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Improving Size Selectivity of Captured Coonstripe Shrimp (*Pandalus hypsinotus*) in Hokkaido by Altering the Slope Length and Angle of Pots

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The purpose of the current study was to optimize shrimp-pot design to allow greater control over the size of captured individuals for the purposes of shrimp resource management. Tank experiments were conducted to determine the optimal slope length and slope angle by analyzing the sizes of shrimp that entered 25 model pots with combinations of five different slope lengths and five different angles. Shrimp size was measured using carapace length. The results showed that as the slope angle of the pot increased, the size of individuals that entered the pot increased. Furthermore, as the slope length increased, each of the five different slope angles of the pot increased, and the size of individuals entering also increased. The data indicated that the optimum pot design for reducing the capture of immature individuals had a 75° slope angle and a 35.4 cm slope length.

Key words: Optimal design, Selectivity, Shrimp pot, Slope angle, Slope length, Tank experiment

Introduction

In Hokkaido, Japan, shrimp-pot fisheries mainly catch coonstripe shrimp (*Pandalus hypsinotus*) and pink shrimp (*Pandalus eous*).

The coonstripe shrimp ("toyama-ebi" in Japanese) is an economically important marine resource in Hokkaido, but at present, approximately 90% of the catch is pink shrimp due to a decline in coonstripe numbers. Recently, the total annual catch of coonstripe shrimp in Hokkaido decreased rapidly from 845 tons in 1996 to 682 tons in 2006 (Statistics and Information Department, Minister's Secretariat, the Ministry of Agriculture, Forestry, and Fisheries of Japan. 2006). The main fishing method for this species is the shrimp pot.

According to a study on the condition of shrimp pot fisheries in 2006 at Sawara, Hokkaido, small shrimp less than about 1.5 years of age were the most abundant group caught in shrimp pots, about 86% of individuals (Kim, S.H, unpubl. data, 2006). Consequently, a new shrimp-pot design is required to selectively target older individuals to maintain the shrimp resource.

Pots designed to catch coonstripe shrimp in the region are of a hemispherical type with an entrance at the top, a height of 36 cm, and a diameter at the base of around 110 cm.

Many studies have reported that catch efficiency varies according to pot structure (Stasko, 1975; Koike et al., 1979; Yamane and Iitaka, 1987; Sheaves, 1995; Yamane, 1995; Li et al., 2006). Other studies have described the effect of mesh size on the size of animals caught (Watanabe and Sasakawa, 1984; Kawamura and Tumura, 1990; Nishiuchi, 1990, 2001; Omoto et al., 1998; Jeong et al., 2000), but this has rarely been investigated specifically with regard to shrimp pots (Koike, 1979; Koike et al., 1981).

In contrast to fish and crabs that enter pots by swimming and walking, respectively, shrimp are capable of entering pots by both methods. In crab fisheries, the size of individuals entering pots was affected by mesh size. In the case of shrimp, mesh size also has an effect when the shrimp enter by walking, but they appear to be more affected by pot shape than by mesh size when swimming.

The purpose of the current study was to optimize the design of shrimp pots to allow greater control

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*Corresponding author: pelamis@pknu.ac.kr over the size of captured individuals for the purposes of shrimp resource management. Tank experiments were conducted to determine the optimal slope length and slope angle by analyzing the size of individuals that entered 25 model pots representing all possible combinations of five different slope lengths and five different slope angles.

Materials and Methods

The behavioral experiments were conducted in a tank using experimental pots that varied in slope length and angle.

Experimental individuals

Coonstripe shrimp were collected in Funka Bay, Hokkaido using a commercial shrimp pot on 13 March 2007. A total of 234 individuals were used in the behavioral experiments, and carapace lengths ranged from 19 to 36 mm, with each size represented by 13 individuals. The shrimp were kept in a tank (2× 2×1 m, L×W×D) at a water temperature of 3.0-3.5°C and were fed defrosted greenling at intervals of 2-3 days. Previously used individuals were acclimated for 2-3 days before being used again.

Model pots

The tank experiments were conducted with 25 variants of a simple pot design combining one of five slope lengths and one of five angles. The netting was the same as that used in commercial pots (34 mm Rachel netting with *Tetron* 210d/18F). The current shrimp pot used in Hokkaido is shown in Fig. 1.

