AN EVALUATION OF THE EFFECTIVENESS OF MODIFIED CRAB POTS FOR INCREASING CATCH OF PACIFIC COD AND DECREASING CATCHES OF HALIBUT AND CRAB

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DISCLAIMER

The Alaska Department of Fish and Game (ADF&G) does not endorse any of the commercial products mentioned in this report. All products used in this study were supplied by the manufacturers and installed under the express instructions of the their manufacturers.

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ABSTRACT

The purpose of the study was to evaluate the effectiveness of a variety of crab pot modifications for increasing the catch of Pacific cod and decreasing the bycatch of halibut and crab. During September and October 1990, seven types of modified crab pots and one type of unmodified crab pot were fished during a 26 day period. A total of 991 pot lifts were made. Catches were sampled for species composition and length frequency data. Pots modified with fish retention devices had statistically significantly higher catches of Pacific cod than pots without such devices. In addition, pots with retention devices tended to have the lowest catches of halibut, compared to pots without retention devices. Tunnel eye opening dimensions at least as small as 8 x 7 inches may be used to minimize bycatch of halibut without significantly reducing the catch of Pacific cod. More than 90 % of the halibut in all treatments were judged to be in "excellent" condition. Tanner crab were not caught in sufficient numbers to adequately evaluate the effectiveness of the pot modifications for decreasing bycatch of Tanner crab.

INTRODUCTION

Pot fishing for groundfish in Alaska waters began in the early 1980's with long lining of small pots for sablefish (*Anoplopoma fimbria*). The first use of crab pots for harvesting Pacific cod in the Kodiak Island area began in 1985, primarily as a means to utilize crab gear between crab seasons. However, as defined in state regulations, king and Tanner crab pots are not legal gear for harvesting groundfish nor are groundfish pots specifically defined (Alaska Department of Fish and Game 1990). Concern over the use of unmodified crab gear led ADF&G to develop a special-use permit for **modified** crab pot gear that would allow fishermen to utilize this gear inside State waters with the intent of preventing bycatch of crab. A primary condition of the permit required fishermen to modify the tunnel eye opening by dividing it into smaller, individual openings of 30 inches or less in perimeter. This modification created a pot that no longer could legally be defined as a crab pot. By late 1989 the local crab fleet began looking at the pot cod fishery as a legitimate target fishery that could supplement the declining king and Tanner crab fisheries. The cod fishery peaked in 1990 when over 13 million pounds of cod valued at almost three million dollars was landed (Figure 1).

Several retention devices, originally developed for the brown king crab (*Lithodes aequispina*) fishery to keep the crab in the pots, have also been incorporated in pots for targeting Pacific cod. Some of the retention devices included *Gotya*, *Neptune*, and *Norsol* products. The Alaska Fisheries Development Foundation (AFDF) became interested in testing these commercially-made devices for their effectiveness in retaining trapped cod. Additionally, as prohibited species bycatch concerns in the Gulf of Alaska continued to dominate groundfish management, both AFDF and ADF&G wanted to evaluate the extent of halibut and crab bycatch in this gear type. ADF&G was contacted to conduct the project and produce the final report because of previous at-sea observer work on pot vessels during 1987-89.

The purpose of this study was to compare catches of Pacific cod and prohibited species (halibut and crab) among crab pots modified with three commercial retention devices, four sizes of tunnel eye openings and two orientations of tunnel eyes.

METHODS

Experimental Design

The study was conducted as a generalized randomized block design, with three experimental units per treatment-block combination (Fig. 2., Steel and Torrie, 1980, Addelman, 1969).

Treatments - The treatments included a standard 6'x 6'x 3' Tanner crab pot and seven unique modifications to the tunnel eyes of the crab pots. The modifications were designed to 1) promote the entry and retention of Pacific cod in the pots and/or 2) prevent or minimize entry of halibut and crab (primarily King and Tanner crab) into the pots. The principal methods for promoting entry and retention of Pacific cod were to orient the pot tunnel eye vertically (rather than obliquely, as in a standard crab pot) and to install one of three types of retention devices in the openings. These devices are intended to allow cod to enter pots and minimize or prevent the fish from leaving the pots. The principal method for excluding halibut and crab was to reduce the size of the tunnel eye openings by installing rigid, vertical dividers spaced equidistantly across the tunnel eye at predetermined spacings. Specifically the treatments included:

Treatment 1 - Crab pot - A standard crab pot with an oblique tunnel eye (Figure 3) and no rigid dividers in the tunnel eye. Tunnel eye dimensions = 8" X 36".

Treatment 2 - One hole - A crab pot with a vertical tunnel eye (Figure 4) and no rigid dividers in the tunnel eye. Tunnel eye dimensions = 8" X 36".

Treatment 3 - Two holes - A crab pot with a vertical tunnel eye and one rigid divider in the tunnel eye. Dimensions of each of two holes formed by the single division of the tunnel eye = 8" X 18".

Treatment 4 - Three holes - A crab pot with a vertical tunnel eye and two rigid dividers in the tunnel eye. Dimensions of each of three holes formed by the two divisions of the tunnel eye = 8" X 11.5".

Treatment 5 - Five holes - A crab pot with a vertical tunnel eye and four rigid dividers in the tunnel eye. Dimensions of each of five holes formed by the four divisions of the tunnel eye = 8" X 7".

Treatment 6 - Three holes + 'Gotya' - Treatment 4 (Three holes) further modified by the inclusion of a 'Gotya' brand fish inclusion device (Fig. 5).

Treatment 7 - Three holes + 'Neptune' - Treatment 4 (Three holes) further modified by the inclusion of a 'Neptune' brand fish inclusion device (Fig. 6).

Treatment 8 - Three holes + 'Norsol' cod sock - Treatment 4 (Three holes) further modified by the inclusion of a net cod sock fish retention device.

Each treatment was represented in three pots, for a total of 24 pots at each location.

Blocks - The blocks for the experimental design were the nine different locations where fishing occurred (Fig. 7).

Field Methods

The study area included nine locations in the Kupreanof Strait, Viekoda Bay and Cape Uganik areas of northern Kodiak Island (Figure 7). Ocean depths fished in these areas ranged from 20 to 80 fathoms.

The charter vessel was a 78-foot steel-hulled commercial crabber equipped with facilities for three crew and 2-3 biologists and included all necessary pots, lines and buoys. Retention devices were supplied by the manufacturers.

The 24 pots used in the study were set sequentially, usually in two separate strings of twelve pots each, at the individual locations. The order of each pot in the sequence was randomly assigned, using a unique randomization for each location. At each location the pots were spaced from 0.2 to 0.3 mile apart. Pots were fished repeatedly from four to six times at a location, before being moved, one string at a time, to the next location (block). All pots at any one location were fished the same number of times. Thus, part of the "block effect" included the number of times the pots were fished. It was necessary to move the pots in 12-pot strings, because of the limited deck space aboard the vessel and to allow randomization of the pots at each new location. Pots were hauled twice daily except when prevented by weather or other factors.

Species composition and length frequency data were recorded for each pot. Halibut were counted, measured for length and returned to the sea. Pacific cod were counted, measured for length and total weights were recorded before releasing them. The crab species were sexed, counted, measured and total weights of each sex were taken before releasing them. Other species were counted and, when time permitted, weighed before disposing of them. Occasionally subsamples of the total catch of a species in a pot would be weighed to obtain average weights for later expansion if the samplers fell behind or the catch was large. Halibut lengths were converted to weights using a length to weight conversion table after sampling was done.

In all the pots tested, one quart jars and small onion sacks were filled with herring and used for bait. Bait jars were hung in the center of the pot and rebaited each evening. The onion sacks were suspended in the center of the pot with a rubber tie and hook for attachment to the top and bottom of the pot and were changed with each set.

Pots with tunnel eye dividers (Treatments 3 - 8) were rigged using four to six strands of heavy seine twine bundled together with a separate strand. The twine was tied vertically across the 7" x 36" tunnel eyes forming equal sized individual openings. An exception to this was the gear rigged with *Gotyas* in which the *Gotya* itself had galvanized metal crossbars about one half inch wide. All retention devices used in the study were orange in color, although other colors were available.

The *Gotya* insert is constructed of interlocking injection-molded polyethylene fingers that are alternately positively and negatively buoyant in sea water. The fingers swing inward but not outward, creating a one-way opening. The frame is steel with a polyester coating custom-made to fit any tunnel eye. The *Gotya* is installed in the each tunnel eye with four hose clamps, one in each corner (Figure 5).

The *Neptune* retention device is also a one-way tunnel device constructed from flexible plastic. The interlocking fingers are attached to a black plastic tube frame which is fastened to the tunnel eye using hose clamps, plastic wire ties or seine twine (Figure 6). Both *Neptune* and *Gotya* devices are fastened flush to the inside of the tunnel eye with the fingers angled into the interior of the pot; the tunnels are then tied into the vertical position using heavy seine twine.

