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The Gaiting Behaviour of the Shrimp *Macrobrachium nipponense* on the Nettings

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The mechanics of the walking shrimps is useful to clarify the fishing mechanisms in relation to the fishing gears. The gaiting behaviour concerning step positions and step timings on the flat board and the nettings, 16, 23 and 37*mm* in mesh size were experimented in the aquarium using video camera from June to October, 1984.

It was found that the irregular movements of walking legs in step positions and step patterns were appeared on the nettings more than the flat surface due to the absence of mechanical contact with the substrates. The mean stride length and coefficient of variation of the periods in the walking shrimps on the flat board were significantly different from those values on the nettings.

However, the velocity, the period and the ratio of forestroke to backstroke were unsteadily changed with the carapace length, and showed little difference under the four conditions. The mean phase difference on the flat board was greater than those values on the nettings which were decreased, while standard deviation on the flat board was smaller than those values on the nettings which were increased with increasing in mesh size.

Introduction

Shrimps were caught mainly by the trap, gillnets and bottom trawl, and locomotion of the shrimp in relation to the those fishing gears was generated by walking and swimming. The mechanics of walking and swimming in addition to biological behaviour was helpful to explain the fishing mechanism and to improve the fishing gears.

The walking behaviour of the crustacea was recapitulated elaborately by Lochhead (1961), and Evoy and Ayers (1982). The recent works have been devoted to describing the unusual step patterns in the crayfish (Pond, 1975; Grote, 1981) and in the insect (Graham, 1978a; 1978b; 1979; Dean and Wendler, 1982; Foth and Graham, 1983). However, all of these researches were based on the walking on flat surface or treadmill, and the question of whether the gait differs on flat surface and nettings was not mentioned (Ko and Kim, 1983).

The main purposes of this study were to find the difference of gaiting behaviour in the shrimp on the flat board and the nettings under freely walking condition, and to demonstrate the basic solution for the fishing mechanisms of the various nets.

The walking experiments of the freshwater shrimp were carried out in the aquarium and analyzed on the stride, the period, the velocity and the phase difference by using video tape recorder.

Material and Methods

The freshwater shrimps, *Macrobrachium nipponense*, were collected locally from the Nak Dong River at Kim Hae and maintained in the oval aquaria, L 120 X B 50 X D 30*cm*, using filtered running water system in the laboratory at the room temperatures 23~25°C on July, 1984. The fourteen shrimps ranged from 22 to 31 *mm* in carapace length were discriminated from each others by tying up the colored rubber band to the telson. The walking legs are represented by L for left and R for right, and numbered 3~5 from front to rear.

The experiments for the gaiting behaviour of the shrimp were carried out in a glass aquarium, L 120 X B 30 X D 45*cm*, with the water depth 25 *cm* at the water temperatures 21~23°C under normal indoor artificial light within 5 days of their capture. The shrimps were released on a horizontal graph paper surface of acrylic board, L 80 X B 28 *cm*, or on the netting frameworks, L 60 X B 28 *cm*, setting in the aquarium under the Victor GX-V8 video camera as shown in Fig. 1. The three

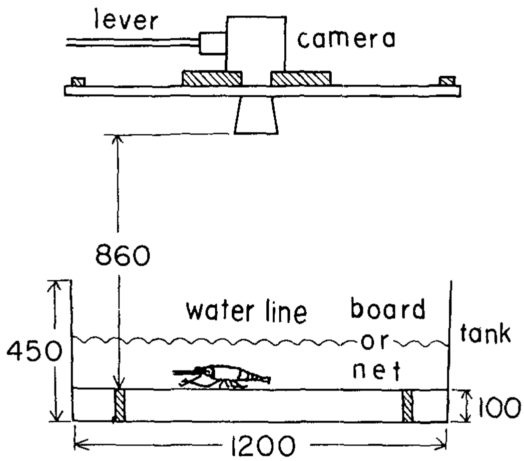

Fig. 1. Experimental set-up.

netting frameworks differentiated in mesh size, 16, 23 and 37 *mm*, were made of nylon netting twines 0.5 *mm* in diameter giving the hanging ratio 0.75.

Straight, forward, uninterrupted walks under each of the four conditions were recorded intermittently on video tape for more than three minutes per one animal by using the Victor HR-2200 V.T.R. The video tapes were analyzed frame by frame with its interval 1/30 sec to determine the timing of the leg movements and to trace the tips of legs for the selected ten shrimps by using the Victor C-1320 B monitor. Being measured from the still picture of monitor, all values of the stride, protraction, retraction, period, speed except the phase were dealt with the same terms of Lochhead (1961). The relative phase differences of the walking shrimp were evaluated by positive or negative sign especially on the nettings.

