

# Efficiency of the Korean Bottom Survey Trawl for Snow Crab *Chionoecetes opilio*

Jung Hwa Choi<sup>1\*</sup> and David A. Somerton<sup>2</sup>

<sup>1</sup>National Fisheries Research and Development Institute, Busan 619-900, Korea

<sup>2</sup>Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, Seattle, WA 98125, USA

## Abstract

The Korean bottom trawl survey was conducted using a trawl designed by the National Fisheries Research and Development Institute (NFRDI). The capture efficiency and size selectivity of this trawl for snow crab *Chionoecetes opilio* was investigated by experimental tows. An auxiliary sampling net (underbag) was attached beneath the trawl net to capture crabs escaping under the trawl footrope. Experimental tows were made by the same vessel speed (3.4 knots) as in the bottom trawl survey, but toing time was shortened from the standard 30 min to 10 min to reduce possible trawl distortion due to the high catch rate of mud and debris in the underbag. In averaged over 17 tows conducted between 110-383 m depth, trawl efficiency of both males and females combined increased from about 10% at 20 mm (carapace width) to about 70% at 100 mm, with a width of 50% capture equal to 78 mm.

**Key words:** Size selectivity, Trawl efficiency, Bottom trawl, Korean, Snow crab, *Chionoecetes opilio*

## Introduction

Bottom trawl surveys have been conducted in the Korean waters from the Yellow Sea to the East Sea each spring and fall since 2008, using a bottom trawl designed by the National Fisheries Research and Development Institute (NFRDI; see Appendix 1 for net diagram and other specifications). The main objective of these surveys was to provide indices of relative abundance of various commercially important species for use in stock assessments. Of these species the snow crab *Chionoecetes opilio* (J. C. Fabricius, 1788) supports a Korean fishery in the East Sea amounting to 1,000 ton year recently.

In other areas where snow crab fisheries occur, such as the Eastern Bering Sea, trawl survey estimates of relative abundance are used to tune or calibrate fishery management models to fit catch data (Turnock, 2010). Part of the model fitting process involves the estimation of survey catchability or the proportionality constant between a survey index of relative abundance and the true population abundance. However,

when a relative abundance time series is short, as it is for the Korean bottom trawl survey, it typically lacks sufficient information to adequately constrain model estimates of catchability (Somerton et al., 1999). In such situations, the variance of model outputs can be substantially reduced if the values of the catchability parameters in the model are set at or constrained by estimates obtained from experimental data. One approach to doing this is to conduct an experiment designed to provide data on trawl efficiency or the proportion of crabs in the trawl path which is retained by the net.

The efficiency of a bottom trawl is the result of both the design and performance of the trawl as well as the behavior of the target species (Dickson, 1993), but for snow crab it is believed that efficiency is primarily determined by escape-ment under the trawl footrope (Fujita et al., 2006). Previous experimental approaches to estimating trawl efficiency for crabs have used either an auxiliary sampling bag attached be-

**Open Access** <http://dx.doi.org/10.5657/FAS.2012.0337>

This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/3.0/>) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

pISSN: 2234-1749 eISSN: 2234-1757

**Received** 6 August 2012; **Revised** 27 September 2012

**Accepted** 9 November 2012

**\*Corresponding Author**

E-mail: [choijh@nfrdi.go.kr](mailto:choijh@nfrdi.go.kr)

neath the trawl (underbag) to capture the crabs escaping under the trawl footrope (Somerton and Otto, 1999; Weinberg et al., 2004; Dawe et al., 2010) or video techniques to estimate the absolute density of crabs in the trawl path (Watanabe, 2002; Watanabe and Kitagawa, 2004). In this paper we describe an experiment to estimate the efficiency of the NFRDI survey trawl for snow crab using the underbag approach.

