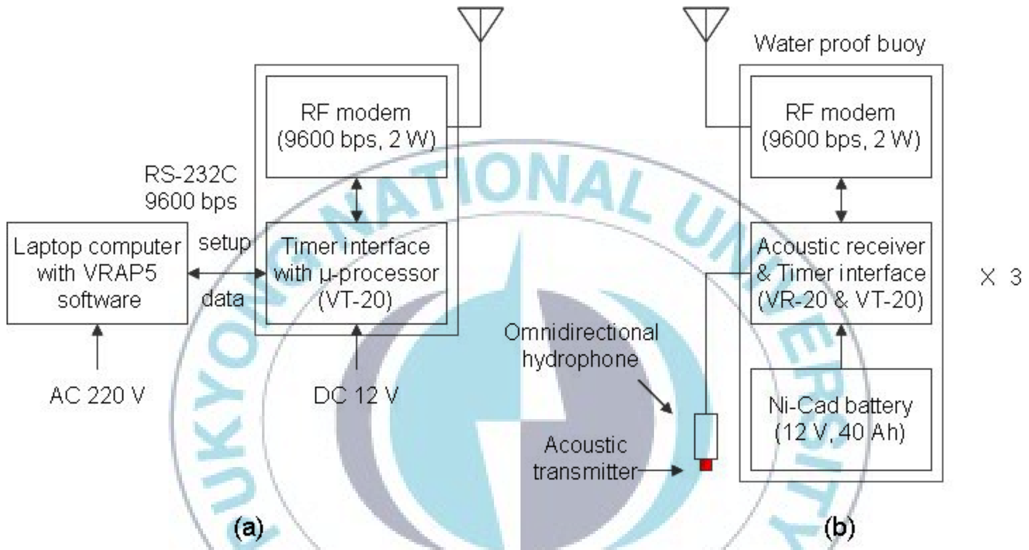


Fig. 1. Composition of the acoustic positioning system (VRAP, AMIRIX System Inc., Canada). (a) indicates a base station, and (b) shows three sea stations.

Table 1. Specification of the acoustic positioning system (VRAP, AMIRIX System Inc., Canada)

Equipments		Specifications
RAP buoy	Tracking mode	Long baseline
	Positioning accuracy	0.5 m to 2 m
	Frequency	Receiving: 50~85 kHz, Transmitting: 51 kHz
	Detectable range	Typically 500 m
	Operating hours per charge	7 days
	Dimensions of buoy	60 cm diameter × 100 cm height
	Buoy weight	43 kg (reserve buoyance: 60 kg)
RF MODEM	Frequency	456.2 MHz
	Communication mode	Two ways
	Modulation	FM 9600 baud
	Output power	2 W
Software	Multitarget tracking	Up to 12 continuous type pingers
	Chart overlays	Yes
	Version	VRAP 5.0

Study site and installation of system

The study was conducted in the marine ranching area in Tongyeong, South Korea. The area is approximately 20 km^2, and the sea sediment consists of mud with granules and grovels around islands and along the coast. The investigation was performed using an experimental sea cage station, which is managed by the Korea Ocean Research and Development Institute (KORDI). Total area of the experimental sea cage station is about 2,000 m^2 (except the area of main office, work place and storage), and it has three different sizes of the cages. Ten of the cages are 12.0 × 12.0 × 6.0 m and others consist of 6.0 × 12.0 × 6.0 m and 6.0 × 6.0 × 6.0 m. Netting is made of polyethylene, and mesh size composes of 30 mm and 50 mm. In the study, the cage and mesh size was 6.0 × 6.0 × 6.0 m and 30 mm (ϕ 2.0 mm), respectively (Fig.2).

To monitor the acoustic positioning system, three sea stations were installed in a triangular shape to cover the area of cage net. Each sea station put into the empty cage that the net was removed and it was tied to the cage frame. The range of one side was about 70 m.

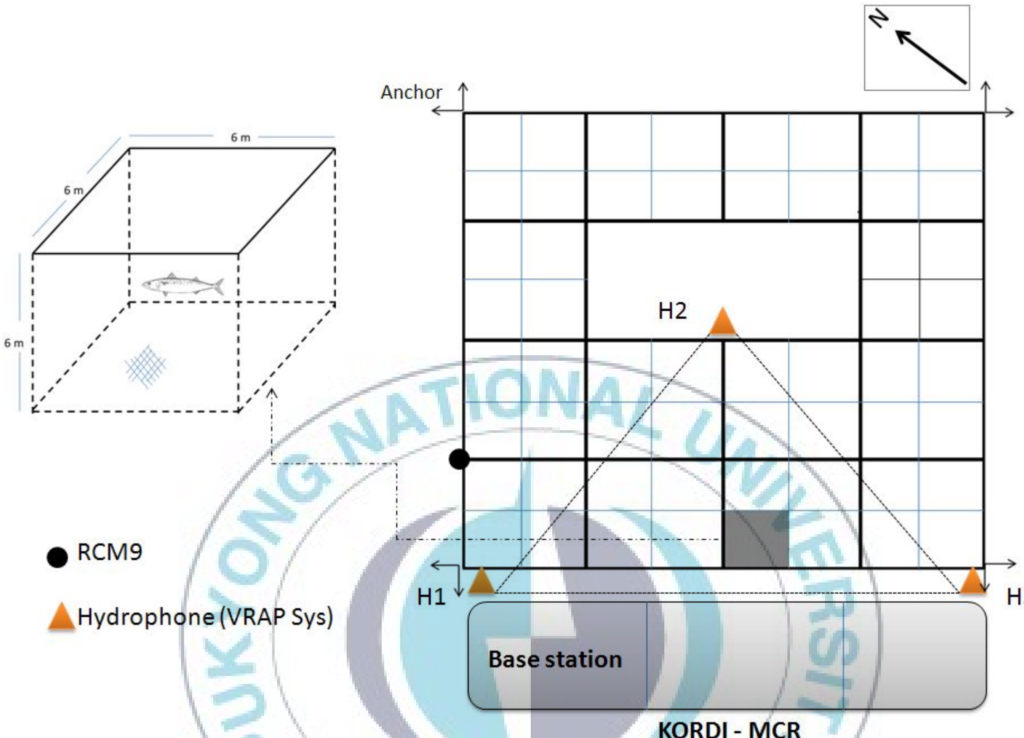


Fig. 2. Arrangement of the cage nets in the experimental sea cage station of KORDI.