Results and Discussion

The relationship between the carapace length (C.L, *mm*) and length of the walking legs (L.L, *mm*) in the freshwater shrimps, *Macrobrachium nipponense*, was shown in Fig. 2, and the length of

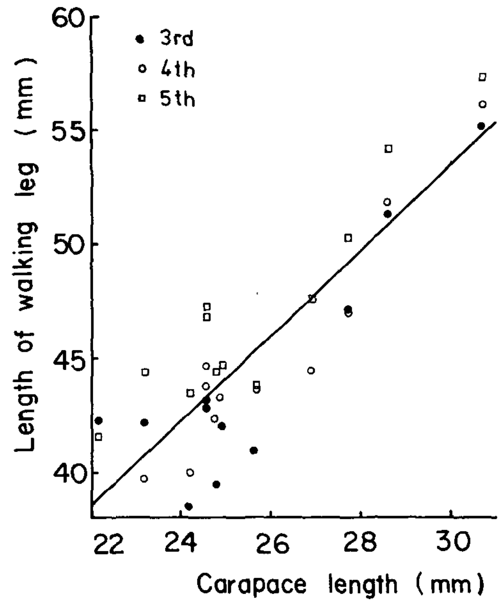

Fig. 2. Relationship between the carapace length and the length of walking legs in the shrimps.

legs were increased gradually in order of 3rd, 4th and 5th leg (Kim, 1977). The regression formula can be expressed as follows:

L.L=1.9 C.L.−2.5 (where correlation coefficient r=0.88, number of sample n=33)

1. General features

General features of the gaiting behaviour in the shrimp were observed that since the walking by the legs which play a major role in a locomotion, and the swimming by the pleopods occurred simultaneously, the co-ordination among the walking legs was interrupted briefly in the step positions and step timing (Evoy and Ayers, 1982). Thus, metachronal or tripod gaiting rhythm disappeared to be related to mechanical contact of the legs with the substrates.

The unusual step features of the walking shrimp were shown on the nettings more than on the flat board substrate. Most of pushing legs made a false step due to the absence of mechanical contact with the mesh of netting, and then passed through the mesh between netting twines. Falling leg might impede the orderly movements of the other walking legs in the neuronal control of locomotion, and entangled its segments, dactylus, propodus or carpus in netting twines of the mesh during its swing of forestroke and backstroke.

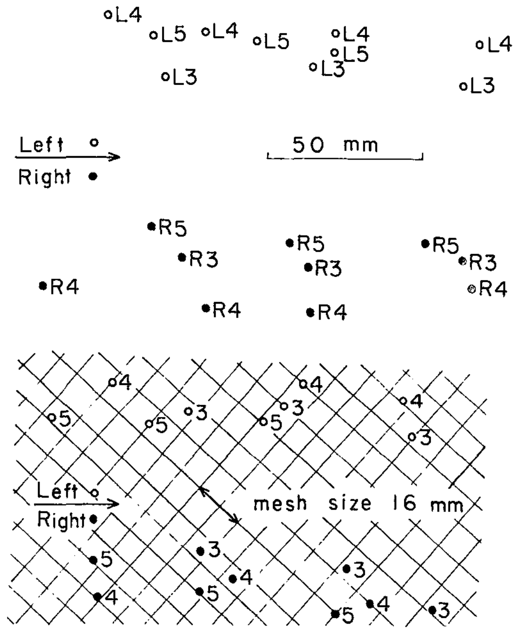

Fig. 3-A

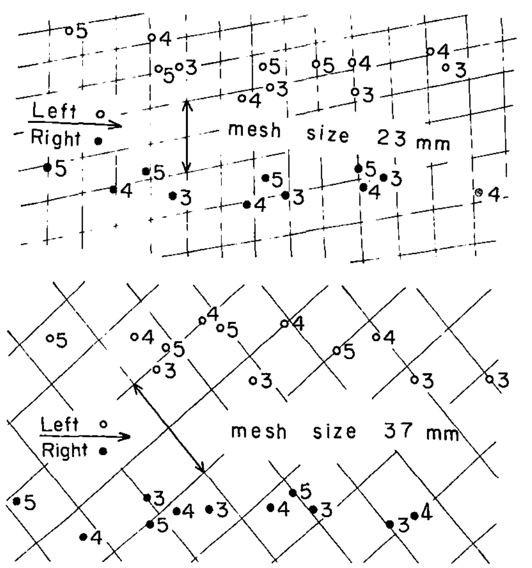

Fig. 3-B

Fig. 3. Examples of the step positions in the walking shrimp on the flat board and the nettings.