## Materials and Methods

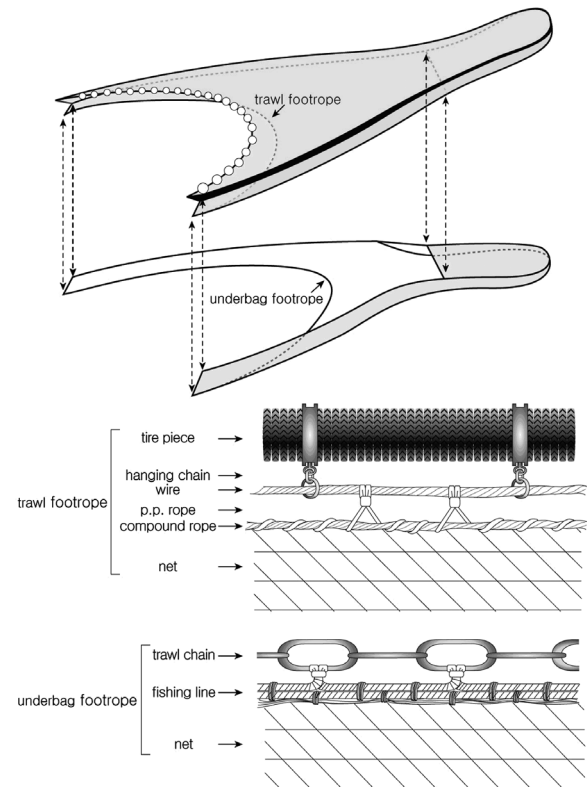
The NFRDI survey trawl has a 6-seam net constructed of 120 mm (stretched) polyethylene mesh in the main body of the net, 80 mm mesh in the intermediate part of the net, and 60 mm mesh in the cod end with a 20 mm cod end liner (see Appendix 1 for a net plan). The 50.5 m footrope is completely covered with 150 mm diameter rubber disks (Fig. 1). The trawl is spread using Jet2 type, 5.14 m<sup>2</sup> quadrangle doors, weighting 1,990 kg each (see Appendix 1 for a door plan). Door spread, averaged by tow, ranges from 73 to 86 m over the survey area, wing spread ranges from 18 to 21 m and vertical net opening ranges from 3 to 4 m.

The underbag is a 2-seam net fitted with small side panels, designed to help maintain steady footrope contact with the bottom during periods of intermittent contact by the trawl footrope (Fig. 1). The side panels and first bottom panel of the underbag are constructed of 120 mm polyethylene mesh and the last panel is constructed of 60 mm mesh constructed with a double layer of 60 mm mesh in the cod end with a 20 mm cod end liner. The 50.5 m long headrope is constructed of 19 mm diameter double braid polyester rope; the 53.7 m long footrope (6% longer than the trawl footrope) is constructed of 19 mm long link chain connected to the net mesh with 14 mm compound wire. A delta plate located just aft of each survey trawl wing extension is used to connect the front ends of the underbag headrope to the fishing line of the trawl footrope. The underbag was attached beneath the trawl as shown in Fig. 1.

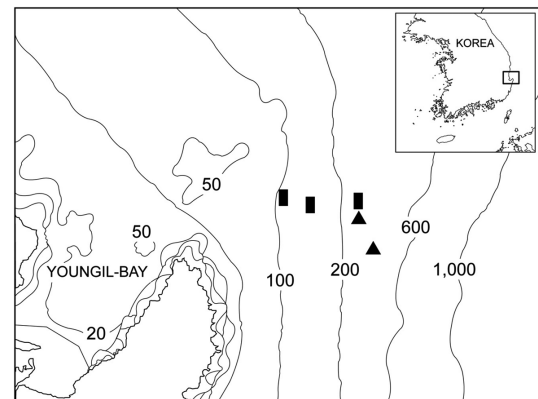
## The experimental trawling

Experimental trawling was conducted during March 14-18, 2011 and again during March 12-16, 2012, in the southern East Sea (Fig. 2), aboard the research vessel *Tamgu 20* using the NFRDI bottom trawl with the attached underbag. The experimental design was patterned after similar snow crab efficiency experiments conducted by Somerton and Otto (1999) for the Eastern 83/112 survey trawl and Dawe et al. (2010) for the Campelen 1800 trawl. All experimental tows were conducted using the same vessel speed (3.4 knots) as standard survey tows. However, the tow duration was reduced from the 30 min survey standard to 10 min because of concerns that high catch rates of mud and debris in the underbag might cause sufficient drag to distort the trawl. For all tows, door spread and

headrope height were acoustically measured using a Scanmar net mensuration system. In addition, on all eight tows conducted during the 2012, the bottom contact of both the trawl and the underbag footrope at their centers was measured using a small, custom-built, underwater tilt meter (Scott McEntire, Alaska Fisheries Science Center, personal communication, based on the Hobo Pendent G data logger; <http://www.onset-comp.com/products/data-loggers/ua-004-64>). Rapid changes in tilt angle indicated the times when the footropes contacted



**Fig. 1.** Footrope design for the trawl and the underbag and the method of attachment of the underbag to the trawl net.