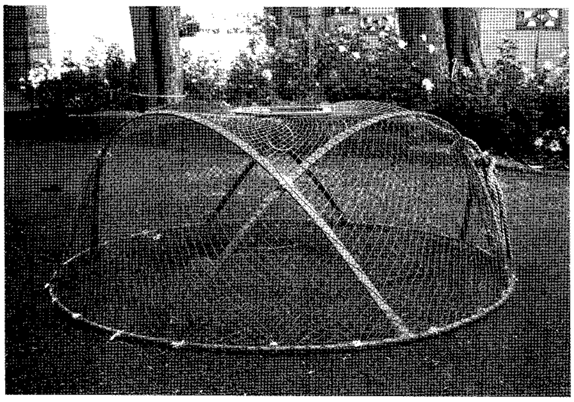

Fig. 1. The current shrimp pot used in Hokkaido.

The model pots were created using a 6 mm diameter iron frame and a column of PVC pipes (diameter, 16 mm). The height of the pots was adjusted by changing the length of the PVC pipes. A schematic illustration of a model pot is shown in Fig. 2.

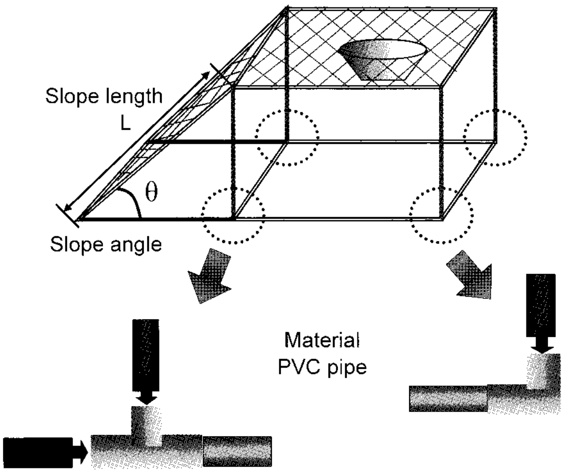

Fig. 2. Schematic illustration of an experimental pot used for the selectivity experiments.
L, slope length of experimental pot; *θ*, slope angle of experimental pot.

The slope lengths (distance between the top and bottom frames) were set at 24, 34, 44, 54, and 64 cm, thereby incorporating the slope length (44 cm) used in commercial pots. The slope angles were 35, 45, 55, 65, and 75° and also included the slope angle (55°) of commercial pots. The angle between the netting on the slope and the bottom of the pot was defined as the slope angle (Fig. 2).

Experimental setup

The experiments were conducted in a square tank, as shown in Fig. 3. The model pot was placed in the experimental tank. The environment in front of the slope of the model pot was made using acrylic partitions. Two infrared cameras (TR-850WBP, Teistar, Tokyo, Japan) positioned to view the slope and entrance were used to observe shrimp behavior. The infrared cameras were connected to a monitor (CPD-17MS, Sony, Tokyo, Japan) and a time-lapse videocassette recorder (VCR; HV-GR2, Aiwa, Tokyo, Japan), and allowed for 24 hour observations (Fig. 3).

The experiments were conducted without illumination to replicate the darkness likely to be found at the 80-100 m depth at which coonstripe shrimp live in Funka Bay, Japan. The water temperature in the tank was kept at 3.0-3.5°C using a seawater cooler.

Experimental protocol

The experiment was conducted three times for each model pot. The order of experimental pots used in the selectivity experiments is shown in Fig. 4. Experimental individuals were released into the ground in front of the model pot in the tank (Fig. 3) and were

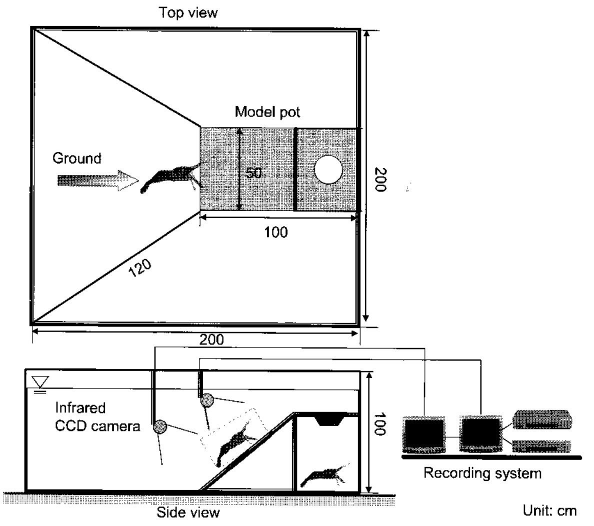

Fig. 3. Schematic illustration of the experimental tank setup.

