4K90-13

DETERMINATION OF EXPERIMENTALLY INDUCED NON-OBSERVABLE MORTALITY ON RED KING CRAB

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Regional Information Report[1] No. 4K90-13

Alaska Department of Fish and Game
Division of Commercial Fisheries
211 Mission Road
Kodiak, Alaska 99615

April 1990

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Determination Of Experimentally Induced Non-observable Mortality On Red King Crab

I. Abstract

Large hardshell male red king crab, Paralithodes camtschatica, were tethered in the path of an Aleutian combination trawl. Six tows were made to estimate the impact of trawl gear on injury rates of crab that were in the trawl path but not caught by the gear. In total, one hundred and sixty nine of the tethered crabs were estimated to be in the six trawl paths as defined by the spread of the doors. Crabs recovered in the trawl onboard the vessel accounted for 21.3% of these crabs. Divers recovered 46.2% of the crabs within the trawl path, leaving 32.5% unrecovered. Three of the 36 (8.3%) crabs recovered in the trawl were injured while two of the 78 (2.6%) crabs recovered by divers were injured. This latter value is an estimate of the otherwise non-observable injury rate of Aleutian combination trawl gear on king crab under the conditions tested. Only one crab, which was caught in a trawl, had injuries assumed to be fatal.

II. Executive Summary

This study was an attempt to estimate the non-observed mortality of crab that are encountered by a bottom trawl. Large hardshell male red king crab were tethered in the path of an Aleutian combination trawl. The study indicated that of those crab within any part of the trawl path, 5 of the 114 which were recovered (4.4%) had new injuries with a single crab (<1%) injured fatally. Three of the crabs injured in the trawl path were captured in the trawl. In total, 21.3% of the crabs were caught by trawl, 46.2% of the crabs were recovered by divers, and 32.5% were not recovered. If recovered and unrecovered crab were injured at the same rate, injury percentages would remain less than 5%. Because five of the crabs that broke free of their tethers were recovered by divers and sustained no injuries, it is unlikely that a higher injury rate would have occurred on the unobserved crab. Additional observations on newly molted red king crab during this study indicate a much higher potential for injury when crab have recently molted. Handling of the soft-shelled crab for the experiment, including capture by pots, tethering and recovery, would probably have resulted in substantial mortality. The presence of newly molted Tanner crab, Chionoecetes bairdi, coupled with the extended time required for completion of experiments on king crab, prohibited similarly planned trawl experiments with Tanner crab. Our approach to studying unobserved crab mortality due to trawling would not be effective on newly molted animals.

Caution is warranted in applying these results to other crab species or crab in conditions other than those we observed. Given the poor behavior of the trawl during these experiments due to operation in shallow waters (<7 fm), further caution in interpretation of results is warranted. In general, a trawl fished at shallow depths would be expected to have more contact with the bottom than when fished at normal fishing depths. As a result, the rate of capture of crab within the path swept between trawl doors (21.3%) was higher than might normally occur.

III. Purpose

A. Problem description.

The Americanization of groundfish fisheries off the coast of Alaska is a major boon to the economies of Alaskan coastal communities. Due to implementation of the Magnuson Fishery Conservation and Management Act, these fisheries are rapidly changing from foreign to U.S. enterprises. This development of the domestic processing industry has created a new fleet of domestic vessels, often smaller than the high seas or joint venture vessels associated with foreign processing.

Development of the American groundfish trawl fleet has occurred when shellfish population abundances are at an all time low. Serious concerns have been raised about effects of trawling on crab stocks, given both the lack of observer coverage on domestic vessels to monitor those crab which are captured and uncertainties about the unobserved impacts of trawling on the shellfish resources which elude capture. Speculation on the unobserved impacts to shellfish have ranged from insignificant to estimates as high as 15 fold above those impacts viewed by observers.