**Fig. 2.** Locations of the trawl efficiency towing areas. Rectangles are areas sampled in 2011; triangles are areas sampled in 2012.

and left the bottom, however the values of tilt angle measured when the ropes were on the bottom differed between footropes because of the differences in their design.

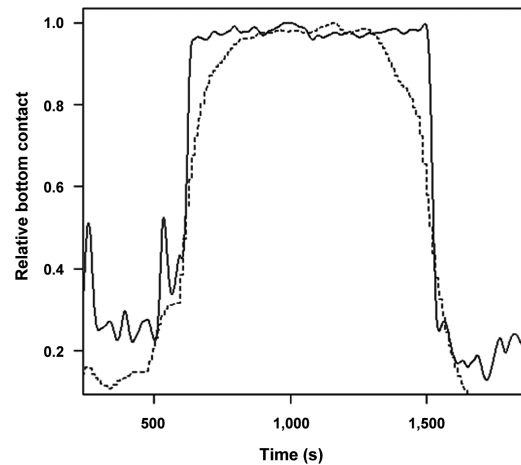
Catches from the trawl and underbag were sampled identically. All snow crab were removed from each catch, sorted by sex, subsampled by weight if the catch was excessively large, then measured for carapace width in mm using digital calipers.

### Modeling trawl efficiency

Assuming that all crabs in the path of the trawl are caught and that the entries of crabs into the trawl net or the underbag are independent random events, then the total catch in the trawl net can be modeled as a binomial process (Munro and Somerton, 2001). This was done by fitting a logistic function to the binomial outcome of each crab (*i.e.*, 1 for capture in the trawl and 0 for capture in the underbag), pooling the data over all hauls and including sex and carapace width, binned into 5 mm increments, as covariates. The model fitting was conducted using generalized linear modeling (function `glm` in the R statistical language; the R project in statistical computing, <http://www.r-project.org/>) with binomial error. Significance of the covariates was tested using analysis of deviance. If a covariate was not significant, the model was refit to the data omitting the covariate. To estimate the error about the mean efficiency function, taking into consideration the likely haul-to-haul variability in efficiency, the empirical 95% confidence intervals were approximated using bootstrapping (Efron and Tibshirani, 1993). This was done by repeatedly (500 times) choosing entire hauls of data in the bootstrap resampling. Then the 500 predicted values of mean trawl efficiency within each 5 mm interval of carapace width were then sorted into ascending order and the lower and upper empirical 95% confidence bounds were chosen as the 13th and 487th elements (95% of the bootstrap estimates are within these bounds).

### Evaluating the performance of the underbag

For the above approach to produce unbiased estimates of trawl efficiency two aspects of the performance of the underbag must be true: it must capture all crabs escaping under the trawl footrope, and must not physically distort or otherwise alter the normal fishing performance of the trawl. The first aspect was examined by measuring the bottom contact at the center of the underbag footrope using the small custom-built underwater tilt meter mentioned above. The underbag footrope contact sensor measured tilt angle in degrees from vertical (90 degrees indicated that the unit was exactly horizontal) every second, which provides a measure of both the strength and consistency of the bottom contact of the underbag footrope. The other aspect was evaluated by statistically testing, using a two sample *t*-test, whether the door spreads measured during the experimental tows differed from those measured



**Fig. 3.** Tilt angles measured by the bottom contact sensors (BCS) mounted at the center of the trawl footrope (dashed line) and the underbag footrope (solid line). Tilt angles were recorded once every second by the underbag BCS, but only once every second by the trawl BCS; both time series were subsequently smoothed. Note that the underbag footrope was just a chain, so that the BCS unit could lay flat on the bottom and therefore measure 90 degrees when the footrope was on the bottom; however, the trawl footrope was surrounded by 150 mm rubber disks, so the trawl BCS rested at an angle of about 60 degrees when the footrope rested on the bottom.

during normal bottom trawl survey tows over the same depth ranges using a two sample *t*-test.