The representative examples of step positions horizontally at the tips of legs on the flat board and the nettings with the different mesh size were shown in Fig. 3. The step positions of the walking shrimp on the flat board were more systematic in the stride and inter-leg positions than on the nettings (Cruse, Clarac and Chasserat, 1983; Dean and Wendler, 1983). The step positions on the nettings in Fig. 3 indicated that making false steps which were increased in accordance with increasing in mesh size, might take place before touching down the netting twine. It seemed that the false swing and false step exerted strongly to change the posture and direction of the walking shrimp (Clarac, 1981). The irregular phenomena in step positions were similar to those of insects using three pairs of legs in air (Cruse and Epstein, 1982; Dean and Wendler, 1982; 1984; Graham and Cruse, 1981).

The examples of the step patterns in the walking shrimp were described typically with the protraction i. e. forestroke time and the retraction i. e. backstroke time as shown in Fig. 4. Especially in the step patterns on the nettings, the retraction was defined the time interval during any segments of leg staying on the netting twine and the protraction from departing the netting twine to just before arriving the netting twine (Lochhead, 1961).

The protraction, the retraction and the step period on the nettings were varied larger than on the flat board between steps in a leg as well as between steps inter-legs (Clarac and Chasserat, 1983; Chasserat and Clarac, 1980; 1983). The step patterns on the nettings were changed so roughly that relative phase difference in this paper was represented as the ratio of lag between legs to the mean step period of all legs.

The irregular timing movements due to a failure

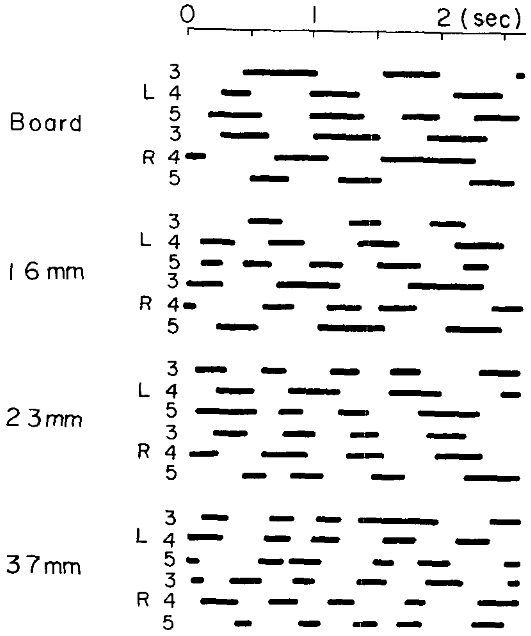

Fig. 4. Stepping patterns of the walking shrimp on the flat board and the nettings.

of steps on the netting were also occurred in the insect walking, when the turning behaviour (Epstein and Graham, 1983; Land, 1972), and having different length of walking legs (Graham, 1978a; 1978b) and other conditions (Graham, 1979; Foth and Graham, 1983). Above articles were discussed that the phase had positive values only in spite of its changing from lagging to leading or vice versa in a consecutive step pattern. However, this paper was suggested that phase difference especially on the netting might be expressed a negative value in order to clarify the time variation between inter-leg movements.

According to the results of general features in the walking shrimp, it was inferred that the locomotions in relation to the trap, the gillnets and the bottom trawl were significantly different from the normal flat substrates. Making a false step and entanglement of legs depend on the mesh size of netting, might clarify the fishing mechanism of gillnets. Further study have to be focused on the relationship between the mesh size and swing of legs.