Acoustic tagging

Two cultured mackerel (*Scomber japonicus*) were used in the experiment during neap and spring tide. For tagging on the fish, surgical tagging method was carried out with an acoustic pinger (V9P-2X, AMIRIX System Inc., Canada) in the neap and the spring tide as a continuous type and included a depth sensor (Fig. 3). Its frequency and battery life were 78 kHz and 14 days, respectively. The pinger emitted acoustic signals contained identification number (ID), date, time and depth. Its size was 9 mm in diameter, 40 mm in length, and weighed 2.6 g in water. The full range of the depth sensor was 50 m in depth.

For surgical tagging, it was used 70% ethanol to sterilize the surgical materials and the pinger before operation. The fish was anesthetized with MS-222 (100 ppm) to reduce trauma and struggle. After fish was immersed in an anaesthetic bath until the tolerance stage, it was placed in dorsal recumbency in a support adapted to its morphology with head and gills immersed in the anesthetic wet towel to keep the fish stabilized during all the making procedure. Length and weight of the fish were measured before tagging (Table 2). Incision length was short as possible to minimize trauma and to limit the risks of tag exit via the incision. Therefore, we made 2–3 cm incision to insert the tag. The tagged fish was moved into a small sea water tank to remove the anaesthesia effect. After checking fish condition, it was released in the cage net with 2 other same fish for school behaviors. The tagged fish swam actively and directly after releasing into the sea net cage in a random direction all around.

Fig. 3. Acoustic tag to measure the behaviour of mackerel (*Scomber japonicus*) in the cage net.

Table 2. Summary of the characteristics of the tagged mackerel (*Scomber japonicus*) equipped with the continuous pinger and released in the cage

Experiments	Weight (g)	Fork Length (cm)
Neap tide	382	32.7
Spring tide	364	31.5

Environmental monitoring

To obtain the detailed description of the fish movement in terms of both tracks over the ground and swimming course relative to the water, the velocity and direction of water movement should be known (Macdonald and Priede, 1983). Therefore, environmental factors were measured by a recording current meter (RCM9, AANDERAA, Norway). It recorded current speed, current direction, water temperature, turbidity, conductivity and water pressure each of the average datum every 10 minutes in succession over 24 hours.

Table.3. Weather conditions in the study site

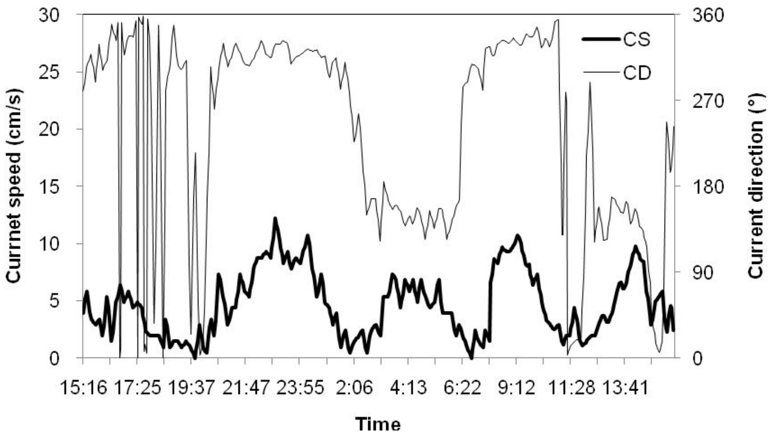
Experiment	Weather conditions	Sunset	Sunrise
Neap tide	Clear	17:22:00	06:59:00
Spring tide	Clear	17:18:00	07:29:00

Results

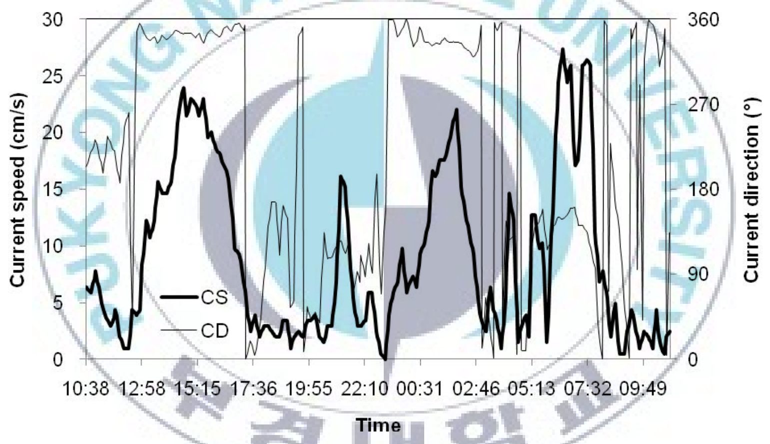
Current speed and direction

During the neap tide (13–14 Nov. 2010), the highest current speed was 19.6 cm/s, and more than 90% of current speed was less than 10 cm/s (Fig. 4a). However, during the spring tide (19–20 Dec. 2010), the highest current speed was 27.4 cm/s. Additionally, 64% of current speed was less than 10 cm/s, and 36% was between 10 cm/s and 30 cm/s (Fig. 4b).

During the neap tide, the current direction was fluctuating from 15:16 to 19:56 on 13 Nov. 2010, but it was changed stably after the period (Fig. 4a). The direction was stable for 4–5 hours before next change. The averages of the direction were 322.6° (±13.7) (from 20:26 to 01:24 and form 07:24–10:55) and 148.9° (±13.9) (from 02:35 to 06:14 and from 12:25 to 14:38). During the spring tide, the current direction was more fluctuated, especially when the current direction was changed (Fig. 4b). The stable time was 3–4 hours. It was shorter than during the neap tide. When the current direction was stable, the average of the direction was 342.3° (±5.2) from 12:30 to 17:12 and from 23:09 to 02:58.