### Determining the relative area swept by the trawl and the underbag footropes

The above analysis is based on the assumption that the areas swept by the trawl footrope and the underbag footrope were identical. Because the underbag was designed to span the full width of the trawl, potential differences in swept area would be the result of differences in tow length. The tow length could differ if the underbag footrope hung beneath the trawl footrope sufficiently far so that it contacted the bottom for a longer period of time (Weinberg et al., 2002). To examine whether this was occurring, a contact sensor was placed at the center of the underbag footrope to determine if the contact time of the underbag footrope was the same as that of the trawl footrope. Due to differences in the design of the trawl and underbag footropes and differences in the size and weight of the two bottom contact sensors, the angles associated with the ropes being fully on the bottom and off the bottom differed between sensors. Therefore, to improve the comparison between units, the angles measured by both units were therefore scaled by their maximum angle (*i.e.*, a value of 1.0 indicates that the rope was fully on the bottom). Rapid changes in the relative tilt angle were interpreted as representing times when the footropes first contacted and then left the bottom (Fig. 3).

## Determining the effect of the underbag on trawl geometry

To determine if the drag from the attached underbag altered the normal fishing performance of the trawl, we used a two-sample Student's *t*-test to statistically compare the door spreads measured during normal survey operations at depths between 150-350 m ( $n = 37$ ) with the values we obtained for the same depth interval during our experiment ( $n = 10$ ).

## Results

### Sampling

Seventeen stations were successfully sampled covering a depth range of 110 m to 383 m (Fig. 2). The 3,949 crabs measured (2,562 female; 1,378 male) (Table 1, Fig. 4) included nearly the entire carapace width range of females but excluded the largest mature males (Kon and Sinoda, 1992) because the intensity of the male-only fishery has reduced the abundance of males above the 50 mm minimum width limit (Fig. 4).

### Area swept by the footropes of the trawl net and underbag

The bottom contact sensor data from the trawl and underbag footropes showed rapid and distinct changes in relative tilt angle indicating when each footrope was on the bottom (Fig. 3).

### Effect of the underbag on trawl geometry

During the annual surveys in the 100-200 m depth range the door spread averaged 87.8 m (coefficient of variation [CV], 4.3%), while during our underbag experiment in the same depth interval, it averaged 78.7 m (CV, 7.6%). This represents a significant (two sample *t*-test,  $P < 0.001$ ) decrease in spread of about 10%.

### Trawl efficiency

Mean trawl efficiency did not differ between sexes ( $P = 0.062$ ), however efficiency significantly increased ( $P < 0.001$ )

with carapace width. Combined over both sexes, efficiency increased from about 0.1 at 20 mm to about 0.7 at 100 mm (Fig. 5), with a width at 50% capture (equivalent to the selection parameter  $L_{50}$  [Wileman et al., 1996]) of 78 mm. The logistic equation predicting the mean efficiency is:

$$P_c = \frac{1}{1 + \exp(2.54 - 0.033 \times CW)},$$

where  $P_c$  is the probability of capture and  $CW$  is carapace width in mm. The 95% empirical confidence intervals about  $P_c$  are quite broad (Fig. 5), indicating that there was considerable haul-to-haul variability in response to factors other than carapace width.

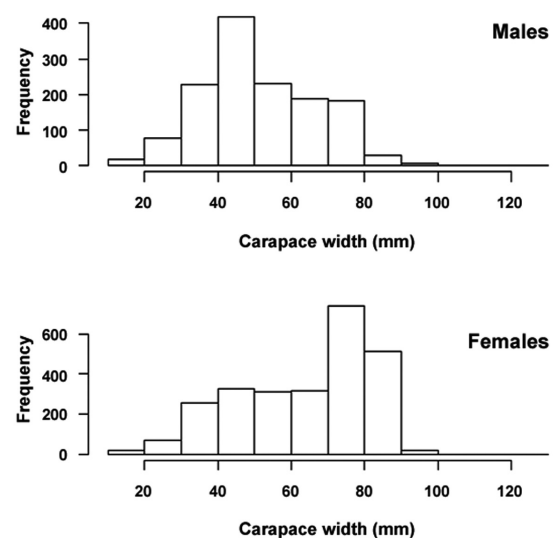


Fig. 4. The carapace width distribution, combined over all tows, by sex.