Data on bycatch of crab and the resulting injury and mortality is of critical importance to the fishing industry and to fishery regulators so that they may resolve issues concerning the impact of "hard on the bottom" trawling on shellfish stocks. Surveys have shown that hard-on-bottom trawling can cause varying degrees of injury and mortality to crab recovered by trawls (Blackburn & Schmidt, 1988). However, data are lacking on the unobserved impact of trawling on crab in the path of trawls that are not caught and observed aboard the vessel. Previous investigations involving underwater video photography of a fishing trawl have failed to provide any definitive answers about this subject (Bublitz 1989).

The general lack of information on the unobserved bycatch and an urgent need to protect dwindling stocks of crab have resulted in the closure (to bottom trawling) of state and selected federal waters around Kodiak Island since 1986 and periodic closures in areas of the Bering Sea as well. There are additional concerns about whether time and area closures may require more conservative or more liberal application, depending upon the degree of unobserved crab mortality associated with trawls. There is also a growing sentiment that the rationale for time and area closures should be expanded to include other prohibited species besides red king crab (Paralithodes camtschatica).

In addition to time and area closures, conservative bycatch limits have been placed on the trawl fleet, at least in part, because of concerns about unobserved mortalities. Bycatch restrictions affect the developing groundfish fishery by closing the fishery when bycatch limits are reached.

This study is to obtain some insight into the impact of the trawl gear on crab beyond those impacts recorded by observers onboard trawl vessels. In this report, these impacts are referred to as "non-observable mortality". The experimental design employed in this study requires several assumptions that must be considered when interpreting the data, however the approach does allow the investigator to examine crab that have had a trawl pass over them but were not captured. These methods differ from other studies which simply recorded observations of trawls in action.

B. Objectives of the project.

This project was an experiment to determine direct mortality of a typical bottom trawl, rigged for flatfish harvesting, on "seeded" king and Tanner crabs.

Specific objectives of this study were:

1. Identify the catch rate of known tagged crab, "seeded" in the path of a bottom trawl.

2. Determine the mortality and injury rate of crab collected in the trawl and of crab that the trawl and associated gear have passed over.

3. Photograph and observe avoidance behavior of the crab as the trawl passes over them.

IV. Approach

A. Work description.

The selected study design required an evaluation of experimental gear, a determination of study site suitability, an analysis of tethering techniques for crab, and development of an experimental design for deployment of gear and tethered crab. These are discussed below.

Description of gear. The R/V Resolution was rigged to tow an Aleutian combination net, Appendix Figure 7. This net was chosen after consultation with industry groups as best representing a typical net used in the fisheries. This net is specifically designed to fish Pacific cod, *Gadus macrocephalus*, and flatfish, Pleuronectidae, and was loaned by industry. Members of the fishing industry were consulted as to the actual configuration and deployment of the gear to comply with the study design. The net had a 23 m (74 ft) headrope with 9 floats 30 cm (12 in) in diameter. The footrope was 31 m (103 ft) long with 36 cm (14 in) roller gear placed every 0.9 m (3 ft) separated by 17 cm (6 1/2 in) disks. The body of the net had 203 mm (8 in) mesh while the intermediate section had 140 mm (5 1/2 in) mesh and the codend had 114 mm (4 1/2 in) mesh. The doors were 3.0 m (15 ft) super "V" style. The sweeplines (1.9 cm ((0.75 in)) cable) were 83 m (271 ft) with 76 mm (3 in) rubber disks used as mud gear on 55 m (180 ft) cable lengths. This net was designed to hold fast to the bottom.