(a) neap tide



(b) spring tide

Fig. 4. Current speed and direction during the neap tide (from 13 to 14 Nov. 2010) and the spring tide (from 19 to 20 Dec. 2010). CS and CD indicate current speed and current direction, respectively.

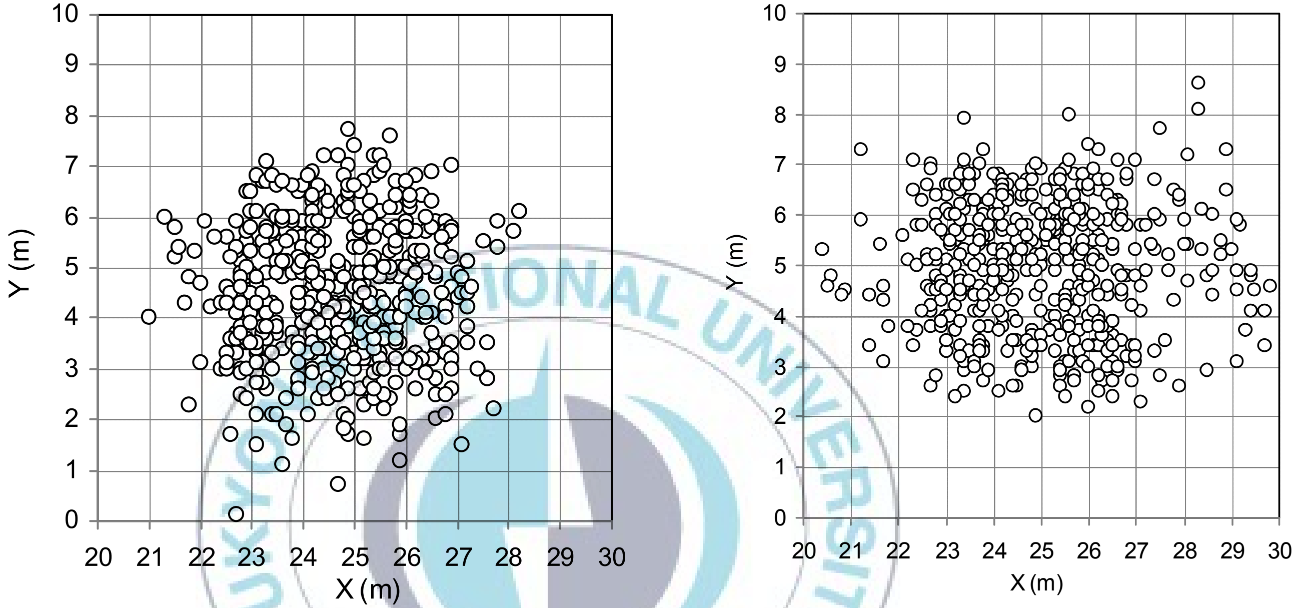
Fish behaviour in cage net

a. Horizontal movement

Fish behavior was analyzed by dividing into horizontal and vertical movement for the neap tide and the spring tide. In the first place, all the horizontal positions of fish in the cage net are shown in Fig. 5. The positions were received by an interval of 2 ~ 3 min, and a total of 525 data was received in neap tide and 526 data in spring tide.

In the neap tide, the distribution of the positions had a circular shape and was focused in the middle of the net cage. The positions were, however, more scattered along the x-axis in the spring tide than in the neap tide and appeared an ellipsoidal shape. In general, it can be easily observed that mackerel swims circularly around in a small square cage and uses more than half of a horizontal area, because it has a higher swimming speed than other shore fish species. Therefore, this shape was supposed to arise from the situations that the movement of cage net by the strong current restricted the fish behavior in the spring tide.

The fish behavior was also divided into particular situations by the current and the sunlight condition. Horizontal movement of fish, as mentioned above, can be restricted by the net shape which is changed by a current, and their vertical movement is generally related to the sunlight condition. Therefore, it was easily divided into eight situations, which have a maximum and a minimum current speed during a daytime and at night for the neap and the spring tide. The environmental conditions for eight situations and their abbreviations for the following are represented in Table 4.



(a) neap tide

(b) spring tide

Fig. 5. Total of horizontal movement positions of tagged fish in the sea net cage during the neap tide and spring tide.

Table 4. The eight situations and abbreviations divided by the environmental conditions