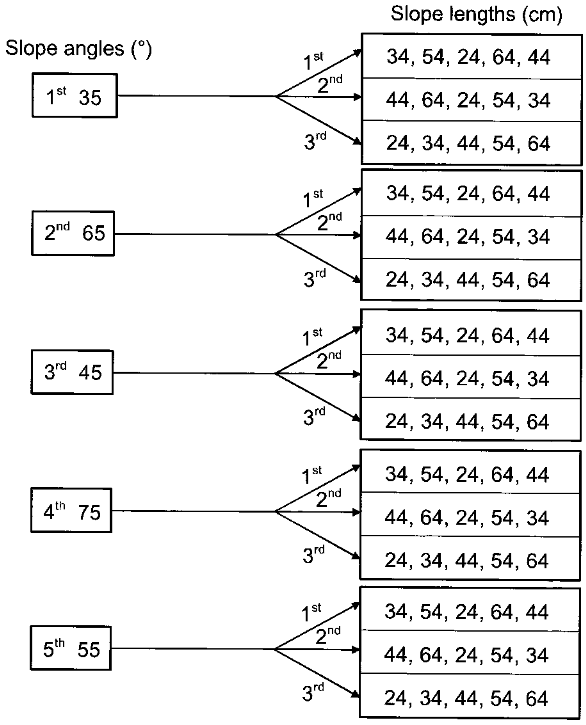

Fig. 4. The order of experimental pots used in the selectivity experiments.

acclimated for 1 hour with the pot entrance closed. Observations started immediately after setting the bait (50 g defrosted greenling) in the pot and opening the entrance.

Observations were conducted for 24 hours, after which the individuals that had entered the pot were separated from those that had not entered, and the carapace length of each group was measured.

Size selectivity analysis

The optimal slope length and angle were evaluated by selectivity analysis based on the carapace length of the individuals that entered each model pot.

The entrance rate was defined as the rate of individuals that entered the pot relative to the total number of individuals released into the experimental tank, given as:

$$ø=\frac{C_E}{C_E+C_R} \qquad (1)$$

where ø is the entrance rate, C_E is the number of individuals that entered the pot, and C_R is the number of individuals that did not enter the pot. A selectivity curve was fitted using the most commonly used logistic function for carapace length l (Pope et al., 1975):

$$S(l)=\frac{\exp(a+bl)}{1+\exp(a+bl)},\ 0<S(l)<1 \qquad (2)$$

where $S(l)$ denotes selectivity, which translates as the entrance rate, a and b are the selectivity curve parameters, and l denotes carapace length.

The selectivity curve parameters (a and b) were estimated by a maximum likelihood method (Hiramatsu, 1992; Jeong et al., 2000; Fujimori and Tokai, 2001).

If N is the total number of individuals released into the tank, n is the number that entered the pot, p is the probability of entering the pot, and 1-p is the probability of remaining outside, then the likelihood function $L(p)$ is given as:

$$L(p)={}_NC_n p^n(1-p)^{N-n} \qquad (3)$$

The probability p of an individual of a given carapace length class l entering can be written as Eq. (4) using a logistic function.

$$p(l_k)=\frac{\exp(\alpha+\beta l_k)}{1+\exp(\alpha+\beta l_k)},\ 0<p(l_k)<1 \qquad (4)$$

where $p(l_k)$ is selectivity of the carapace length class l_k, k=1,2,3,···,K, and α and β are the logistic curve parameters.

The logistic curve parameters α and β were estimated by maximizing the following likelihood function:

$$L(\alpha,\beta)=\prod_{k=1}^{K}{}_{N_k}C_{n_k}p(l_k)^{n_k}[1-p(l_k)]^{N_k-n_k} \qquad (5)$$

Solver on Microsoft Excel (Microsoft Corp., Redmond, WA, USA) was used to maximize this function (Tokai, 1997).