The *Norsol* insert consists of two triangular pieces of one-inch nylon web sewn together on the sides to form a funnel-shaped cod sock. The ends are left open, and the large end is sewn around the frame of the tunnel eye with the small end drawn inside the pot and tied into position with the smaller open end of the sock hanging loose. This lets cod into the pot but makes it difficult for them to find their way out. These devices can be rigged many different ways depending upon application and effectiveness. For the purpose of this study, the socks were shortened by about 12 inches to fit the pots. Opposing socks were then tied together with a piece of twine about 10 to 12 inches long at a point about 12 inches from the end of the sock. This left the last 12 inches hanging loose near the center of the pot creating a flap that loosely closes the end of the sock.

The fishing operation was conducted in a manner as similar to an actual pot fishing operation as possible. Specifically, the skipper of the vessel was encouraged to set the pots in locations and depths where he would expect to maximize catch of cod. The approach also entailed repeatedly fishing the pots at each specific location until the skipper deemed the catch-per-unit effort to be inadequate before moving to the next location.

Statistical Analyses

Analyses of covariance (ANCOVA) were used to test the null hypotheses:

> H_{01}: No differences in the mean cumulative catch of Pacific cod among the eight treatments.
>
> H_{02}: No differences in the mean cumulative catch of halibut among the eight treatments.

The random variable used for testing these hypotheses was the cumulative catch per pot, across the multiple sets for each pot at each location. For example, at Location 2 each pot was set four times. The variable used in the tests of hypotheses was the sum of the catches from the four, separate sets. The number of sets at each location ranged from four to six.

When results of ANCOVAs indicated significant overall treatment differences, Scheffe's tests were used to test for differences among individual treatments.

Tests of hypotheses were not conducted for crab catch because the catch of crabs was so small. Sufficient numbers of crabs were caught only at a single location, Location 8.

The linear model used for testing these hypotheses was:

$$y_{ijk} = \mu_{..} + \alpha_i + \beta_j + \alpha\beta_{ij} + \beta_0(x_{...} - x_{ijk}) + \varepsilon_{ijk}$$

where: y_{ijk} = cumulative catch of cod or halibut for treatment i (i = 1,2,...,8), block j (j = 1,2,...,9), pot k (k = 1,2,3).

$\mu_{..}$ = the overall mean catch of cod or halibut

α_i = the effect due to treatment i

β_j = the effect due to block j

$\alpha\beta_{ij}$ = the effect due to interaction between treatment i and block j.

β_0 = the regression coefficient for the relationship between catch and soak time.

$x_{...}$ = the mean soak time

x_{ijk} = the soak time for pot k, treatment i, block j.

ε_{ijk} = random error

Soak time was used as a covariate to evaluate the influence of soak time on catch of Pacific cod and halibut, and to increase the power of the tests for differences among the eight treatments. To further evaluate the influence of soak time on catch, we performed individual regression analyses for each treatment. For these treatment-specific analyses, we regressed both cumulative catch per pot per location and catch per pot, per set, per location, against soak time.

In addition to hypotheses H_{01} and H_{02}, we tested hypotheses to determine whether any of the pot modifications had an effect on the mean size of individual Pacific cod or halibut. Null hypotheses tested were:

H_{03}: No differences in mean length of individual Pacific cod among the eight treatments.

H_{04}: No differences in mean length of individual halibut among the eight treatments.

Analyses of variance (ANOVA) were used to test these hypotheses. The linear model for testing these hypotheses was:

$$y_{ijk} = \mu_{..} + \alpha_i + \beta_j + \alpha\beta_{ij} + \varepsilon_{ijk}$$

where: y_{ijk} = length of individual cod or halibut k, for treatment i (i = 1,2,...,8), block j (j = 1,2,...,9).

$\mu_{...}$ = the overall mean length of cod or halibut

α_i = the effect due to treatment i

β_j = the effect due to block j

$\alpha\beta_{ij}$ = the effect due to interaction between treatment i and block j.

ε_{ijk} = random error

As indicated by this model, and in contrast to the ANCOVAs, catch from individual pots within each treatment-block combination were not used for the final ANOVAs. Rather, the mean weights of individual halibut, calculated as the the total weight of halibut from *all* pots within a treatment-block combination divided by the total number of halibut in that treatment-block combination, were used for the ANOVA. This approach was used because some pots within certain treatment-block combinations did not have any halibut catch; most notably Treatment 8. An initial ANOVA using multiple pots per treatment-block combination, rather than a single mean weight for each treatment block combination, resulted in an unbalanced design and the inability to estimate the (least square) mean for Treatment 8. For consistency and to allow direct comparison of results, the ANOVA for cod was conducted the same way.

Regression analyses were used to try to define the relationship between average size of Pacific cod or halibut, and the width of the tunnel eye openings. Catches from Treatments 2, 3, 4 and 5 were used for these analyses.

Bycatch rates were calculated as the ratio of halibut catch, in kg to cod catch, in metric tons.

We also analyzed data on halibut condition to determine if there were any differences among the treatments with respect to condition. Fisher's Exact Probability Test was used to test the null hypothesis:

> H_{05}: No differences in the proportions of halibut in poor or excellent condition, among the eight treatments.

Although three condition categories were recorded in the field, "excellent", "poor" and "dead", we collapsed the "poor" and "dead" categories into a single category ("poor") for analysis. This collapsing was necessary to minimize the number of contingency table cells with 0 values, and to overcome computer memory limitations to allow the application of Fisher's Exact Probability Test.

Unless otherwise noted, alpha levels of 0.05 were used to determine statistical significance in tests of hypotheses. The Statistical Analysis System (SAS, 1987) was used in conducting all aforementioned statistical analyses. The GLM (general linear models), REGR (regression), NLIN (non-linear regression) and FREQ (frequency tables) procedures of SAS were used in the analyses.

Plots of cod and halibut weight per pot versus depth of pot were examined to identify relationships between catch and pot depth.

As indicated previously, analyses of crab data were limited to obtaining estimates of mean cumulative catch of Tanner crab, because crab were caught at so few locations.

RESULTS

Hypothesis H_{01} - Mean cumulative catches of Pacific cod differed significantly (P=0.0001, $F_{7,143}$=54.1) among the eight treatments. Mean catches ranged from a high of 149.2 kg, for Treatment 6 (Three holes + 'Gotya') to a low of 8 kg for Treatment 3 (Two holes)(Fig 8, Table 1).

Based on the ANCOVA there was no significant relationship between mean cumulative catch of Pacific cod and cumulative soak time (P=0.98, $F_{1,143}$=0.00). Individual regression analyses of cumulative catch versus cumulative soak time for each of the eight individual treatments also indicated no statistically significant, linear relationships between cod catch and soak time (P=0.28 - 0.86, $F_{1,25}$=0.031 - 1.28). Further, examination of cumulative catches plotted against cumulative soak times did not suggest well-definable, non-linear relationships between catch and soak time.

Because there was no significant relationship between mean cumulative catch and cumulative soak time, mean catches are not adjusted for soak time as a covariate. Additionally, not adjusting for the covariate permits the application of a multiple comparison test, such as Scheffe's.

With respect to cod catch, three groups of treatments emerged from the results of Scheffe's test. Treatments within the following groups did not differ significantly from one another, but did differ significantly from treatments outside the group. The group with the highest mean cumulative catches included Treatments 6 (Three holes + 'Gotya', mean = 149.2 kg; Table 1.) and 7 (Three holes + 'Neptune', mean = 116.2 kg). The second highest group included only one treatement, Treatment 8 (Three holes + cod sock, mean = 67.8 kg). The group with the lowest catches included Treatments 1 through 5. Mean cumulative catches within this group ranged from a high of 22.4 kg for Treatment 1 (crab pot) to a low of approximately 8 kg for Treatment 3 (Two holes).

In addition to significant differences among treatments, mean cumulative catch of Pacific cod differed significantly among the blocks (locations; P=0.0001, $F_{8,143}$=5.39). There was no significant interaction between treatment and block effects (P=0.1, $F_{56,143}$=1.32).

Hypothesis H_{02} - Mean cumulative catch of halibut also differed significantly among the treatments (P=0.0001, $F_{7,143}$=21.2). Mean catches ranged from a high of 30.92 kg for Treatment 1 (crab pot) to a low of 1.8 kg for Treatment 8 (Three holes + cod sock; Fig. 9, Table 1).

As with cod, there was no significant relationship between halibut catch and soak time (P=0.34, $F_{1,143}$=0.91), based on results of the ANCOVA. Regression analyses for individual treatments indicated a weak (r^2=0.15), but statistically significant (P=0.048, $F_{1,25}$=4.3), linear relationship between halibut catch and soak time only for Treatment 8 (Three holes + cod sock). The relationships were not significant for the other seven treatments (P= 0.28 - 0.97, $F_{1,25}$= 0.001 - 1.2). Because of the largely non-significant, linear relationships between halibut catch and soak time, mean halibut catches were not adjusted for the covariate, soak time. As with cod, plots of halibut catch versus pot soak time did not suggest any distinct non-linear relationships between the two variables.