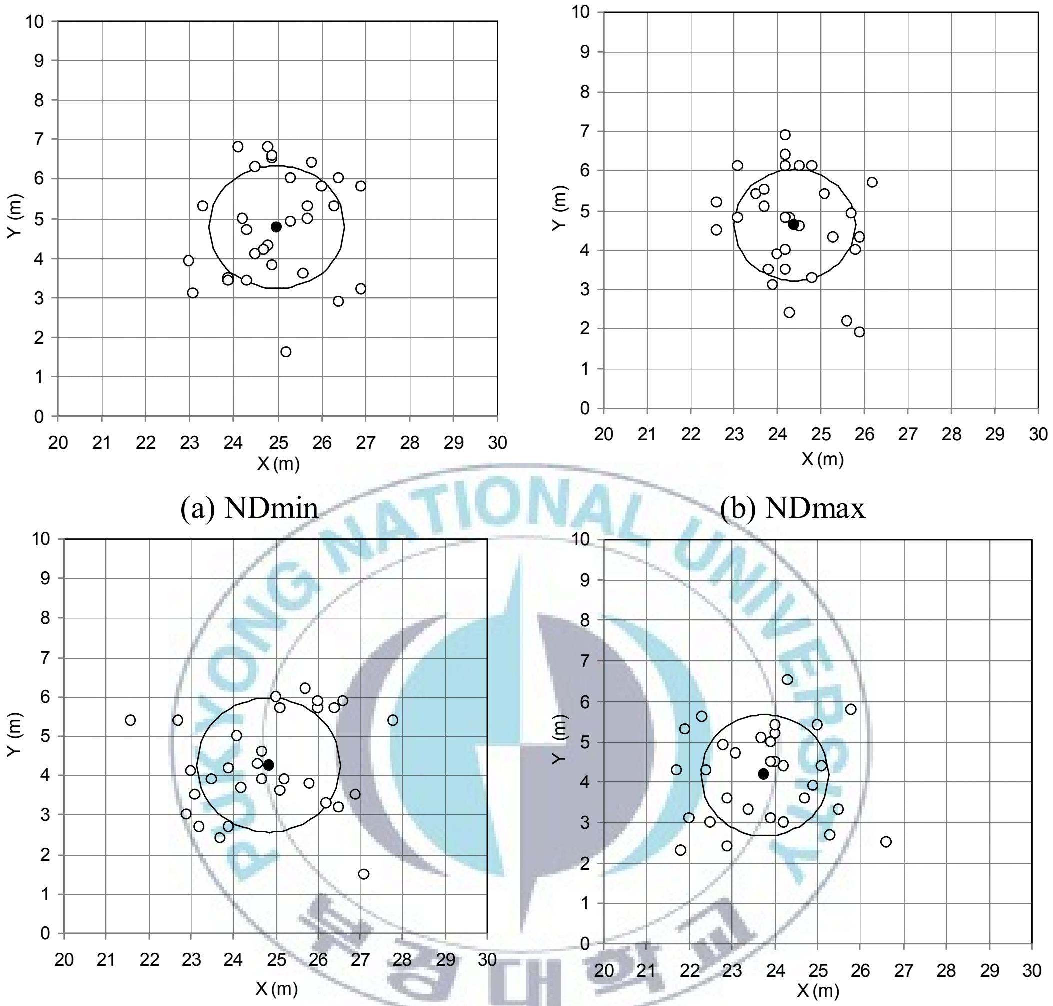
Tide	Sun light	Time	Current speed (cm/s)		Abbreviation
			Minimun	Maximun	
Neap	Day	2010/11/14 10:58~12:19	1.1	4.4	NDmin
		2010/11/14 08:09~09:28	6.6	10.8	NDmax
	Night	2010/11/13 01:34~02:50	0.5	2.7	NNmin
		2010/11/13 22:27~23:45	7.8	12.2	NNmax
Spring	Day	2010/12/20 08:49~10:10	0.5	4.4	SDmin
		2010/12/20 06:07~07:27	17.1	27.4	SDmax
	Night	2010/12/19 18:39~19:42	1.0	3.4	SNmin
		2010/12/19 14:25~15:45	19.6	24.0	SNmax

Horizontal movement of tagged fish in the net cage during the neap tide for four situations is shown in Fig. 6. Black point indicates the central point of fish behavior, which is calculated by averaging all the positions. The circle represents the radius of swimming activity, which indicates the degree of area use, and it is simply calculated by averaging all the distances from the central point to each position.

During a daytime of the neap tide, the coordinate of central point of fish behavior was (25.0, 4.8) and the radius was 1.6 m at ND_{min}. At ND_{max}, the central point is not different from that at ND_{min}. The radius was, however, a little decreased to 1.4 m. In the night time, there was no significant change in the central point and the radius compared with during a daytime, but the radius of swimming activity became a little wider than during a daytime.

Horizontal movement of the tagged fish in the cage during the spring tide for four situations is shown in Fig. 7. In the spring tide, the coordinate of central point of fish behavior at SD_{min} was (25.2, 4.6) and the radius was 1.7 m, which was similar to those during the neap tide. The central point was, however, moved 3 m along the x-axis to (28.5, 4.9) and the radius was decreased to 1.3 m at SD_{max} beside ND_{min} or NN_{min}. There was also not a significant difference in the central point and the radius as (25.0, 4.3) at SN_{min}, but the central point was moved about 2 m along the x-axis to (22.5, 5.46) and the radius was a little decreased to 1.5 m.

The central point and the radius which had a minimum current speed were regarded to represent the situation which is a little external effect. Consequently, fish behavior was not significantly restricted in the neap tide, and it is considered that the fish swims relatively broad area that is defined by normal net cage volume. In the spring tide, the high-current speed such as SD_{max} and SN_{max}, however, central point of fish behavior was moved up to about 3 m from the normal condition and area use was also restricted and decreased by changing of the net cage shape.

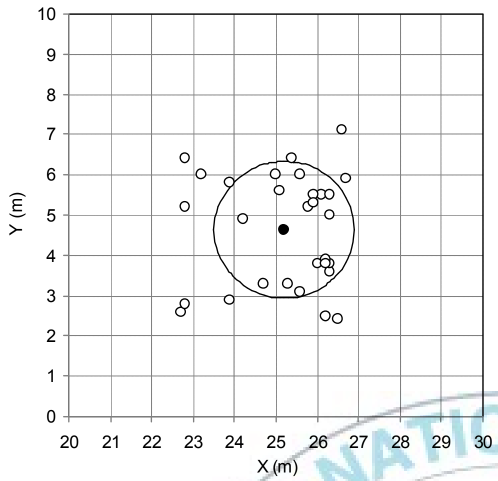


(a) NDmin (b) NDmax

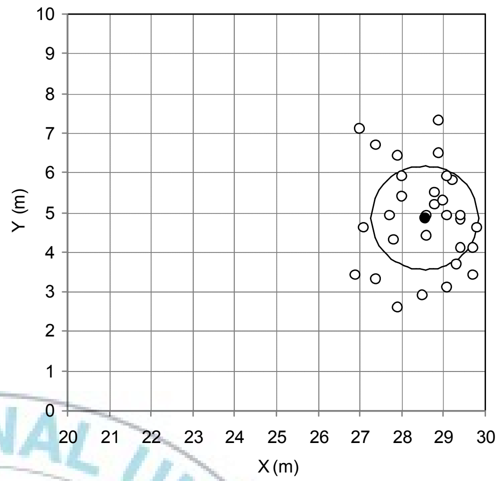
(c) NNmin (d) NNmax

Fig. 6. Horizontal movement of tagged fish in the cage during the neap tide. Four environmental conditions for (a) NDmin, (b) NDmax, (c) NNmin, and (d)

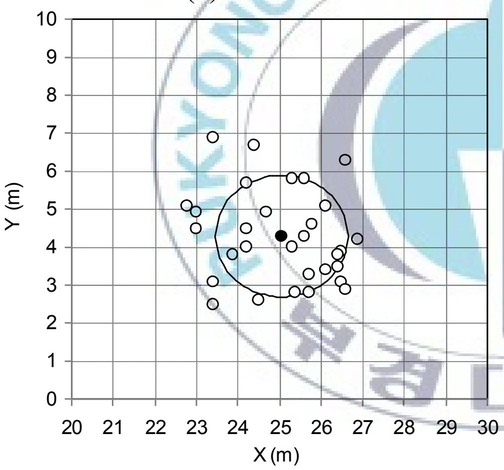
NNmax are shown in table 4. The black spot is averaged position and the radius of circle is averaged distance for each positions.