The carapace length at 25, 50, and 75% selection,

l_{25}, l_{50}, and l_{75} were given as

$$0.25=\frac{\exp(\alpha+\beta l_{25})}{1+\exp(\alpha+\beta l_{25})}, \quad l_{25}=\frac{-\ln(3)-\alpha}{\beta} \qquad (6)$$

$$0.50=\frac{\exp(\alpha+\beta l_{50})}{1+\exp(\alpha+\beta l_{50})}, \quad l_{50}=\frac{-\alpha}{\beta} \qquad (7)$$

$$0.75=\frac{\exp(\alpha+\beta l_{75})}{1+\exp(\alpha+\beta l_{75})}, \quad l_{75}=\frac{\ln(3)-\alpha}{\beta} \qquad (8)$$

Selectivity was based on the number of individuals with a carapace length of 25 mm (about 1 year of age). Additionally, the optimal slope length and angle were determined when a 50% selection (l_{50}) of 25 mm carapace-length individuals was achieved.

The selection ranges SR(l_{75}-l_{25}) were calculated by

$$SR=l_{75}-l_{25}=2\ln(3)/\beta \qquad (9)$$

Results

Catch composition

Fig. 5 shows the number of individuals that entered the pots and remained in the tank during each experiment, which was replicated three times.

As the slope angle increased, the number of individuals that entered the pot decreased regardless of the slope length. Furthermore, the carapace length of those individuals that entered varied with slope length. For any given slope angle, long slopes were associated with the entrance of larger individuals (ANOVA, $P<0.05$).

The selectivity curve was estimated using data on the carapace length composition of individuals that entered each experimental pot. The estimated selectivity curve, shown in Fig. 6, exhibited a knife-edge shape with respect to increases in slope length.

Individuals of all carapace length classes entered the pot when the slope length was 24 cm and when the slope angle was set to any value other than 75°. Consequently, with this slope length, the selection ranges (SR) were wide.

However, as the slope length increased, fewer small individuals of less than 25 mm length were caught regardless of the slope angle. The selectivity curves generated for each combination of slope angle and slope length are shown in Fig. 6. This figure shows that slope angle and length had little impact on the capture rate of individuals with a carapace length over 30 mm. Conversely, shrimp with carapace length less than a 30 mm were more sensitive to slope length.

The l_{50} and SR values of each model pot are shown in Figs. 7 and 8. The slope length and angle required to achieve a 50% selection (l_{50}) with a 25 mm carapace length are shown in Table 1.

The model pot with a 35° slope angle and a maximum slope length of 64 cm was associated with a carapace length at l_{50} was 23.7 mm smaller than the 25 mm selection criterion. Moreover, a wide range of individuals were caught, as a slope angle of 35° is very gradual.

The pot with a 45° slope angle and 64 cm slope length achieved l_{50} of 24.8 mm, which closely approximated the desired selection criterion of a carapace length of 25 mm. The selection range was very broad with a slope length of 24 cm but was

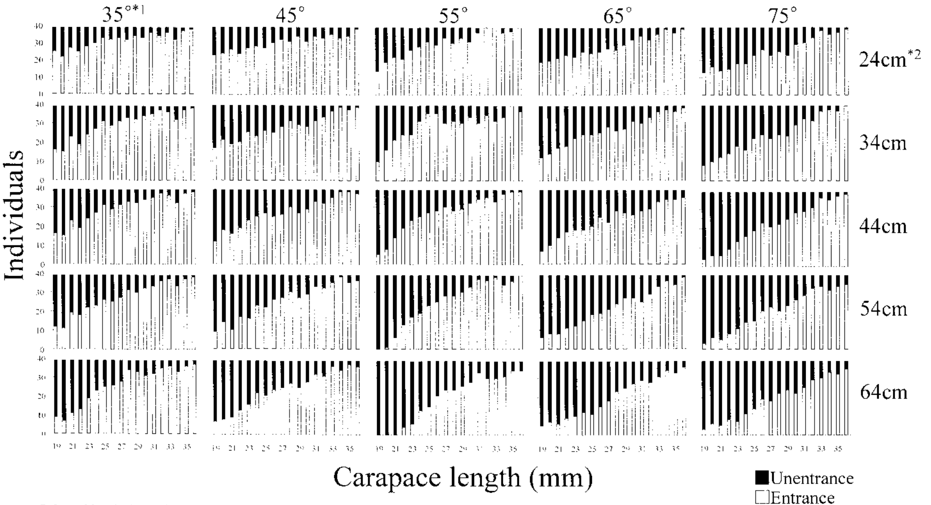

Fig. 5. Proportion of individuals that entered the experimental pots according to slope angle and length. *1slope angle of pot , *2slope length of pot.