Site selection. A short term vessel charter was obtained with the owner of the M/V Chaik and the vessel served as a dive platform in locating a suitable study site. Site prerequisites included reasonable visibility (greater than 9 m (30 ft.)) for scuba diving operations, a bottom type consisting of fine sand and free of debris, reasonable depth for scuba diving (less than 18 m (60 ft)), an area approximately 1.6 km (1 mi) x 0.4 km (0.25 mi) in size and proximity to the town of Kodiak. Good visibility was necessary to insure adequate recovery of experimental animals not caught by the trawl. A water depth of 18 m (60 ft) allows divers a maximum of 60 minutes of bottom time. This duration was estimated to be the minimum needed to complete the work by several divers. Proximity to the town of Kodiak was necessary to forgo cancellations due to weather and to provide for a safe scuba operation. Divers performed spot dives in the Inner Chiniak and Monashka Bay areas. Several locations were identified as adequate based on minimum requirements for scuba and trawl vessel operation. After consultation with the skipper of the State of Alaska trawl vessel R/V Resolution, a site was selected offshore from the Buskin River approximately 3.2 km (2 mi) southeast from the town of Kodiak, Figure 1.

Tethering techniques. Due to crab mobility, tethering crab to the bottom was necessary to ascertain catch and injury rates of crab in the trawl path. Several harnessing and tethering techniques were designed and tested. Harnesses were fashioned from velcro straps and several different thicknesses of treated cotton twine. Experimental tethering techniques consisted of variations of the following: snapping a halibut clip onto the harness of a crab with a 0.6 m (2 ft) length of 2.2 to 7.7 kg (2 to 17 lb) test monofilament line tied to the opposing end of the clip. The line was then either tied individually to a 30.5 cm (12 in) plastic tent peg or tied in a series to 1.27 cm (0.5 in) lead line. These techniques were tested with king crab and observations were made by divers. Techniques were evaluated on two basic criteria: 1) the tether must insure that the crab remain available to the trawl gear and 2) the tether must not prohibit the crab from reacting to the oncoming trawl. The technique which was finally chosen involved looping treated cotton twine twice around the body of the crab in an anterior-posterior direction. The two loops were then tied together dorsally in the cardiac region (Figure 2). A 61 cm (24 in) piece of 7.7 kg (17 lb) test monofilament fishing line was tied off to a plastic electrical tie (used to tie wires together) which was attached to the leadline. On the opposing end of the monofilament was tied a halibut clip which was snapped into the harness at the cardiac region.

Experimental design. Two hundred of both king and Tanner crabs, *Chionoecetes bairdi*, were obtained by pot fishing over a period of 7 days and stored in 2.1 m x 2.1 m (7 ft x 7 ft) commercial size pots adjacent to the study site. Unfortunately, the study timing coincided with the annual molting period of both crab species. Sufficient non-molting king crab were captured but few non-molting Tanner crab were available. King crab were tagged with individually numbered carapace dart tags. Observations on size, carapace condition as well as the tag number were recorded.

The experimental design dictated that the crab would be seeded in a pattern, marked off by surface buoys, in such a manner that the majority of crab would be impacted by the trawl gear. Twenty crabs were attached to each 45.7 m (150 ft) lead line, Appendix Figures 1-6. This tethering technique allowed each crab 0.6 m (2 ft) in all directions to react to the trawl. The lines were deployed on the bottom substrate by scuba divers. The lead line was positioned perpendicular to the expected trawl path as defined by surface buoys and buoy anchors. The line was anchored in place by 30.5 cm (12 in) long tent pegs tied off to the line approximately every 1.5 m (5 ft). The number of these lines differed at each trial depending on weather conditions and logistical considerations.

Prior to conducting the experiments, the *R/V Resolution* towed the Aleutian combination net through a course of buoys to conduct net mensuration work and to test the feasibility of diver observations while riding the trawl. Later, with tethered crab in place, the gear was towed through the grid, which was defined by two parallel rows of surface buoys, to test the entire experimental design. Four days of trials were conducted.