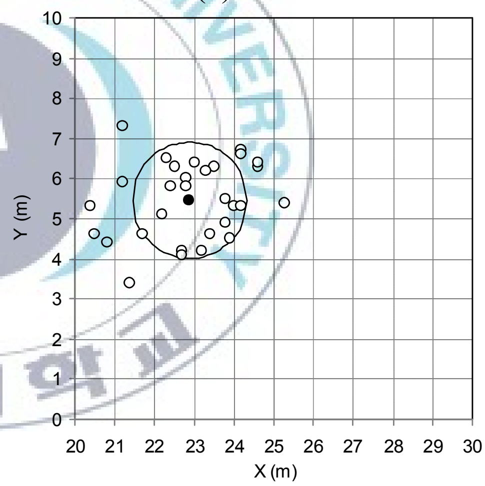
(a) SDmin



(b) SDmax



(c) SN min



(d) SN max

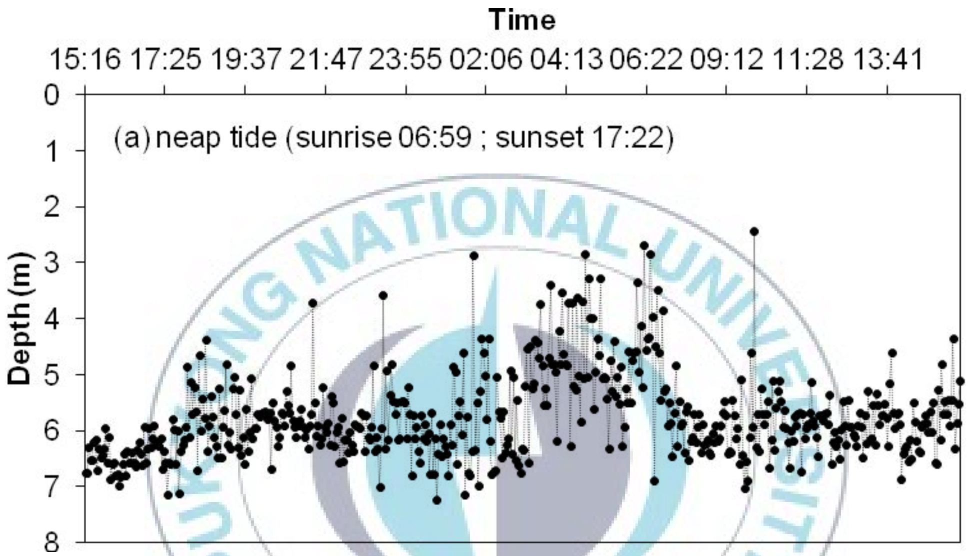
Fig. 7. Horizontal movement of tagged fish in the cage during the spring tide. Four environmental conditions for (a) SDmin, (b) SDmax, (c) SNmin, and

(d) SNmax are shown in table 4. The black spot is averaged position and the radius of circle is averaged distance for each position.

b. Vertical movement

During the neap tide, the average swimming depth was 6.0 m (±0.5) during a daytime and 5.6 m (±0.9) at night (Fig. 8a). The tagged fish was measured once to float shallower than the middle of the cage (depth 3.5 m) during a daytime. Maximum and minimum of the swimming depth was 7.0 m and 2.4 m, respectively. It was measured 3% of the detected numbers at night to swim shallower than the middle of the cage. Maximum and minimum of the swimming depth was 7.2 m and 2.7 m, respectively. The swimming depth was not a significant correlation with current speed (Pearson Correlation, $n=120$, $R=0.075$, $p=0.418$).

During the spring tide, the average swimming depth was 6.6 m (±0.8) during a daytime and 3.9 m (±1.5) at night (Fig. 8b). Maximum of the swimming depth was 7.8 m during a daytime and 7.3 m at night, respectively. Minimum of the swimming depth during a daytime and at night was 4.7 m and 1.3 m, respectively. The tagged fish did not swim shallower than the middle of the cage during a daytime. However, it was measured 42% of the detected number at night to swim shallower than the middle of the cage. Additionally, the swimming depth was a significant correlation with current speed (Pearson Correlation, n=120, R=0.620, p<0.005).



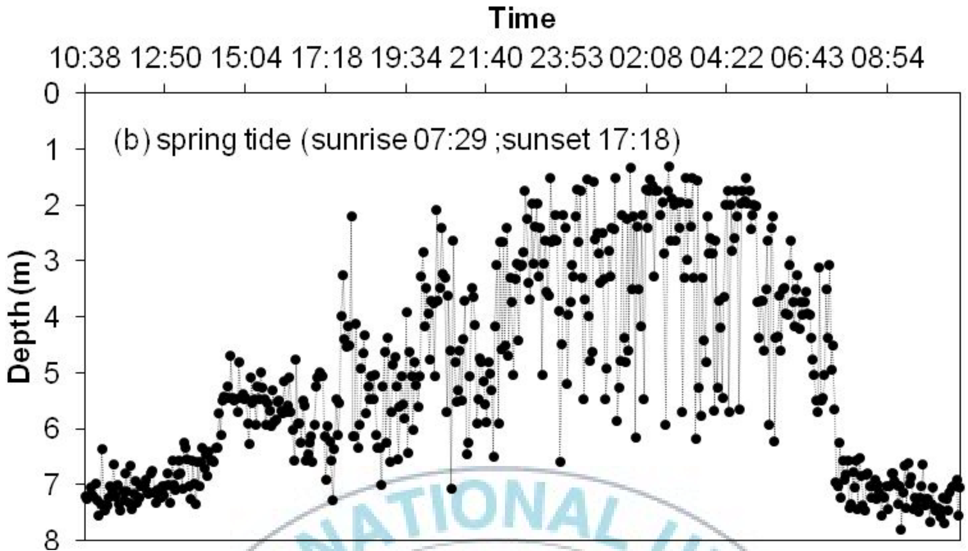


Fig. 8. Comparison of the vertical movement of the tagged fish in the cage net.