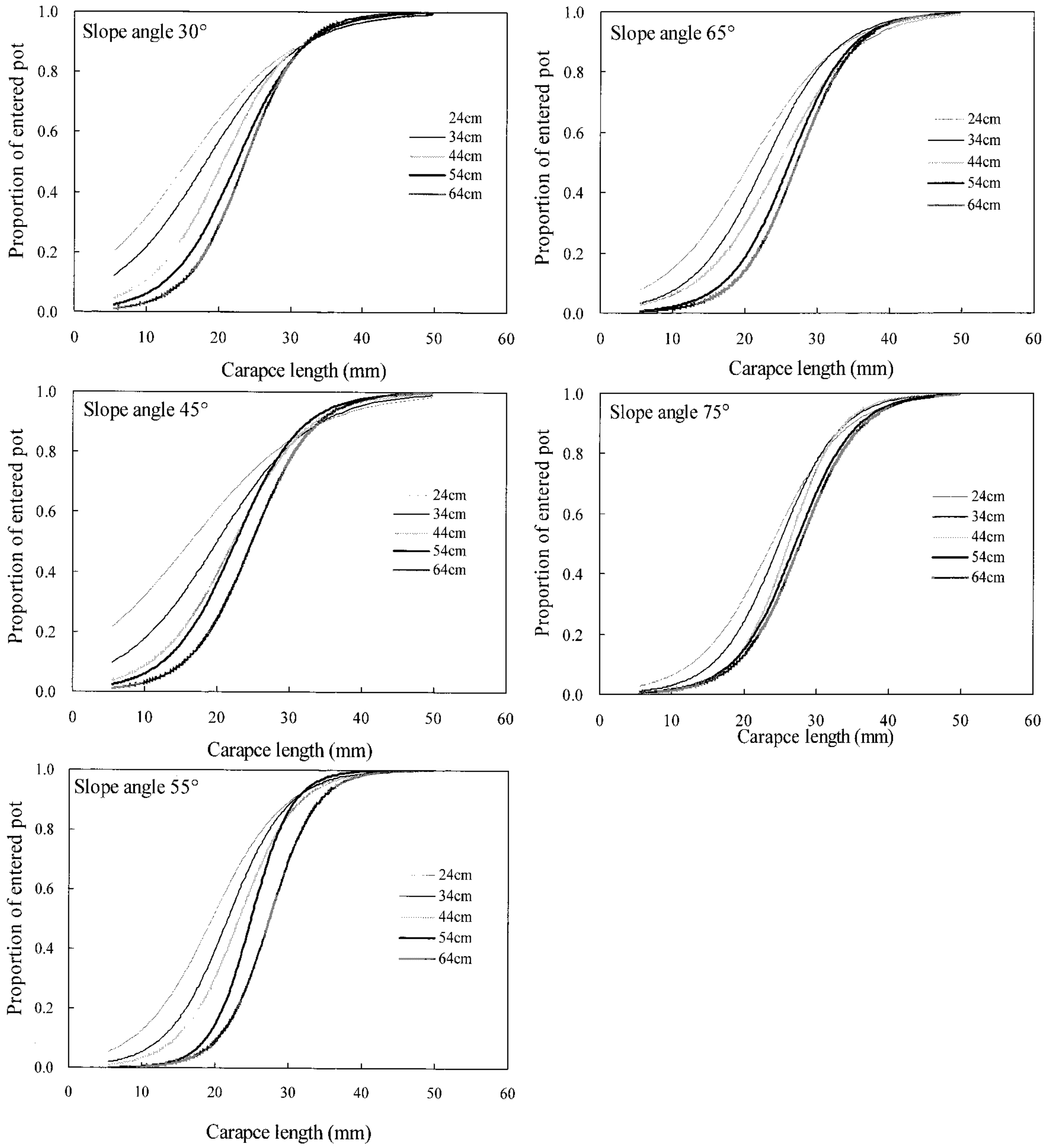

Fig. 6. Selectivity curves generated by the logistic model for the combinations of slope angles and lengths.

reduced as the length increased from 34 to 64 cm.