Results of Scheffe's test for halibut catch are summarized in Table 1. Generally, those treatments with fish inclusion devices had lowest catches of halibut compared to the treatments without the devices. The exception to this tendency was Treatment 5 (Five holes), which had the second lowest catch of halibut (mean = 4.86 kg).

As with cod catch, there were significant differences in halibut catch among the nine locations or blocks (P=0.005, $F_{8,143}$=2.9). There was no statistically significant interaction between treatments and blocks (P=0.99, $F_{56,143}$=0.58).

For comaprison, mean cumulative catches for both halibut and cod are depicted in Figure 10.

Hypothesis H_{03} - A test associated with this hypothesis indicated a significant interaction (P=0.0001, $F_{56,3770}$) between treatments and locations (blocks) for cod lengths. As a result, tests of simple effects were conducted, wherein Hypothesis H_{03} was tested individually for each of the nine locations. Among the nine individual locations, mean cod lengths varied from a high of 71.3 cm for the Treatment 1 (Crab pot) at Location 2, to a low of 52.4 cm for Treatment 4 (Three holes), also at Location 2 (Table 2). Among the nine locations, no consistent order was apparent in the mean lengths of cod. At five of the nine locations (blocks) there were statistically significant differences (P=0.0002 - 0.0054) in the mean lengths of cod among the eight treatments (Table 2). In addition to the statistically significant differences among treatments at the four locations noted in Table 2 (Locations 2, 3, 8 and 9), the overall ANOVA for Location 4 indicated statistically significant differences among two or more of the treatments. However, results of Tukey's studentized range test did not indicate which treatments differed in mean cod length at Location 4.

Hypothesis H_{04} - For this analysis, Treatment 8 (Three holes + 'Norsol' cod sock) was excluded because of the small numbers of halibut retained by pots with this treatment, among the nine locations (range: 0 - 5). Among the remaining seven treatments, least square mean lengths of individual halibut varied from a high of 72.4 cm for Treatment 1 (crab pot) to a low of 62.1 kg for Treatment 5 (Five holes). There were statistically significant differences in least square mean halibut lengths among the seven treatments ($P=0.0001$, $F_{6,554}=4.97$, Table 3). There was no statistically significant interaction ($P=0.16$, $F_{48,554}=1.21$) between treatments and locations (blocks). There were no statistically significant differences ($P=0.34$, $F_{8,554}=1.13$) in least square mean halibut lengths among the nine locations. Tests for differences among least square mean lengths (rather than arithmetic mean lengths) were used because the ANOVA was based on a randomized block design and there were unequal numbers of halibut caught in pots for the various treatments.

Hypothesis H_{05} - The percent of halibut in "excellent" condition ranged from a high of 99.3 % for Treatment 3 (Two holes) to a low of 91.7 % for Treatment 8 (Three holes + 'Norsol' cod sock). Therefore the percentage of halibut in either "poor" or "dead" condition (these two categories were combined for this analysis) ranged from a high of 8.33 % for Treatment 8 (Three holes + 'Norsol' cod sock) to a low of 0.72 % for Treatment 3 (Two holes). However, there were no statistically significant differences ($P=0.104$) among the treatments with respect to percentages of halibut in "excellent" or "poor/dead" condition.

The relationship between halibut catch and width of tunnel eye openings fit a negative exponential growth function reasonably well (Figure 11). However, we were unable to define the relationship between cod catch and tunnel eye width using the negative exponential growth function or other readily-identifiable function.

Bycatch rates of halibut ranged from a high of 2509.4 kg of halibut per metric ton of cod caught, for Treatment 3 (modified pot with two 8" x 18" tunnel eye openings) to a low of 26.5 kg of halibut per metric ton of cod caught, for Treatment 8 (modified pot with 'Norsol' cod sock and three 8" x 11.5" tunnel eye openings)(Table 4).

Mean cumulative catches of Tanner crab ranged from a high of 6.9 kg for Treatment 8 (Three holes + 'Norsol' cod sock) to a low of 0.17 kg for Treatment 3 (Two holes). Tanner crabs were caught at six of the nine locations (Locations 2, 3, 5, 7, 8 and 9). However, at most of those six locations, Tanner crabs were caught in very low numbers. Tanner crabs were caught in Treatment 1 (Crab pot) at only three locations (Locations 3, 7 and 8). Crabs were caught in in each of the eight treatments only at Location 8.

Based on examination of plots of cod and halibut catch versus pot depth, no readily discernible relationship was evident between catch and pot depth.

DISCUSSION

Catches measured in this study represent the cod and halibut that were caught *and* retained. The pot modifications used in the study may have served both functions, to varying degrees, with the two species. For example, cod catch in Treatments 6 - 8, (with fish retainers and three tunnel eye holes) significantly exceeded the catch in Treatment 4 (three tunnel eye holes). Presumably the difference in catch is attributable to the fish retention capability of the devices, the purpose for which the devices are intended.

While the primary purpose of reducing the width of tunnel eye holes was to reduce the bycatch of halibut and crab, the dividers may also promote retention of fish. This is suggested by the trend of greater cod catches with increased numbers of divisions in the tunnel eye. This is only an apparent trend however, since there were no significant differences among Treatments 2 - 5 in mean cumulative cod catch. However, it is notable that Treatment 5, with tunnel eye openings of 8" X 7" caught and retained more cod than the other three treatments with wider tunnel eye openings. Also noteworthy is the fact that Treatment 5 had the second lowest catch of halibut; second only to Treatment 8 (Three holes + cod sock).

Although the intended function of the retention devices is to keep fish in pots once they have entered, the retainers may also tend to prevent halibut from entering pots. Although the differences were not significant, the three treatments (6, 7 and 8) with retention devices and tunnel eyes with three holes had lower mean cumulative catches than Treatment 4, with three holes, but no fish retainers.

Although the difference was not statistically significant, 'Gotya' retainers had greater cod catch than 'Neptune' retainers. However, the 'Gotya' retainers also had greater halibut catch than did the 'Neptune' retainers. Again, these differences were not statistically significant. The 'Gotya' and 'Neptune' devices significantly exceeded the 'Norsol' cod sock in catch and retention of cod. However, there is inherently more variability in how the cod socks could be installed in pots. Modifications to the cod sock might result in increased catch and retention of cod.

The condition of the great majority of halibut (> 90 %) in this study was judged to be "excellent" regardless of the treatment. Several factors may have contributed to this condition. Soak times were rarely over 24 hours. Minimizing time in pots would serve to reduce injuries associated with predation (e.g. by sand fleas or octopus). In addition, cod catches were relatively low throughout the study. This may have minimized injuries to halibut associated with full pots and attendant battering in the pots. In general, measurements and condition assessment was done on any halibut before other species, serving to minimize time on deck for halibut.

Results of the ANCOVAs suggest that a critical minimum tunnel eye width, which may reduce mean cod catch, was not achieved in this study. It is possible that tunnel eye openings with dimensions less than 8" X 7" could be used without significantly reducing the total catch of cod. However results of ANCOVAs and non-linear modelling of the relationship between halibut catch and width of tunnel eye openings, suggest that a critical minimum width for halibut may have been at least bracketed by the tunnel eye widths used in this study, at least for halibut of the sizes encountered under the conditions of this study. This is suggested by the general decrease in halibut catch with decreasing tunnel eye width and the significantly lower halibut catch in Treatment 5 (Five openings) compared to Treatment 3 (Two openings). For cod, it can be assumed that there would be critical tunnel eye dimensions, less than or equal to 7" x 8", below which cod catch would be reduced.

It appeared that fish retainers enhanced the mean catch of Pacific cod and may have also tended to decrease the bycatch of halibut. Division of tunnel eyes into holes 8" X 7" may have also tended to increase catch of cod and decrease catch of halibut. However, since fish retainers were not combined with 8" X 7" tunnel eye holes, it is not clear what effect this combination would have had on cod or halibut catch. While smaller tunnel eye holes may serve some fish-retention function in the absence of specific fish retainers, the addition of fish retainers would probably override any fish retention function of the tunnel eye dividers. However, the tunnel eye holes with smaller dimensions would probably still serve to reduce bycatch of halibut.

The various treatments resulted in differing mean cumulative catches of cod, mainly by influencing the numbers of fish caught rather than the weight of individual cod caught. This is shown by the fact that there were no significant differences in mean weights of individual cod fish among the eight treatments. In contrast, the differing mean cumulative weights of halibut caught by the different treatments may be attributable, in part to differing weights of individual halibut. This is suggested by the statistically significant difference in weight of individual halibut between Treatments 1 (Crab pot) and 5 (Five holes).

Catch of Tanner crab was too low in the locations where this study was conducted to adequately evaluate the influence of the various pot modifications on catch of Tanner crab.