The result of vertical movement was also divided by 8 situations in the neap and the spring tide (Table 4). During the neap tide, the tagged fish swam between 5.1 m and 6.7 m during a daytime (Fig. 9a, b). The tagged fish has a tendency to spend time on the net bottom, and the swimming depth was not affected by current speed during a daytime (Independent t-test, n=30, p=0.165). However, the swimming depth was fluctuating at night. The tagged fish swam between 2.9 m and 7.0 m (Fig. 9c, d). It has a tendency to move toward surface. It was also not affected current speed on the swimming depth (Independent t-test, n=30, p=0.812).

During the spring tide, the fluctuation of the swimming depth between during a daytime and at night was similar to the result during the neap tide. The swimming depth was between 4.7 m and 7.8 m during a daytime (Fig. 10a, b), and between 2.6 m and 7.2 m at night (Fig. 10c, d). It was likely to move toward surface at night. However, current speed affected on the swimming depth during a daytime (Independent t-test, n=30, d.f.=57.7, $p<0.005$) at night (Independent t-test, n=30, d.f.=57.5, $p<0.005$).

Consequentially, the swimming depth was not affected by current speed during the neap tide because of relatively low current speed. In this result, sunlight was a main stimulus to affect on the vertical movement in the cage. However, there was a different tendency during the spring tide. Sunlight was more powerful stimulus on the vertical movement in the cage (GLM, $n=120$, $F=175.4$, $p<0.005$). Also, high current speed (above 15 cm/s) affects on the vertical movement in the cage (GLM, $n=120$, $F=166.2$, $p<0.005$).

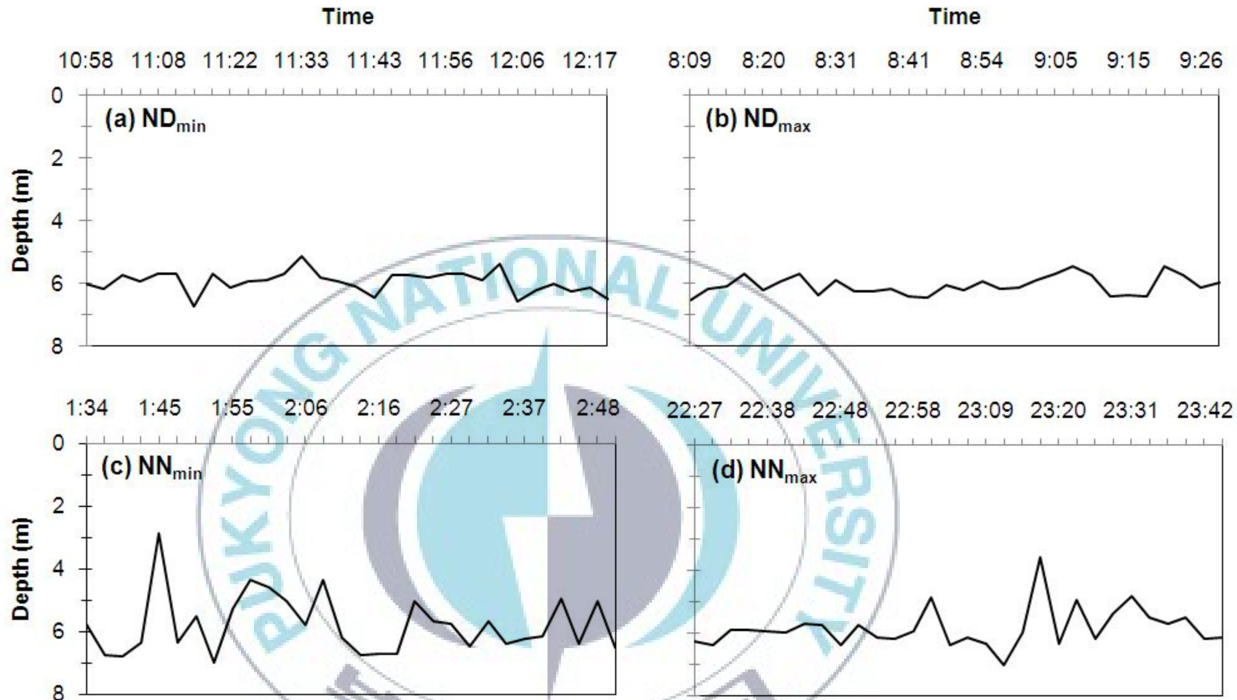


Fig. 9. Vertical movement of the tagged fish in the cage during the neap tide. Four environmental conditions for (a) NDmin, (b) NDmax, (c) NNmin, and (d) NNmax are shown in table 4.