2. Positions and timings of the step

The first indication of major positional differences was found by measuring step distances. The mean stride length under the four conditions of substrate in accordance with the carapace length were given in Fig. 5. There was little relationship

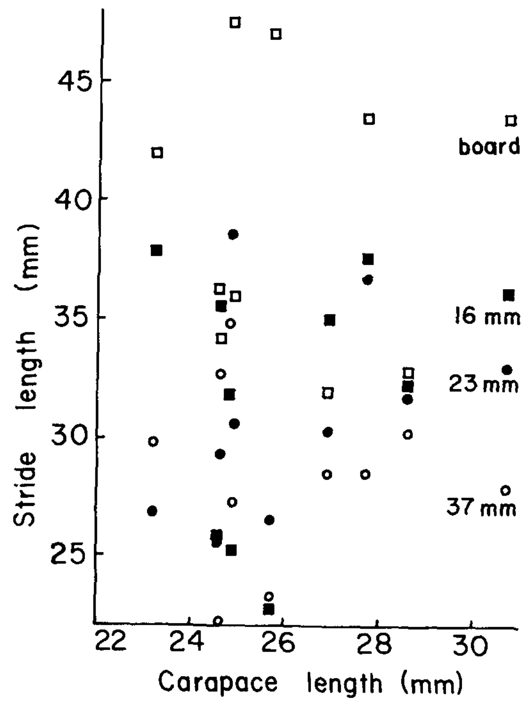

Fig. 5. Relationship between the carapace length and the stride length of the shrimps.

between the stride length and the carapace length under any conditions (Burrows and Hoyle, 1973). The mean stride length was found significantly (probability $p<0.01$) greater on the flat board than the nettings, but no difference between each mesh size of nettings by a paired difference T-test with the ten shrimps. Pond (1975) reported that the distance moved per step of the crayfish was clearly greater on the rough cloth than the smooth sheet of plate glass and greater in water than on land (Grote, 1981; Graham and Cruse, 1981). But, the netting used in this paper was different from the cloth in roughness of surface and physical characteristics of substrate.

The mean step periods consisted of a protraction

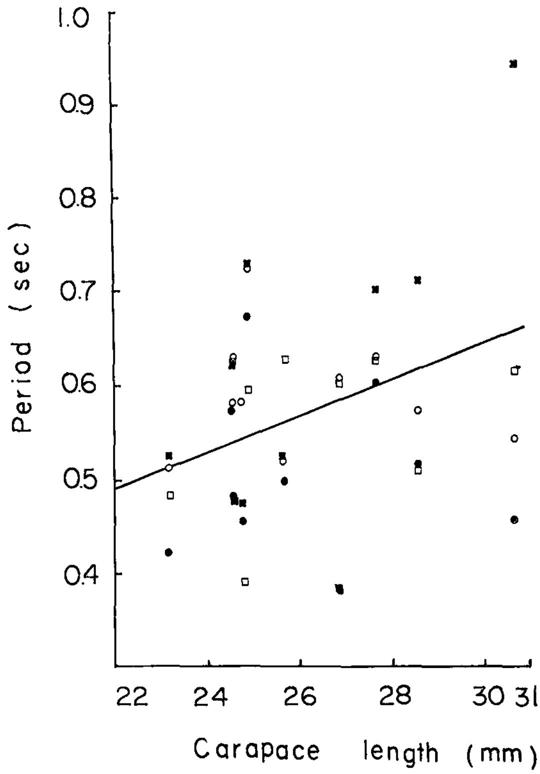

Fig. 6. Relationship between the carapace length and the step period of the shrimps.

and a retraction under the four conditions were shown in Fig. 6. No significant differences between the step period and each condition of the substrates were found in the walking shrimp, and the same results were obtained by Pond (1975). The step period (T, sec) was increased slightly in accordance with the carapace length (C. L, *mm*) and regression line was as follows:

$T = 0.019\ C.L. + 0.083$ ($r = 0.35$, $n = 38$, $p < 0.02$)

As the walking on the netting caused the absence of mechanical contact with the substrate, the coefficients of variation (C. V.) in the step period were greater than those values of other experiments under normal conditions (Chasserat and Clarac, 1980; 1983; Clarac and Chasserat, 1983). The C. V. of the period showed obvious differences between the flat board and each mesh size of three nettings ($p < 0.01$), between mesh size 16:23*mm* ($p < 0.05$) and between mesh size 16:37*mm* ($p < 0.02$). The mean values of the C. V, the period, the stride, the moving speed and F. S. /B. S. were given in Table 1.

The irregular step patterns in the forestroke, the backstroke, the step period and F. S. /B. S. were also occurred in the cases of different substrates (Graham and Cruse, 1981; Epstein and Graham, 1983) and unusual step conditions (Evoy and Ayers, 1982; Graham, 1978a; 1978b; Land, 1972). According to the variations of the stride length and the step period, the mean walking speeds were changed a little under the four substrates between mesh size 23:37 *mm* ($p < 0.02$), and between flat board and mesh size 23 *mm* ($p < 0.05$). F. S. /B. S. were changed roughly from 0.8 to 1.4 regardless the four conditions, however, S. D. of F. S. /B. S. were increased in accordance with increasing in mesh size.