CONCLUSIONS

1. Pots with the fish retention devices manufactured by 'Gotya', 'Neptune' and 'Norsol', and with tunnel eye openings 7" x 8", had significantly higher catches of Pacific cod than pots without such devices.

2. Fish retention devices which relied on inter-digitating, rigid fingers (i.e. 'Gotya' and 'Neptune') to retain fish had significantly higher catches of Pacific cod than did the retention device which relied on a collapsible net funnel for retaining fish (i.e. 'Norsol' cod sock).

3. Pots with the fish retention devices and 7" x 8" tunnel eye openings tended to have the lowest catches of halibut, although differences in halibut catch between pots with and without the devices were often not statistically significant.

4. When combined with tunnel eye openings at least as small as 8" x 11.5", fish retention devices appeared to further reduce the catch of halibut beyond catch reductions displayed by 8" x 11.5" tunnel eye openings alone. Thus, in addition to their fish retention function, fish retention devices, at least when combined with reduced tunnel eye opening dimensions, may enhance the halibut bycatch reducing function of the smaller dimensions.

5. At least in the absence of fish retention devices, pots with tunnel eye openings as small as 7" x 8" did not significantly reduce the catch of Pacific cod. Unknown is whether these dimensions are a lower limit, below which catch of Pacific cod may be significantly reduced.

6. Halibut condition among the eight treatments was "excellent" the vast majority of the time and did not differ statistically significantly among the eight treatments.

7. In order to evaluate the effect of the eight treatments on catch of Tanner crab, this study would need to be repeated, perhaps in another area and/or at another time when sufficient numbers of Tanner crab are available.

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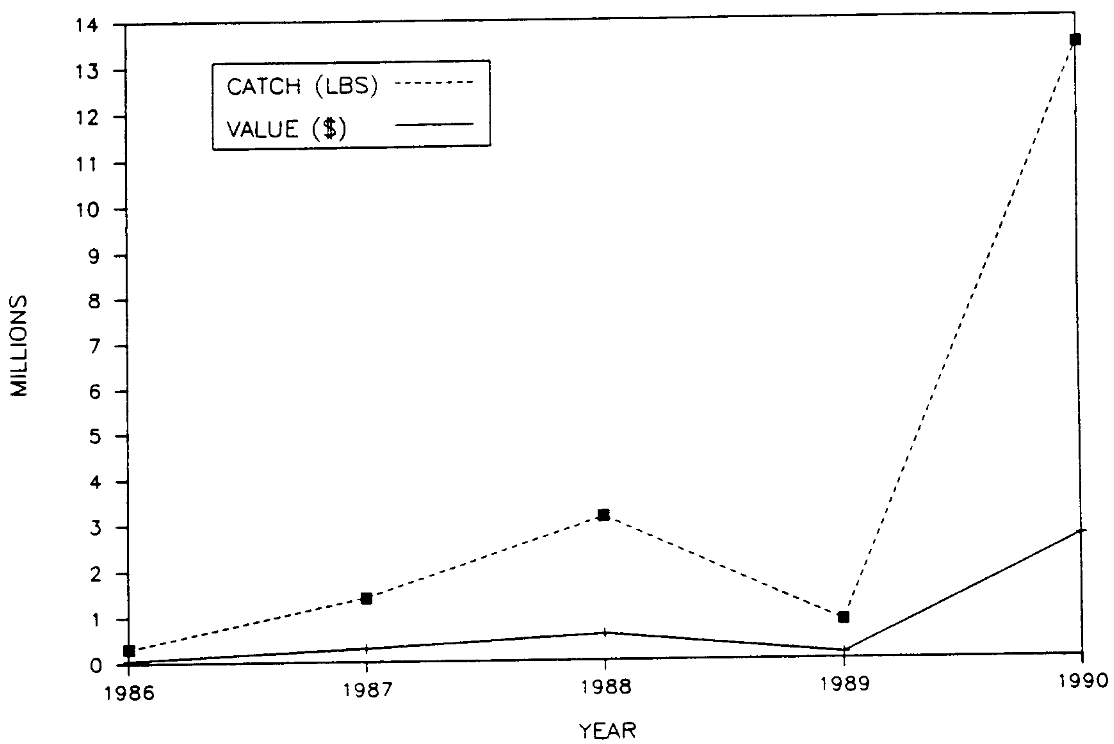

Figure 1. Catch and ex-vessel value of Pacific cod landed by pot vessels in the Central Gulf of Alaska, 1986-1990 (source: Pacific States Marine Fisheries Commission PacFIN reports, 1986-1990).

	LOCATION								
TREATMENT	1	2	3	4	5	6	7	8	9
1	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X
2	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X
3	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X
4	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X
5	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X
6	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X
7	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X
8	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X

Figure 2. Schematic diagram of the experimental design for the cod pot study. Each 'X' in the body of the diagram represents an individual pot. There were 3 pots for each of the 8 treatments and 9 locations (blocks).

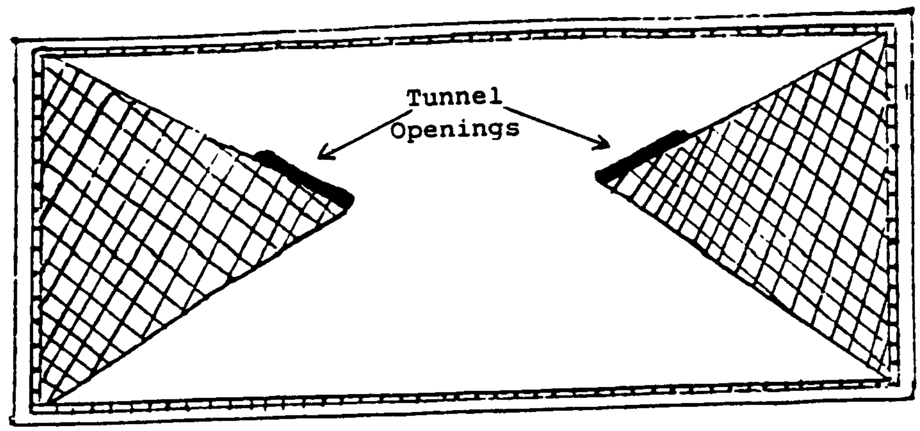

Figure 3. Standard crab pot showing tunnel eye openings set up for crab fishing. Here the openings are obliquely oriented.

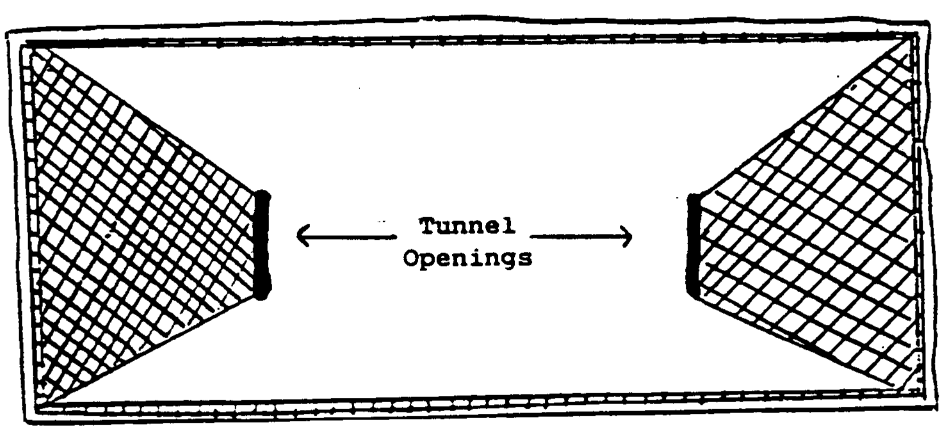

Figure 4. Modified crab pot showing tunnels set up for cod fishing. Tunnel eye openings have been moved to a vertical orientation.