The pot with a 55° slope angle represents the angle adopted commercially in the Sawara area. Using this angle, the number of larger individuals caught also increased as the slope length increased. Additionally, when the slope length was 54 cm, the l_{50} value matched the target selection criterion of 25 mm carapace length. This length was approximately 10 cm greater than that used in current commercial shrimp pots.

A pot with a 65° slope angle and a 44 mm length also approached the selection criterion, with l_{50} of 24.7 mm. The slope length required to achieve a 50% selection of 25 mm individuals at this slope angle was 48 cm.

The 75° slope angle is approximately 20° steeper than that used in the current commercial pot design. Compared to the other pot designs in the study, a short slope length of only 35.3 cm was required to achieve a 50% selection of 25 mm individuals, and SR appeared to have a low linear relationship to slope angle compared to the other pot designs because the individuals that entered the experiment pot represented a broad range of carapace-length classes.

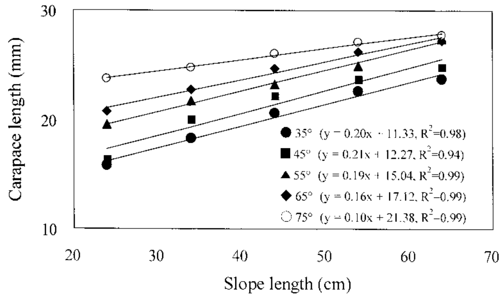

Fig. 7. 50% selection carapace length (l_{50}) for each slope angle and length combination.

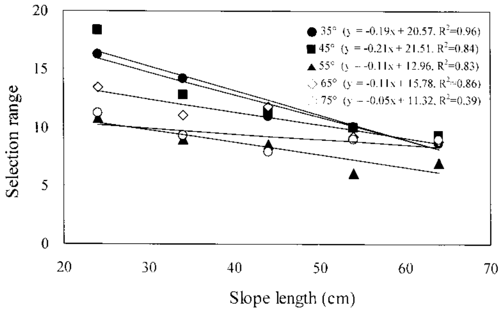

Fig. 8. Selection range (SR) for each slope angle and length combination.

Table 1. The 50% selection carapace length values of experimental pots with five different slope angles and slope lengths

Slope length (cm)	Slope angle (°)				
	35	45	55	65	75
24	15.8	16.3	19.6	20.8	23.8
34	18.3	21.1	21.7	22.8	24.8
44	20.6	22.2	23.2	24.7	26.1
54	22.6	23.8	24.9	26.2	27.1
64	23.7	24.8	27.4	27.3	27.8

Discussion

The effect of slope length and angle at the entrance to fishing pots on the size of captured shrimp was examined to determine the optimal design of pots for use in Hokkaido, Japan.

Tank experiments were performed using model pots each of which combined one of five different slope lengths and five slope angles. The results showed that as the slope angle increased, the size of individuals entering the pots also increased. Moreover, irrespective of the slope angle, longer slopes favored the capture of larger individuals.

Therefore, by changing either the slope angle or length independently, it should be possible to select more mature shrimp. However, if both the slope length and angle are increased simultaneously, the pot height must be increased to accommodate these changes, which may result in reduced underwater stability.

The selectivity curves indicated that l_{50} for individuals with a 25 mm carapace length could be achieved by changing only the slope angle while retaining a short slope length. Therefore, the capture of immature individuals can be reduced by only increasing the slope angle of the current commercial design.

Therefore, this study has demonstrated that the optimal shape of shrimp pots for use in Sawara can be estimated using l_{50} for 25 mm carapace length individuals by varying the slope angle and length of the pot.

Currently, pots are cast overboard by hand, so increasing the diameter of the pot base from the current 110 cm may reduce the efficiency of this procedure. Furthermore, a new pot would be required to have an adequate inner volume to hold the proper catch.

The estimated optimum slope lengths, angles, shapes, and inner volumes of pots with a 110 cm base diameter designed to achieve l_{50} for 25 mm individuals are shown in Table 2, and the expected basic shapes of the new pot designs are shown in Fig. 9.