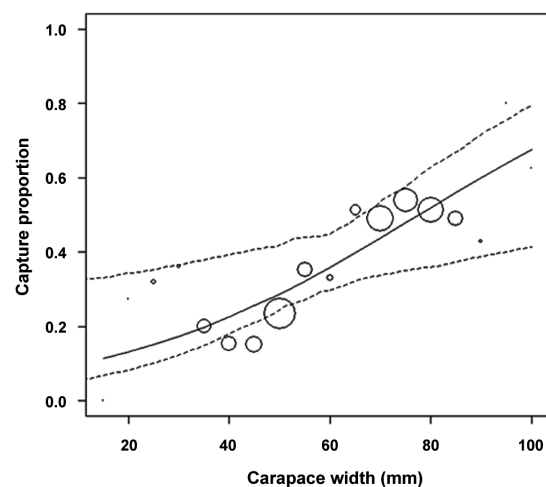


Fig. 5. Estimated efficiency of the National Fisheries Research and Development Institute (NFRDI) survey trawl for both sexes of snow crab as a function of carapace width. The dotted lines represent the 95% empirical confidence intervals. The circles represent the relative sample size within 5 mm intervals of carapace width.

Table 1. Number of tows and number of crabs captured by depth interval in the trawl efficiency experiment

Depth (m)	Number of tows	Males		Females		Total
		Main	Underbag	Main	Underbag	
100-200	7	79	516	106	476	1,177
200-300	8	164	106	767	714	1,751
300-400	2	176	337	168	331	1,021

## Discussion

To provide unbiased estimates of the efficiency of the NFRDI survey trawl for snow crab, the experimental approach we used required that the underbag successfully captured all crabs escaping under the footrope of the trawl net. To do this, the footrope of the underbag needed to be sufficiently heavy to penetrate the bottom substrate because snow crabs sometimes partially bury themselves. Such a heavy footrope, however, could lead to two sources of bias in the estimates of efficiency. First, it could increase the drag on the bottom sufficiently to distort the trawl and alter its normal fishing properties. One indication of this effect would be a decrease in door or wing spread when the underbag is attached (Somerton and Otto, 1999). In our case we found a decrease in door spread of about 10% when the underbag was attached to the NFRDI trawl. We do not know if this affected the trawl efficiency, however previous studies (Von Szalay and Somerton, 2005) have shown that reductions in wing spread can increase footrope contact, potentially increasing trawl efficiency for epibenthic animals such as snow crab. Second, a heavy underbag footrope could hang below the trawl footrope so far that it touches the bottom before, and leaves the bottom after, the trawl footrope, which would result in the underbag having a greater sweep distance than that of the trawl footrope. Similar to the studies of Weinberg et al. (2002) and Dawe et al. (2010), this was examined by attaching bottom contact sensors to the centers of both the trawl and underbag footropes to simultaneously measure the times of bottom contact. Although there is some uncertainty in interpreting exactly when each footrope started and finished catching snow crab, the change in tilt angle was sufficiently rapid (Fig. 3), that it appeared that the two footropes contacted the bottom nearly synchronously. Thus unlike in the study of Weinberg et al. (2002), the underbag design used in our study did not result in a difference in tow length between the trawl and underbag footrope.

Unlike previous studies of snow crab trawl efficiency (Somerton and Otto, 1999; Dawe et al., 2010), we found no difference in trawl efficiency between sexes. One possible explanation for this is that our samples included few large males (Fig. 4) which have a maximum width of about 100 mm. This maximum includes the maximum width of adult females but is considerably less than the maximum width of adult males of 120 mm (Kon and Sinoda, 1992). Thus, we estimated the efficiency of the NFRDI survey trawl for snow crab in the areas sampled by our experiment. However, to be useful in fisheries management models, an efficiency estimate must represent the average conditions over the survey area, that is, it must be an estimate of survey efficiency or catchability rather than simply a measure of trawl efficiency in the sampled area. The difference between the two arises when efficiency is spatially variable due to depth (Von Szalay and Somerton, 2005) or bottom type (Dawe et al., 2010). In such cases, an unbiased estimation of survey catchability requires a random selection

of sampling sites over the entire survey area, to capture the range of environmental conditions that could influence trawl efficiency. The results of our experiment clearly do not meet this criterion.