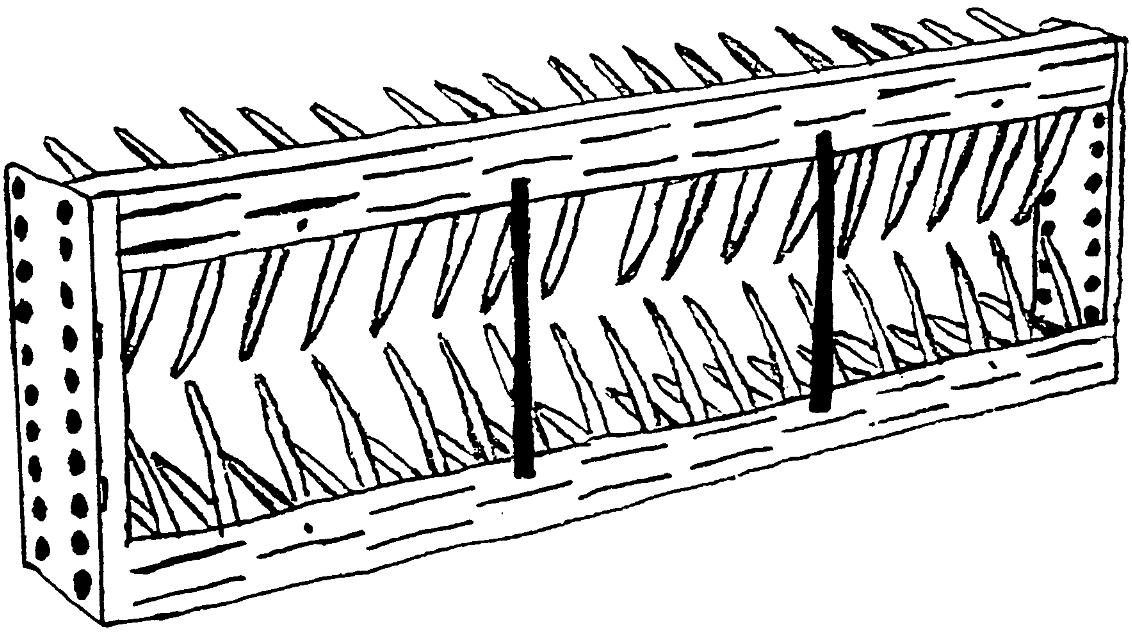

Figure 5. Diagram of a 'GOTYA' tunnel eye insert.

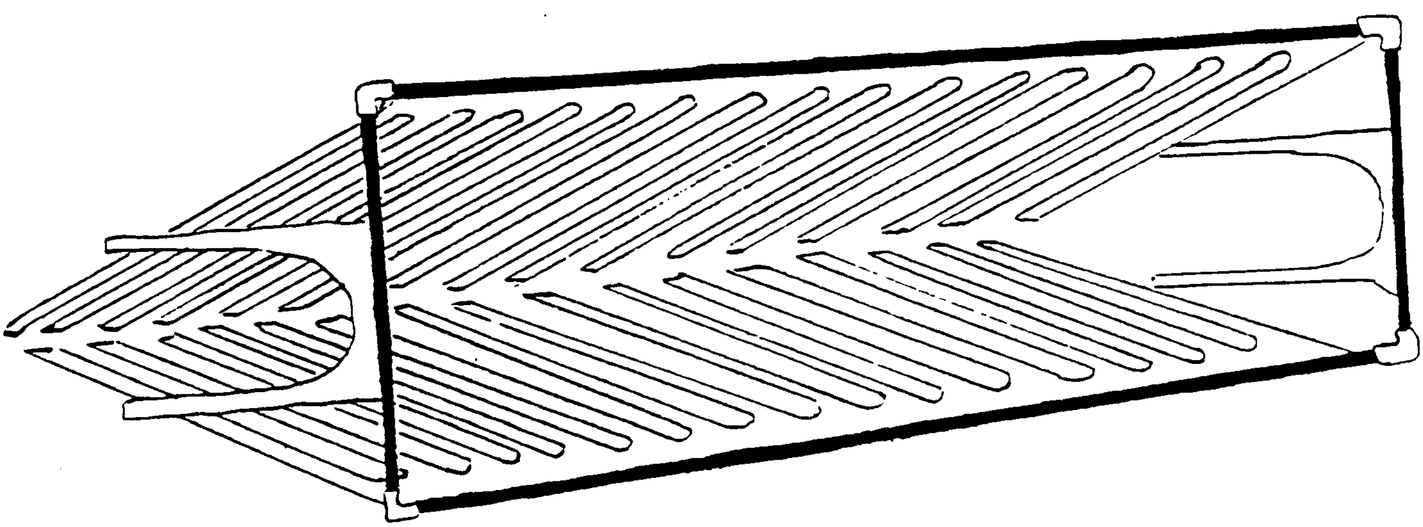

Figure 6. Diagram of a 'NEPTUNE' tunnel eye insert.

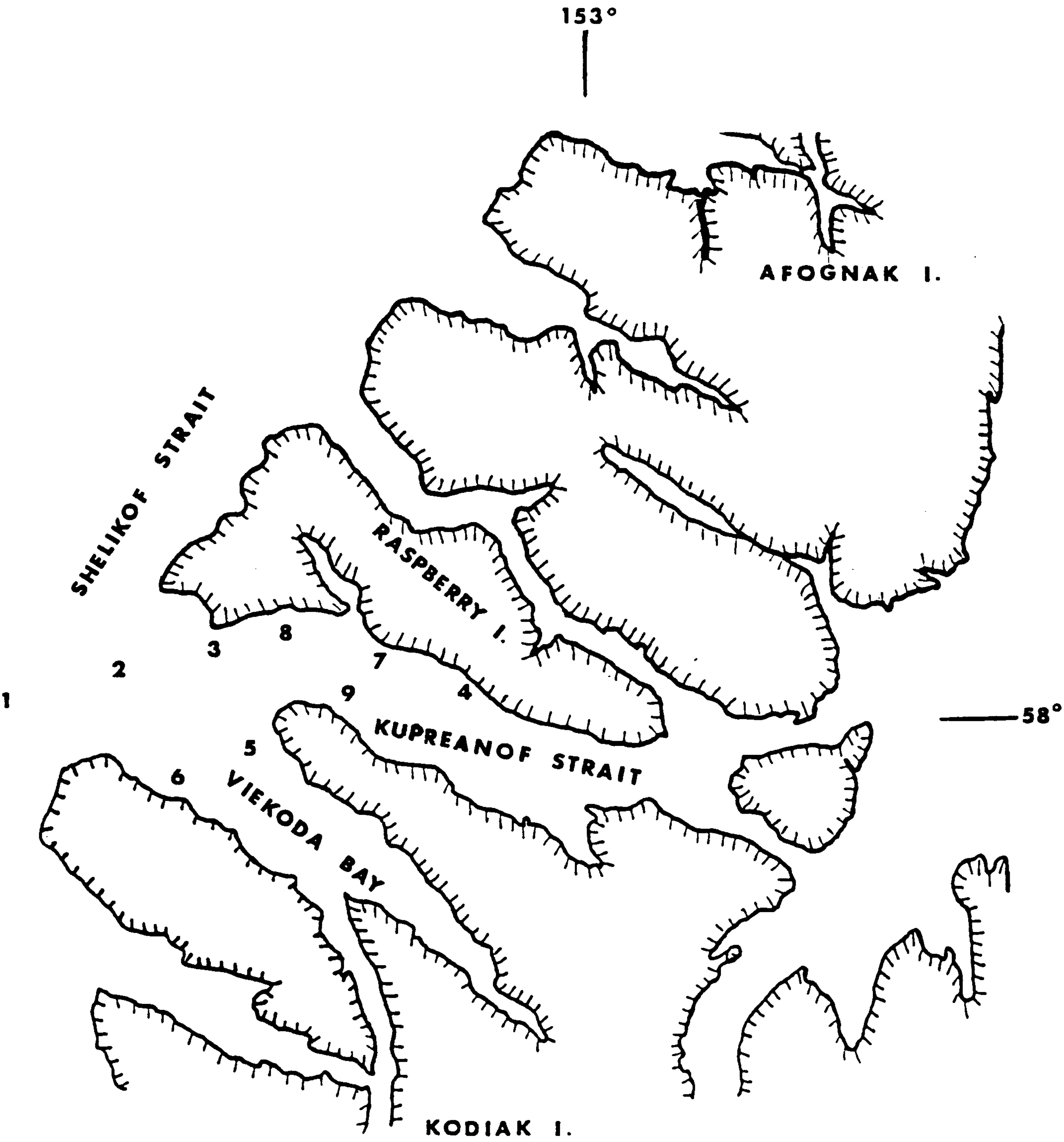

Figure 7. Pot cod study locations. Numbers represent actual sites, in chronological order, where gear was set.