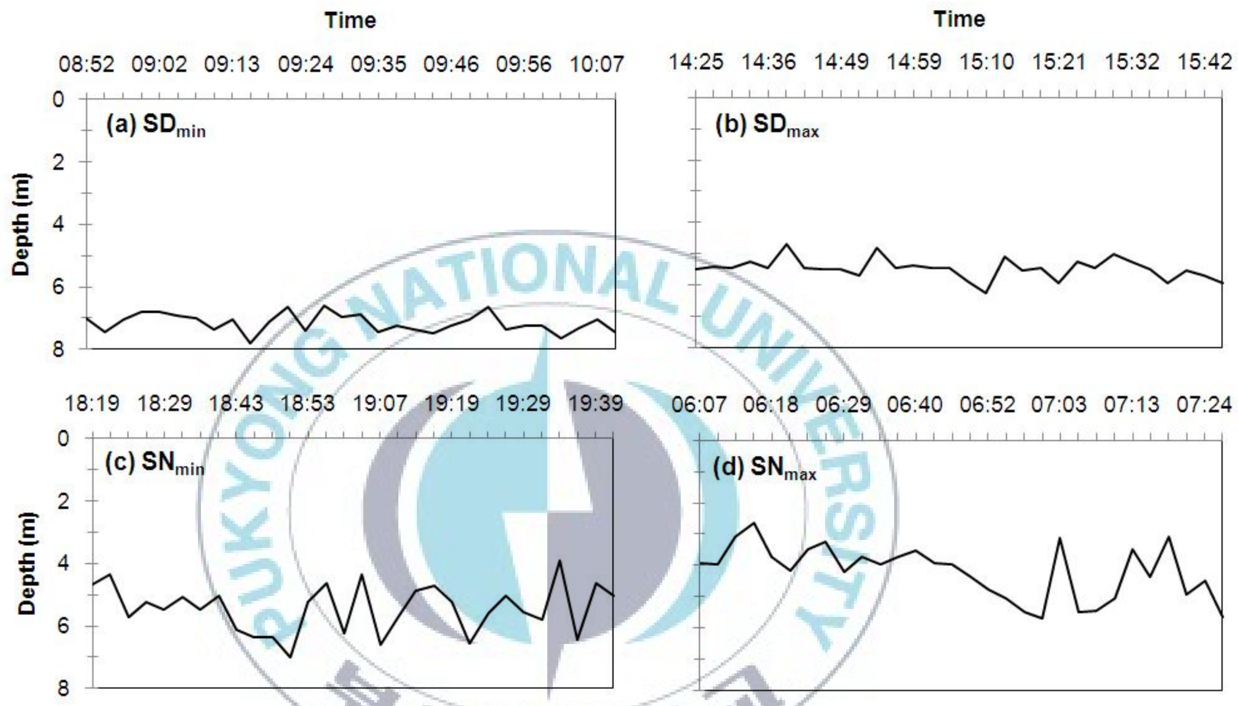


Fig. 10. Vertical movement of the tagged fish in the cage during the spring tide. Four environmental conditions for (a) SDmin, (b) SDmax, (c) SNmin, and (d) SNmax are shown in table 4.

Discussion

Mackerel (*Scomber japonicus*) is a coastal pelagic species and they migrate to a lesser extent epipelagic to mesopelagic over the continental slope. Adults stay near the bottom during a daytime and go up to the open water at night where they feed on copepods and other crustaceans. In Asian waters, they move to deeper water and remain inactive during the winter season (Collette and Nauen, 1983). Its basal swimming speed is 1.5 B.L/s (Body length per second). This speed is also required for the sustained ram gill ventilation (Roberts, 1975).

The experiment was monitored the behaviour of free-swimming *Scomber japonicus* in the cage-net. Because of the worldwide importance of the chub mackerel fishery, several study have been carried out mainly related to its biology, feeding regime and general behavior (Angelescu, 1979; Scheafer, 1980; Castro, 1993,1995). With the advanced technology, more information was carried out by the acoustic telemetry method which the case of this study.

According to Lucas and Baras (2000), studies of fish behavior should focus their objectives and select the most appropriate techniques itself or in combination. Techniques for investigating the spatio-temporal behavior of fish using acoustic telemetry should consider the vertical and the horizontal movement which done in a specific period of time with the appropriate technique.

Holland et al. (1990) reported that activities of fishes can be divided into relatively few distinct behavior patterns, which are set into motion by various environmental stimuli and are oriented by gradients of light, currents, and temperature. As light cycle is the most important factor in natural behaviour, results from both experiments were compared according to that different observations were detected. Most pelagic fish are visual predators, and their activity is strongly affected by the diel light cycle (Batty et al., 1990; Ryder, 1990). In this study, the light cycle between day and night had a great influence on the behaviour of the tagged fish. The result was shown a tendency to stay near the bottom of the cage during a daytime and rise up to the surface of water at night. In our study, the same fish behaviour was found with result of vertical movement.

OU et al. (2007) researched a relationship between the net cage volume and the flow velocity with a modelling net cage. In the result, the cage volume was reduced to 79% by 25 cm/s flow velocity and to 48.92% by 50 cm/s flow velocity. In this study, current speed during the spring tide was much higher than during the neap tide, which means that the space occupied by the tagged fish during the spring tide was less than occupied during the neap tide (Fig. 6 and Fig. 7). Other researchers mentioned that the bottom panel of the net cage tends to rise to the free surface in the minimum hydrodynamic forces (Le Bris and Marichal, 1998). Therefore, we supposed that the alteration of the swimming depth during the neap tide was relatively less than during the spring tide.

Surgical internal tagging method was successfully achieved in this study. To reduce impediment by the tag, its size and weight should be minimized. Several researchers recommend that the tag weight in water is less than 1.5% of fish body weight, because it can affect on fish buoyancy by the additional weight (Perry et al., 2001).

This study was performed to test the feasibility of acoustic tracking under close to real aquaculture situation. The analysis of swimming behaviour of *Scomber japonicus* was successfully achieved. The vertical and horizontal movement, space utilization of the net cage and daily behavior were altered by light cycle between day and night and the changing volume of the net cage under the external forces mainly by the current speed. We supposed that fish behaviour was affected by more complicated external factors. In future study, it is necessary to analyze fish behavior in the various circumstances

Acknowledgement

First of all, I would like to express my profound gratitude and my sincere thanks to Almighty God, who give me strength and endurance during my lifetime, without his help this dissertation would not have been possible. I would like to express my profound gratitude to my supervisor Prof. Dr. Hyeon-Ok Shin for his invaluable advice, sincere guidance, great support and assistance. My special thanks go to my co-supervisor Dr. Kyoungmi Kang who I had the opportunity to work and cooperate with, for her valuable advice and assistance during my study.