The relative phase differences as evaluated by the previous definition from the step patterns of the walking shrimp were established with ipsilateral, bilateral and contralateral legs as shown in Fig. 7. The mean values of the phase in the walking shrimp on the flat board were relatively less than

Table 1. The stride, period, speed and F. S. /B. S. of the walking shrimp on the flat board and the nettings

Walking parameter	Flat board	Nettings		
		16 *mm*	23 *mm*	37 *mm*
Stride(*mm*)	39±11(167)*	32±11(171)	29±9(164)	31±11(181)
Period(sec)	0.59±0.15(247)	0.61±0.20(235)	0.60±0.19(269)	0.52±0.21(315)
C. V. of period(%)	17±2(10)	21±3(10)	28±10(10)	28±9(10)
Speed(*mm*/sec)	64±22(10)	54±15(10)	48±6(10)	59±12(10)
F. S. /B. S.	1.10±0.19(10)	0.97±0.14(10)	1.00±0.23(10)	1.07±0.30(10)

* Values represent mean±standard deviation (number of sample)
C. V. : coefficient of variation
F. S. /B. S. : ratio of the forestroke to the backstroke

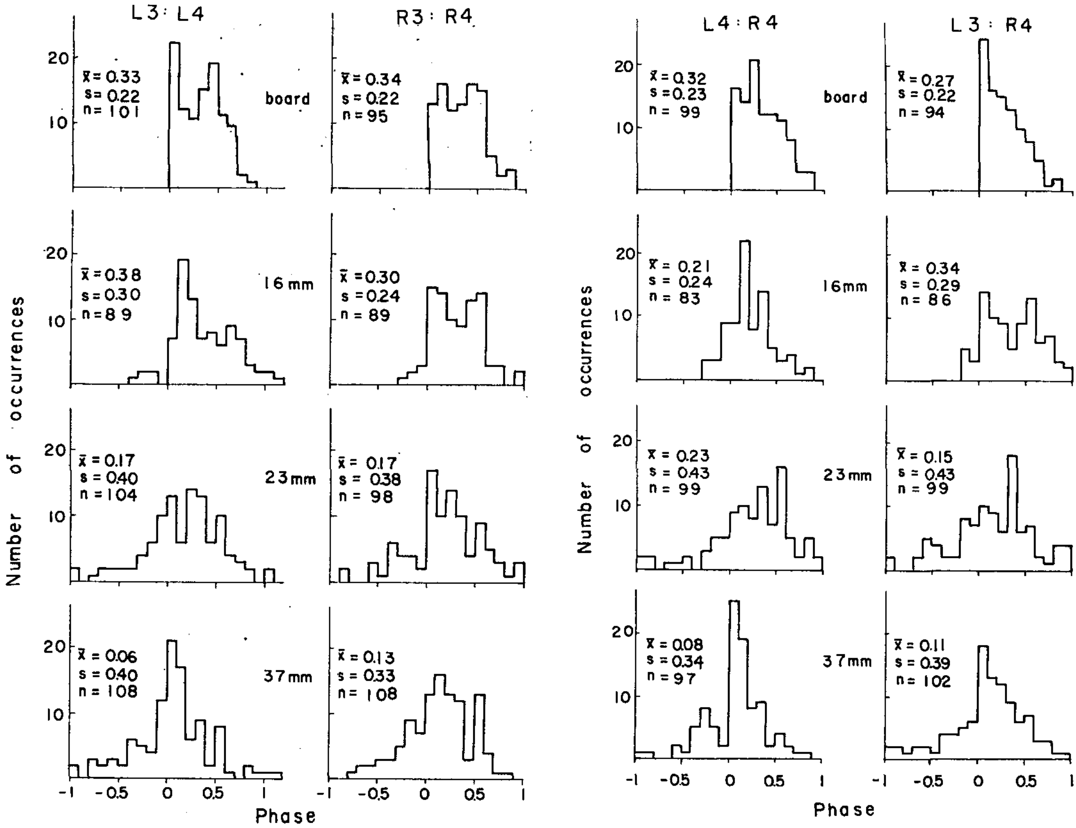

Fig. 7-A Fig. 7-B

Fig. 7. Relative phase histograms of the walking shrimp for ipsilateral, bilateral and contralateral legs.
$\bar{x}$: mean value of the phase S: standard deviation n: number of sample

those of the rock lobsters, while standard deviation of the phase distribution were more than those of them (Chasserat and Clarac, 1980; 1983; Clarac and Chasserat, 1983). The main reason of these tendencies was considered that swimming behaviour by the rhythmic rowing movements in the exopodites of pleopods was appeared in addition to the walking movement so that the co-ordination of the walking legs became a little systematic (Evoy and Ayers, 1982).