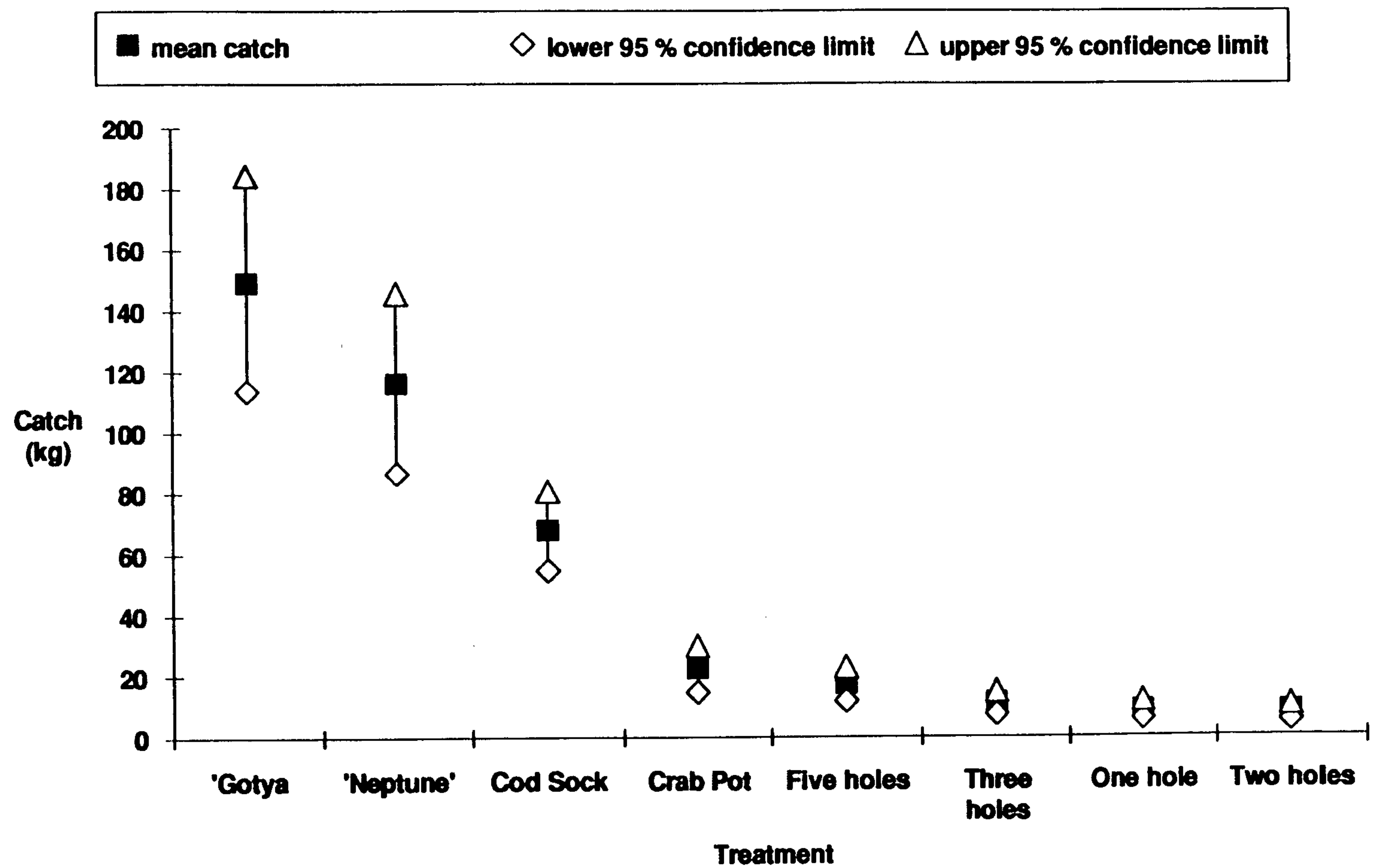

Figure 8. Mean catch of Pacific cod. Catch is cumulative catch for multiple deployments and retrievals of pots.

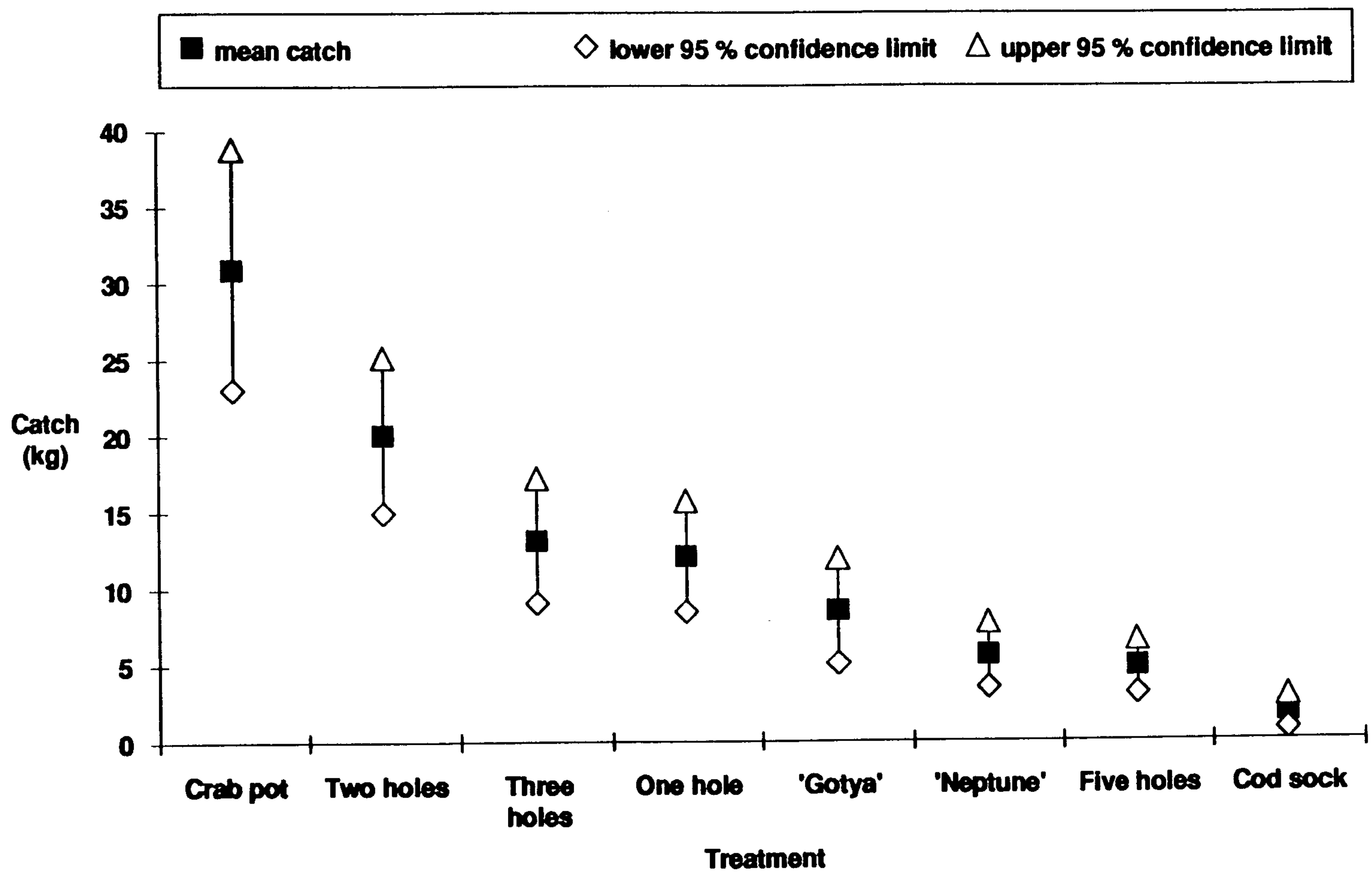

Figure 9. Mean catch of halibut. Catch is cumulative catch for multiple deployments and retrievals of pots.