Besides providing estimates of catchability for management models, trawl efficiency experiments can be used in the calculation of absolute abundance in a survey area, but this requires the additional effort of obtaining trawl swept area estimates of abundance. This, in turn, requires estimation of the effective width of the trawl path and the effective tow length. Based on the video observations of Fujita et al. (2006), snow crabs are not herded by the trawl bridles, therefore the effective width of the trawl path (Dickson, 1993), is equal to the horizontal distance between the wing tips of the trawl net. The tow length, however, is often longer than the distance covered between the winch break set and haul back, and typically varies with depth (Von Szalay, 2004), because a considerable amount of towing cable must be retrieved before the trawl starts to leave the bottom. This effect is important for the NFRDI trawl and the trawling protocols used because the footrope can leave the bottom as much as 6 min after haulback is started.

## Acknowledgments

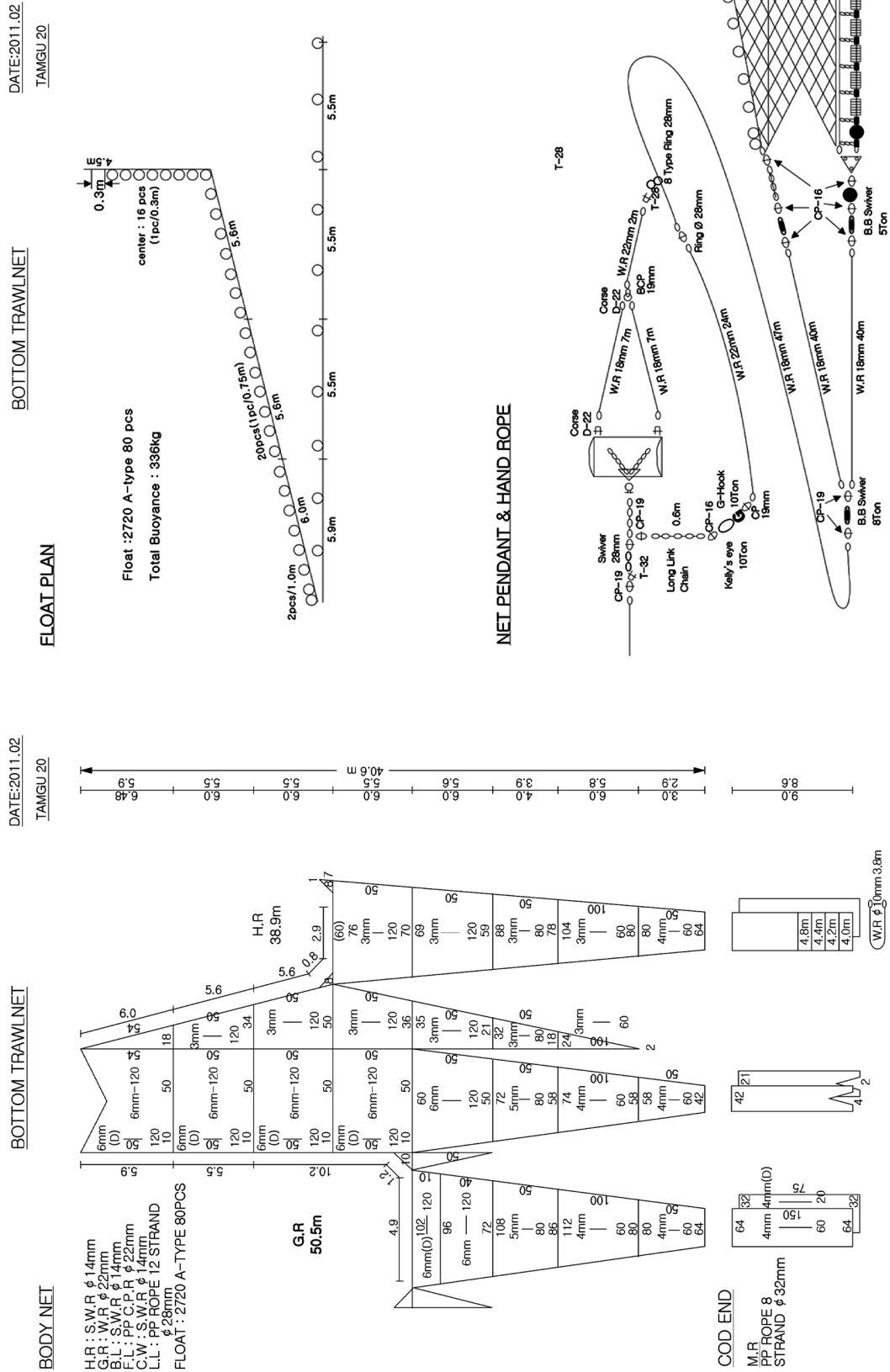
This work is funded by a grant from the National Fisheries Research and Development Institute (RP-2011-FR-026) and Korea-US Joint project. We express our thanks to Ken Weinberg for reviewing the manuscript. We also thanks to the captain and crew of RV *Tamgu* 20 who contributed to the success of our experiment.