The mean phase difference: 0.3 and its standard deviation: 0.2 on the flat board were definitely different from those values on the nettings which were varied from 0.3 to 0.1 in the phase and from 0.2 to 0.4 in S.D. with increasing in mesh size. The phase histograms on the netting were concentrated looser than on the flat board and had a negative value in the case of its changing from lagging to leading or vice versa in a consecutive step pattern. Being increased mesh size of the nettings, the mean values of the phase without any directional turning of walking shrimp were decreased rapidly, but the number of occurrences with the negative phase value was increased gradually (Graham, 1979; Dean and Wendler, 1982; Foth and Graham, 1983).

The experiments on the turning of insects (Land, 1972; Epstein and Graham, 1983) and on the walking insects using different length of leg (Graham, 1978a; 1978b) showed that the relative phase changed to lagging or to leading alternately with the time elapsed. However, there was no evidence to support their expression of the relative phase difference that was more rational, and more clear than this paper used both of negative and positive phase values.

As shown in the results, the walking of the shrimp was obstructed on the nettings more than on the flat surface not only in step positions but also in step timings. Hence, it was considered that the shrimp avoided the walking on the netting entrance and entering into the trap (Ko and Kim, 1983).

Summary

The gaiting behaviour of the freshwater shrimp on the flat board and the nettings, 16, 23 and 37 *mm* in mesh size, were investigated on the step positions and the step timings in the aquarium by using video camera and recorder. It was found that the irregular movements of walking legs in step positions and step patterns were appeared on the nettings more than on the flat board due to the absence of mechanical contact with the substrates.

1. The length of the walking legs (L. L, *mm*) were increased with the carapace length (C. L, *mm*) as follows:

   $$L.L. = 1.9\ C.L. - 2.5$$

2. The mean stride length 40 *mm* on the flat board was significantly greater than each of those values about 30 *mm* on the nettings of 16, 23, 37 *mm* in mesh size.
3. The step period (T, sec) with the carapace length (C. L, *mm*) was as follows:

   $$T = 0.019\ C.L. + 0.083$$

   and no relationship was found between the periods under the four conditions of substrate. However, the coefficients of variation ranged from 0.2 to 0.3 on the nettings were greater than 0.2 on the flat board.
4. The mean walking speeds were changed roughly from 40 to 80 *mm*/sec and the ratio of the forestroke to the backstroke from 0.8 to 1.4 regardless the four conditions.
5. The mean phase difference : 0.3 and its standard deviation : 0.2 on the flat board were definitely different from those values on the nettings which were varied from 0.3 to 0.1 in the phase and from 0.2 to 0.4 in S. D. with increasing in mesh size.

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망지에 대한 징거미 새우(*Macrobachium nipponense*)의 보행운동

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(1985년 3월 15일 수리)

망지에 대한 새우의 보행운동은 통발이나 자망 등 그물어구에 어획되는 메카니즘을 규명하고 어구를 개량하는데 기본적인 필수요인이 될 것이다. 여기서는 김해 낙동강 지류에서 채집한 갑장 22~31*mm* 정도의 징거미 새우를 사용하여 평판과 망목크기가 각각 16, 23, 37 *mm* 인 망지위에서의 보행운동을 비디오카메라로 촬영하고, 직선적인 보행운동을 V.T.R로 분석. 비교하였다.

망지에서의 보행운동은 진행방향으로 내뻗는 다리가 그물코의 망사위에 바로 착지하지 못하고 다리마디가 그물코 사이로 빠져서 그물코위에 다리가 걸리게 되는 경우가 대부분이었다. 따라서 한 다리간, 또는 각 다리간의 보행위치, 이동순서, 시간차이, 연쇄적인 동작 등 보행 형식이 평면에서의 경우보다 매우 불규칙하게 나타났다. 징거미 새우의 보행운동을 분석한 결과 보폭, 각 다리간의 상대위상차, 주기의 변동계수 등은 평판과 망지의 망목 크기에 따라 큰 차이를 보였으나 이동속도, 주기, 뻗기와 오므리기의 시간비 등에서는 별로 차이가 없었다.