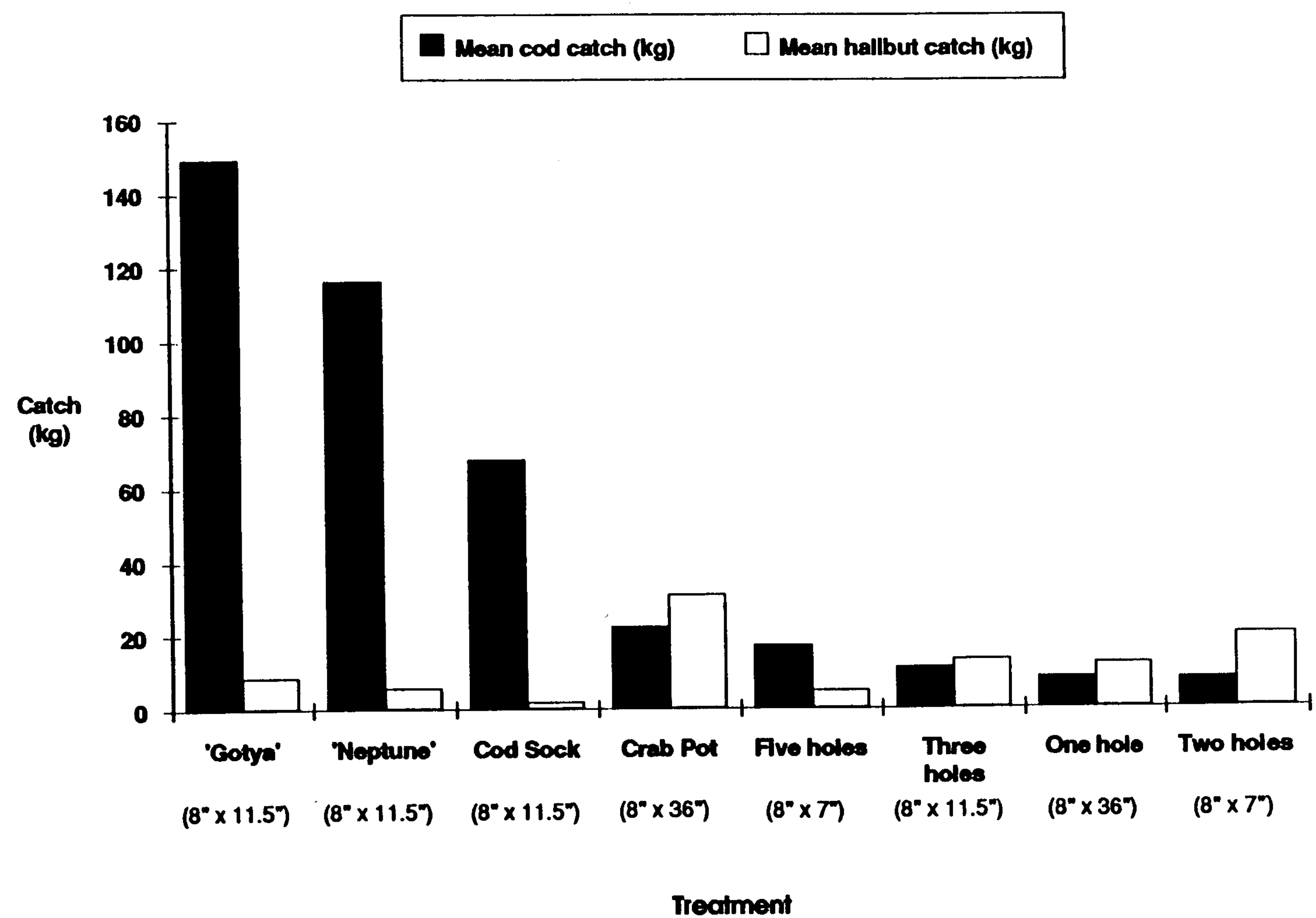

Figure 10. Mean catch of cod and halibut. Catch is cumulative catch for multiple deployments and retrievals of pots. Numbers in parentheses below treatments are dimensions (height x width) in inches.

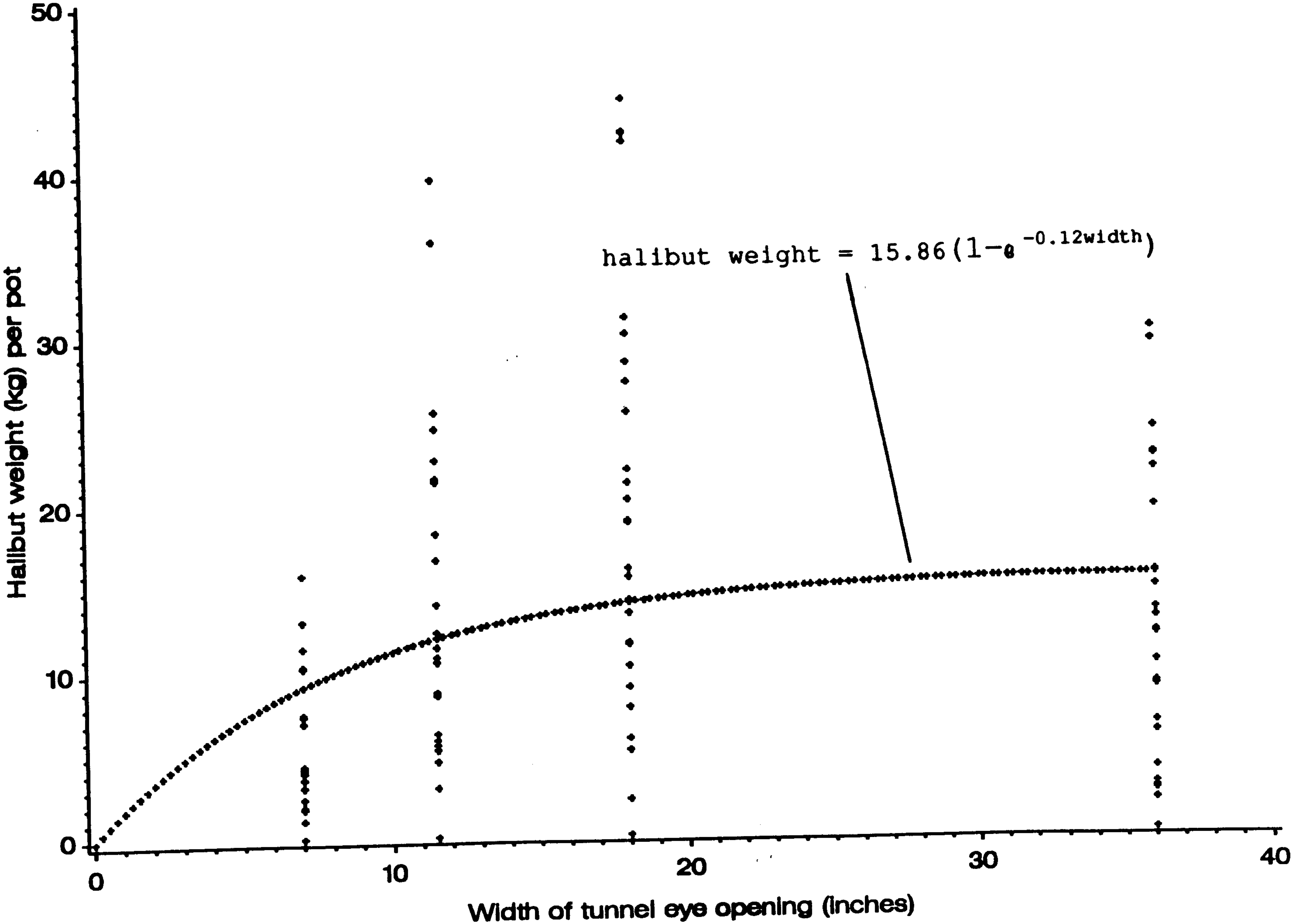

Figure 11. Total weight of halibut (kg) per pot as a function of tunnel opening width (inches).

Table 1. Summary statistics for cumulative catches of cod, halibut and Tanner crab.

Species	Treatment	Mean catch (kg)*	Statistical Difference**	Sample Size (n)	Coefficient of variation (%)	95 % Confidence Interval: Lower 95 % confidence limit	95 % Confidence Interval: Upper 95 % confidence limit
Pacific cod	Three holes + 'Gotya'	149.19	a	27	59.91	113.75	184.62
	Three holes + 'Neptune'	116.24	a	27	64.07	86.71	145.76
	Three holes + cod sock	67.84	b	27	48.41	54.82	80.86
	Crab pot	22.37	c	27	85.46	14.79	29.94
	Five holes	17.24	c	27	81.28	11.69	22.8
	Three holes	11.11	c	27	84.86	7.38	14.85
	One hole	8.27	c	27	102.59	4.9	11.63
	Two holes	7.99	c	27	68.53	5.82	10.16
Halibut	Crab pot	30.91	a	27	64.55	23	38.83
	Two holes	20.05	a b	27	64.01	14.96	25.14
	Three holes	13.15	b c	27	77.85	9.09	17.21
	One hole	12.1	b c d	27	75.47	8.48	15.72
	Three holes + 'Gotya'	8.52	c d	27	101.45	5.09	11.94
	Three holes + 'Neptune'	5.62	c d	27	94.6	3.51	7.73
	Five holes	4.86	c d	27	90.96	3.11	6.61
	Three holes + cod sock	1.8	d	27	152.79	0.71	2.9
Tanner crab	Three holes + 'Neptune'	6.9	***	27	344.91	0	16.34
	Five holes	2.54		27	367.69	0	6.24
	Three holes	1.93		27	519.62	0	5.92
	Crab pot	1.57		27	455	0	4.4
	Three holes + 'Gotya'	1.21		27	467.19	0	3.45
	One hole	0.31		27	406.38	0	0.82
	Three holes + cod sock	0.26		27	351.61	0	0.62
	Two holes	0.17		27	329.47	0	0.4

* Mean of cumulative catch per pot, per site fished.

** Treatments with the same letter are not statistically, significantly different. Treatments that do not share the same letter are statistically, significantly different (alpha = 0.05).

*** Statistical tests for differences in cumulative catch of Tanner crab were not conducted because of the limited catch of Tanner crab.

Table 2. Summary statistics for lengths of Pacific cod. Individual estimates are provided for each location because of the statistically significant interaction between location and treatment, and the subsequent need to conduct individual tests for differences in mean cod length for each location.