I would like to express my sincere thanks to all professors in the department of fisheries for their teaching, guidance and kindness. Also, it is my honor to thank Prof. Prof. Dr. Hyeon-Ok Shin for taking part on my thesis evaluation and for additional reporting. My gratitude is also expressed to Dr. Kyoungmi Kang and Dr.Bo-Kyu Hwang for managing his valuable time and chairing the master committee for reviewing my dissertation. I should also remember, all Professors and friends in the Department of fisheries, who helped me in numerous ways to complete my master dissertation a successful event.

I offer my regards and blessings to all of those who supported me in any respect during the completion of the project. It's my pleasure to express my gratefulness to my lab mates and friends for their helpfulness, kindness, and friendliness extended towards me to make my research work successful. I would like to mention some of them in this small space; Kim teasuk, Gyoem, Afri, Suji Kang…

Lastly, I would like to present my deep appreciation to the Korean government through the KOICA, for accepting me as a foreigner student in its program.

References

Angelescu V. 1979. Trophic ecology of the mackerel of the Argentine continental shelf. (Scombridae, *Scomber japonicus marplatensis*). Part I. Feeding and growth. Rev Investig Pesq 1, 5– 44.

Batty RS, Blaxter JHS and Richard JM. 1990. Light intensity and the feeding behaviour of herring, *Clupea harengus*. Mar Biol 107, 383– 388.

Baras E and Lagardère JP. 1995. Fish telemetry in aquaculture: review and perspectives. Aquac Int 3, 77– 102.

Castro JJ and Del Pino AS. 1995. Feeding preferences of *Scomber japonicus* in the Canary islands area. Sci Mar 59, 325– 333.

Castro JJ. 1993. Feeding ecology of chub mackerel *Scomber japonicus* in the Canary Islands area. South Afr J Mar Sci 13, 323– 328.

Cooke SJ, Chandroo KP, Beddow TA, Moccia RD and Mckinley RS. 2000. Swimming activity and energetic expenditure of captive rainbow trout *Oncorhynchus mykiss* (Walbaum) estimated by electromyogram telemetry. Aquac Res 31, 495– 505.

Collette BB and Nauen CE. 1983. FAO Species Catalogue. Vol. 2. Scombrids of the world. An annotated and illustrated catalogue of tunas, mackerels, bonitos and related species known to date. FAO Fish Synop 125(2), 137 p.

Fredrik Sundstrom L, Samuel H. Gruber, Susi M. Clermont, Jo˜ao P.S. Correia, Jean R.C de Marignae, John F. Morrissey , Courtney R. Lowrance, Lori Thomassen and Miguel T. Oliveira. 2001. Review of elasmobranch behavioral studies using ultrasonic telemetry with special reference to the lemon shark, *Negaprion brevirostris*, around Bimini Islands, Bahamas. Environ Biol Fish 60, 225– 250

Hawkins AD, Maclennan DN, Urquhart GG and Robb C. 1974. Tracking cod, *Gadus morhua* L., in a Scottish sea loch. J Fish Biol 6, 225–236.

Holland KN, Brill RW and Chang RKC. 1990. Horizontal and vertical movements of Pacific blue marlin captured and released using sportfishing gear. Fish Bull 88, 397– 402.

Hwang BK and Shin HO. 2010. Analysis on the detection ability of acoustic telemetry receiver for fish detection by installation depth. J Kor Fish Aquat Sci 43(1), 83– 88.

Juell JE and Westerberg H. 1993. An ultrasonic telemetric system for automatic positioning of individual fish used to track Atlantic salmon (*Salmo salar L.*) in a sea cage. Aquacult Eng 12, 1–18.

Kang KM and Shin HO. 2006. Movement ranges and routes of black rockfish *Sebastes schegeli* in summer and autumn from acoustic telemetry. J Fish Technol 9(2), 91– 96.

Kang KM and Shin HO. 2008. Behavioral characteristics of black seabream *Acanthopagrus schlegeli* in Yeosu water during winter. J Kor Fish Soc 41(1), 48– 53.

Lagardère JP, Ducamp JJ, Favre L, Mosneron J Dupin and Spérando M. 1990. A method for the quantitive evaluation of fish movements in salt ponds by acoustic telemetry. J Exp Mar Biol Ecol 141, 221–236.

Lucas MC. and Baras E. 2000. Methods for studying spatial behavior of freshwater fishes in the natural environment. Fish and Fisheries 1, 283–316.

Le Bris F and Marichal D. 1998. Numerical and experimental study of submerged supple nets: Applications to fish farms. J Mar Sci Technol 3, 161– 170.

Ou CH, Ding DL and Liu-And WH. 2007. Use of non-linear regression to evaluate drag force and volume coefficient of structure of square cage. Fish Sci 73, 1249–1256.

Olla BL, Pearson WH and Studholme AL. 1980. Applicability of behavioral measures in environmental stress assessment. Rapp. P.-V. Re´un.-Cons. Int. Explor. Mer 179, 162– 173.

Perry RW, Noah S. Adams, and Dennis W. Rondorf. 2001. Buoyancy Compensation of Juvenile Chinook Salmon Implanted with Two Different Size Dummy Transmitters. Transactions of the American Fisheries Society 130, 46– 52.

Roberts JL. 1975. Active branchial and ram gill ventilation in fishes. Biol Bull 148, 85–105.

Ryder RA. 1990. Biology of percid fishes. Environ Biol Fish 27, 157–159.

Schaefer KM. 1980. Synopsis of biological data on the chub mackerel, *Scomber japonicus* Houttun. 1782, in the Pacific Ocean, Inter-Amer Trop Tuna Comm S pec Rep 2, 395–446.

Shin HO and Kang MK. 2004. Acoustic telemetry tracking of the response behavior of red seabream (*chrysophrys major*) to artificial reefs. J Kor Fish Soc 37(5), 433–439.

Shin HO, Tae JW and Kang KM. 2005. Acoustic measurement of the movement range and durinal behavior of rockfish (*sebastes schlegeli*) at artificial reef. J Kor Fish Soc 38(2), 129–136.