Table 2. The design of new pots to achieve the 50% s election carapace length value (l_{50})

Model pot	Slope angle (°)	Slope length (cm)	Height (cm)	Radius^{*1} (cm)	Inner volume (m^3)
$P_0{}^{*2}$	55	44.0	36.0	30.0	0.210
P_1	35	68.4	39.2	-	-
P_2	45	64.0	45.3	9.7	0.173
P_3	55	54.0	44.2	24.0	0.228
P_4	65	48.0	43.5	34.7	0.279
P_5	75	35.4	34.2	45.8	0.274

In Table 3 and Fig. 9, P_0 is the current shrimp pot, P_1 is the shape in which it is impossible to locate the entrance on the upper surface, and P_4 provides the greatest interior volume, approximately 1.33 times that of the current pot.

A successful new design must have low height to maximize stability and large internal volume to hold a sizable catch, and yet it must be as small as possible for easy handling.

Pot size is more influenced by the slope length than the slope angle; therefore, manipulating the slope length will have greater effects on pot volume and stability.

From this viewpoint, P_4, with a 65° slope angle and a 48 cm slope length, provides the greatest volume;

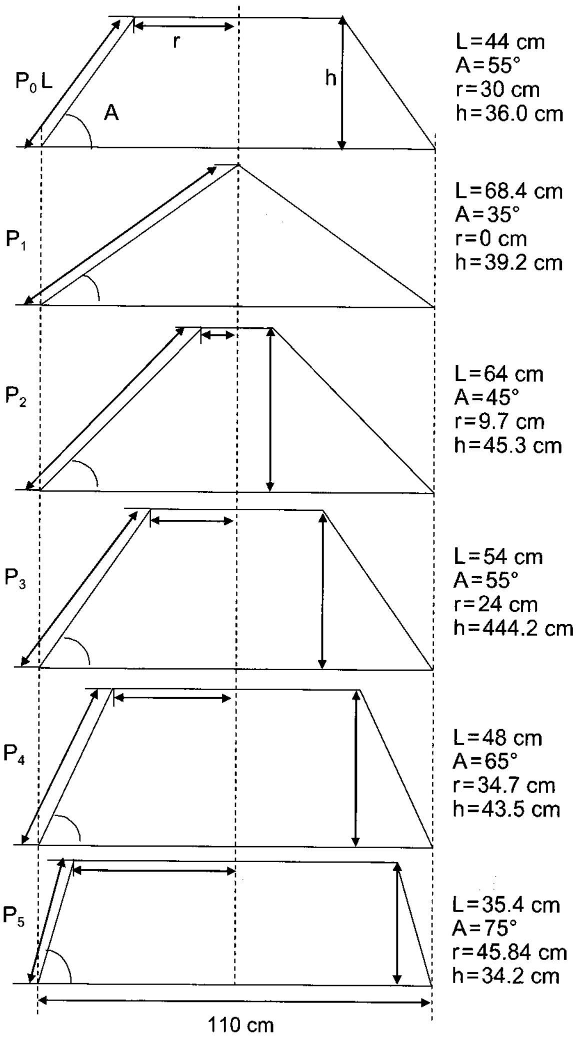

Fig. 9. Schematic representations of the new pot to be designed in accordance with l_{50}.
*P_0, the current shrimp pot used in the Sawara area of Hokkaido, Japan; L, slope length, θ, slope angle; γ, radius of the upper part of pot; h, height of pot.

however, due to its increased height, it is likely to be unstable underwater.

Conversely, P_5 with, a 75° slope angle and a 35.4 cm slope length, has greater volume yet lower height than the current commercial design and is expected to be stable underwater.

In the case of P_5, which has a greater volume than the current pot, it should be possible to reduce the base diameter without reducing the volume to less than that currently used. This should improve its ease of handling.

From this study, type P_5, with a 75° slope angle and a 35.4 cm slope length, is predicted to be the optimum design for reducing the likelihood of catching immature shrimp.

As shrimp can enter a pot by either swimming or walking, the size of individuals caught is affected not only by mesh size but also by pot shape (slope angle and length). Consequently, both shape and mesh size can be altered to manipulate the size of fishes caught and, as this study has shown, emphasis on the pot shape can improve catch selectivity.

Acknowledgments

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