						95 % Confidence Interval	
Location	Treatment	Mean length (cm)	Statistical difference *	Sample size (n)	Coefficient of variation (%)	Lower 95 % confidence limit	Upper 95 % confidence limit
1	Two holes	66.1	a	8	17.5	54.1	78.1
	Three holes + 'Neptune'	65.7	a	127	13.6	62.7	68.7
	Three holes + 'Gotya'	65.5	a	143	11.7	62.7	68.3
	One hole	65.1	a	19	13.0	57.3	72.8
	Three holes + 'Norsol'	64.6	a	80	11.7	60.8	68.4
	Crab pot	64.0	a	26	17.7	57.3	70.6
	Three holes	63.2	a	13	19.8	53.7	72.6
	Five holes	58.8	a	12	11.2	49.0	68.5
2	Crab pot	71.3	a	21	9.0	61.7	80.9
	Five holes	67.3	abc	8	19.0	51.7	82.8
	Three holes + 'Gotya'	67.2	a	123	17.4	63.2	71.1
	Three holes + 'Norsol'	65.2	a	63	18.0	59.6	70.7
	Three holes + 'Neptune'	64.9	ab	112	16.4	60.8	69.1
	One hole	64.2	bc	11	19.4	50.9	77.4
	Two holes	54.6	bc	8	16.5	39.1	70.2
	Three holes	52.4	c	8	16.2	36.8	67.9
3	Three holes + 'Gotya'	62.7	a	81	15.4	58.6	66.9
	Five holes	62.3	ab	8	14.7	39.0	75.5
	Crab pot	60.1	ab	17	19.8	51.1	69.2
	Three holes	59.9	ab	8	21.0	46.7	73.1
	Three holes + 'Norsol'	58.7	ab	37	14.5	52.5	64.8
	Two holes	56.8	ab	9	12.3	44.3	69.2
	One hole	56.5	ab	4	14.8	37.8	75.2
	Three holes + 'Neptune'	56.3	b	84	15.8	52.2	60.4

* Treatments with the same letter are not statistically, significantly different. Treatments that do not share the same letter are statistically, significantly different (alpha=0.05) based on Tukey's studentized range test.

Table 2. (contd.) Summary statistics for lengths of Pacific cod. Individual estimates are provided for each location because of the statistically significant interaction between location and treatment, and the subsequent need to conduct individual tests for differences in mean cod length for each location.

Location	Treatment	Mean length (cm)	Statistical difference*	Sample size (n)	Coefficient of variation (%)	95 % Confidence Interval: Lower 95 % confidence limit	95 % Confidence Interval: Upper 95 % confidence limit
4	Crab pot	60.7	a	34	14.8	55.4	66.0
	Three holes + 'Neptune'	60.3	a	143	13.3	57.7	62.9
	Two holes	59.1	a	12	18.4	50.1	68.1
	Three holes + 'Norsol'	58.4	a	109	12.4	55.4	61.4
	Three holes + 'Gotya'	57.8	a	187	13.7	55.5	60.1
	Five holes	56.6	a	45	12.2	51.9	61.2
	One hole	56.0	a	17	15.6	48.4	63.6
	Three holes	53.2	a	9	10.2	42.8	63.6
5	Crab pot	61.5	a	17	18.7	52.0	71.0
	Three holes	61.1	a	8	17.5	47.3	75.0
	Three holes + 'Neptune'	60.6	a	91	17.9	56.5	64.7
	Three holes + 'Gotya'	60.1	a	96	14.5	56.1	64.1
	Three holes + 'Norsol'	59.5	a	50	15.9	53.9	65.0
	Two holes	58.2	a	6	21.6	42.2	74.2
	Five holes	55.6	a	7	12.1	40.8	70.4
	One hole	54.9	a	7	15.9	40.1	69.7
6	Two holes	65.0	a	2	0.0	38.9	91.1
	Three holes + 'Neptune'	61.4	a	105	15.2	57.8	65.0
	Five holes	61.1	a	9	18.2	48.8	73.4
	Three holes	59.0	a	4	29.1	40.6	77.4
	Three holes + 'Norsol'	58.8	a	49	12.9	53.6	64.1
	Three holes + 'Gotya'	58.4	a	86	16.1	54.5	62.4
	Crab pot	57.8	a	5	20.8	41.3	74.3
	One hole	56.5	a	2	6.3	30.4	82.6

* Treatments with the same letter are not statistically, significantly different. Treatments that do not share the same letter are statistically, significantly different (alpha=0.05) based on Tukey's studentized range test.

Table 2. (contd.) Summary statistics for lengths of Pacific cod. Individual estimates are provided for each location because of the statistically significant interaction between location and treatment, and the subsequent need to conduct individual tests for differences in mean cod length for each location.

						95 % Confidence Interval	
Location	Treatment	Mean length (cm)	Statistical difference *	Sample size (n)	Coefficient of variation (%)	Lower 95 % confidence limit	Upper 95 % confidence limit
7	Crab pot	59.8	a	38	15.0	54.2	65.3
	Three holes	59.5	a	32	17.8	53.4	65.6
	Two holes	59.1	a	16	12.5	50.5	67.6
	Three holes + 'Gotya'	58.9	a	209	15.1	56.5	61.3
	Five holes	57.8	a	33	16.2	51.8	63.7
	Three holes + 'Norsol'	57.3	a	90	13.2	53.7	60.9
	Three holes + 'Neptune'	57.1	a	130	15.1	54.1	60.1
	One hole	53.5	a	12	11.1	43.6	63.4
8	Crab pot	65.9	ab	16	12.6	58.7	73.2
	Two holes	65.8	a	26	10.2	60.1	71.5
	One hole	64.7	ab	10	9.9	55.5	73.9
	Three holes + 'Norsol'	64.3	a	88	12.3	61.2	67.4
	Three holes	64.0	ab	16	8.7	56.7	71.3
	Three holes + 'Neptune'	62.7	ab	56	13.0	58.8	66.6
	Five holes	62.4	ab	15	8.1	54.9	69.9
	Three holes + 'Gotya'	61.1	b	179	11.6	58.9	63.3
9	Crab pot	63.1	a	36	18.8	57.0	69.1
	Five holes	61.5	a	38	19.2	55.6	67.4
	Three holes + 'Gotya'	61.1	a	302	14.4	59.0	63.2
	Three holes + 'Norsol'	59.4	ab	95	12.9	55.6	63.1
	Two holes	59.0	ab	11	24.7	48.0	70.0
	Three holes + 'Neptune'	58.7	ab	219	15.5	56.2	61.1
	Three holes	57.8	ab	21	16.8	49.9	65.7
	One hole	53.2	b	24	14.6	45.8	60.6

* Treatments with the same letter are not statistically, significantly different. Treatments that do not share the same letter are statistically, significantly different (alpha=0.05) based on Tukey's studentized range test.

Table 3. Summary statistics for lengths of halibut.

Treatment	Sample size (n)	Mean length (cm)	CV (%) of mean length	Least square * mean length (cm)	Statistical difference **	Standard error of least square mean length
Crab pot	164	71.8	19.9	72.4	a	0.98
Three holes + 'Gotya'	48	71.8	15.2	72.3	ab	2.23
Two holes	140	67.3	17.6	69.0	abc	1.18
One hole	79	67.9	19.4	68.7	abc	1.49
Three holes + 'Neptune'	40	67.8	16.1	67.7	abc	2.55
Three holes + 'Norsol'	14	66.9	12.1	***	bc	***
Three holes	94	65.5	14.9	66.5	bc	1.37
Five holes	52	61.6	18.5	62.1	c	1.98

*Because the number of halibut in each pot varied, the analysis of variance was based on unequal subclass numbers. Therefore, the most appropriate estimate of the mean halibut length is the least square mean. The least square mean is an estimate of the mean that would be expected assuming equal numbers of halibut for each location (block) and treatment combination. Standard arithmetic means ["Mean length (cm)"] are included here for comparison with the least square means.

** Tests for differences in least square means of halibut lengths were conducted using multiple t-tests. The alpha level chosen for the individual tests was 0.001. Therefore the maximum overall alpha level was less than or equal to 0.02. Treatments with the same letter are not statistically, significantly different. Treatments that do not share the same letter are statistically, significantly different.

*** For statistital tests of differences in halibut lengths among treatments, the treatment "Three holes + 'Norsol' " was excluded from the analysis because of the very small numbers of halibut retained in that treatment. For this treatment, four of the nine locations had no halibut retained and the numbers of halibut retained at the other five locations ranged from only two to five.

Table 4. Mean cumulative catches of cod and halibut per pot, and halibut bycatch rates based on catch of Pacific cod.

TREATMENT	Mean catch of cod (kg)	Mean catch of halibut (kg)	BYCATCH RATE * (kg halibut/metric ton cod)	BYCATCH RATE (%) (metric tons halibut/metric tons cod)*100
Crab pot	22.37	30.91	1381.8	138.2
One hole	8.27	12.1	1463.1	146.3
Two holes	7.99	20.05	2509.4	250.9
Three holes	11.11	13.15	1183.6	118.4
Five holes	17.24	4.86	281.9	28.2
Three holes + 'Gotya'	149.19	8.52	57.1	5.7
Three holes + 'Neptune'	116.24	5.62	48.3	4.8
Three holes + cod sock	67.84	1.8	26.5	2.7

* NOTE: This bycatch rate is expressed as kg of halibut per metric ton of COD caught, not per metric ton of ALL fish landed.