## References

- Dawe EG, Walsh SJ and Hynick EM. 2010. Capture efficiency of a multi-species survey trawl for snow crab (*Chionoecetes opilio*) in the Newfoundland region. *Fish Res* 101, 70-79.
- Dickson W. 1993. Estimation of the capture efficiency of trawl gear. I: Development of a theoretical model. *Fish Res* 16, 239-253.
- Efron B and Tibshirani RJ. 1993. *An Introduction to the Bootstrap*. Chapman and Hall, Boca Raton, FL, US.
- Fujita K, Watanabe T and Kitagawa D. 2006. Behavioral responses of the snow crab *Chionoecetes* spp. to the groundrope of a bottom trawl. *Nippon Suisan Gakkaishi* 72, 695-701.
- Kon T and Sinoda M. 1992. Zuwai crab population. *Mar Behav Physiol* 21, 185-226.
- Munro PT and Somerton DA. 2001. Maximum likelihood and non-parametric methods for estimating trawl footrope selectivity. *ICES J Mar Sci* 58, 220-229.
- Somerton DA and Otto RS. 1999. Net efficiency of a survey trawl for snow crab, *Chionoecetes opilio*, and Tanner crab, *C. bairdi*. *Fish Bull* 97, 617-625.
- Somerton D, Ianelli J, Walsh S, Smith S, Godo OR and Ramm D. 1999.



- Incorporating experimentally derived estimates of survey trawl efficiency into the stock assessment process: a discussion. ICES J Mar Sci 56, 299-302.
- Turnock BJ. 2010. Eastern Bering Sea snow crab. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. North Pacific Fishery Management Council, Anchorage, AK, US, pp. 31-124.
- Von Szalay PG. 2004. The effect of improved footrope contact measurements on trawl area swept estimates. Fish Res 69, 389-398.
- Von Szalay PG and Somerton DA. 2005. The effect net spread on the capture efficiency of a demersal survey trawl used in the eastern Bering Sea. Fish Res 74, 86-95.
- Watanabe T. 2002. Method to estimate the population density of the snow crab *Chionoecetes opilio* using a deep-sea video monitoring system on a towed sledge. Jpn Agric Res Q 36, 51-57.
- Watanabe T and Kitagawa D. 2004. Estimating net efficiency of a survey trawl for the snow crabs (*Chionoecetes opilio* and *C. japonicus*) using a deep-sea video monitoring system on a towed sledge. Nippon Suisan Gakkaishi 70, 297-303.
- Weinberg KL, Somerton DA and Munro PT. 2002. The effect of trawl speed on the footrope capture efficiency of a survey trawl. Fish Res 58, 303-313.
- Weinberg KL, Otto RS and Somerton DA. 2004. Capture probability of a survey trawl for red king crab (*Paralithodes camtschaticus*). Fish Bull 102, 740-749.
- Wileman DA, Ferro RST, Fonteyne R and Millar RB. 1996. Manual of Methods of Measuring the Selectivity of Towed Fishing Gear. ICES Cooperative Research Report No. 215. ICES Working Group, Copenhagen, DK.



**Appendix 1.** Net and door plans for the National Fisheries Research and Development Institute (NFRDI) bottom trawl.