Diver observations showed that the path of the trawl could not be accurately discerned on the bottom substrate. Therefore the following method was used to estimate the trawl gear path. A series of 30.5 cm (12 in) stakes were driven approximately 10 cm (4 in) into the substrate and 30.5 cm (12 in) apart in a row perpendicular to the path of the trawl on one end of the course. This row was located approximately 1.5 m (5 ft) in front of the first row of tethered crab. Chicken eggs were also placed in the same arrangement as the stakes. It was assumed that a trawl in contact with the bottom would disturb the stakes and eggs or that the turbulence from the trawl would move the eggs as it passed nearby. Such disturbances (see Appendix Figures 1-6) were observed by divers and the path of the trawl was estimated by this method. In this report, the path of the trawl is defined to be the distance between trawl doors.

The experiments were conducted during April 18-21, 1989, and six tows were made. Once crab were tethered for each tow, the skipper of the R/V Resolution was directed to trawl through the course. The trawl was brought aboard, the captured crab were recorded by tag number, and observations were made on the extent of injuries. Divers reentered the water as soon as the trawl had passed through the course to recover crab still attached to the leadline by tether, to recover crab that had broken loose, and to record observations of the trawl path. Divers swam outside of the perimeter of the course in an attempt to retrieve any crab that may have strayed after the trawl passed.

Several deviations from planned objectives and methods were necessary due to unforseen difficulties. These are discussed in sections "V. Findings, Section B" and "VI. Evaluation, Section A" of this report.

B. Project management.

Staff of the Alaska Department of Fish and Game (ADF&G) managed all phases of the project. Dr. Dana Schmidt was the project manager. He is the ADF&G regional research supervisor for the westward region. Dr. Schmidt provided liaison with granting agency personnel and the fishing industry during the course of the project. He supervised staff and budgets, assisted in completion of the study, and helped prepare the results. Bill Donaldson, a shellfish biologist with ADF&G, was the project biologist responsible for supervision of surface crews, the diving operation, and report completion. Ron Kutchick is the skipper of the R/V Resolution and was responsible for rigging fishing gear and conducting the trawling operations. Additional ADF&G crew aboard the Resolution included B. VanAtta and R. Gottwald. ADF&G office staff assisting on various phases of the field trials included L. Greer, M. Beasly, L. Neal, D. Jackson and D. Pengilly. ADF&G divers were B. Donaldson, F. Blau, S. Byersdorfer, D. Schmidt and P. Craig. National Marine Fisheries Service divers participating in the study included B. Stevens, E. Munk and P. Cumminsky. Additional assistance with this study was provided by ADF&G biometrics staff. The M/V Chaik was chartered with a crew of 3 for a dive platform during site selection and to aid in deploying and retrieving crab. Other ADF&G staff, P. Murphy, G. Kruse, and D. Ackley provided editorial assistance with the final report.

V. Findings

A. Accomplishments.

After experimental design and trial runs, six tows were made during April 18-21, 1989 to estimate the trawl injury/mortality rate on tethered king crab not normally recovered or observed. The data from this experiment is summarized in two forms. First, statistics are presented for all crab tethered outside the path of the trawl (Table 1). Secondly, statistics are presented on tethered crab estimated to have been in the path of the trawl gear by observations of disturbance to the stakes and/or eggs (Table 2).

A total of 237 king crabs were selected for the experiments. All were adult hardshell males greater than 151 mm (5.9 in) carapace length. Of these, 169 were estimated to have been in the path of the trawl gear during the 6 trials. Those in the path of the trawl varied from a low of 19 on trial 5 to a high of 39 on trial 1 (Table 2). Detailed schematic descriptions of results for each tow are shown in Appendix Figures 1-6. The path of the gear, shown as vertical lines in the appendix figures, was estimated from diver observations of disturbance patterns of stakes and/or eggs. Evaluation of these results strongly suggest that the fishing dimensions of the gear varied for each trial. Reasons for this could include impacts on gear performance by slight changes in towing speed, cable length and the angle of approach of the gear to the course.

Of the 169 crabs which were determined to have been in the path of the trawl, a total of 114 or 67.5% were recovered in the six trials (Table 2). Of those recovered, 36 (31.6%) were recovered in the trawl and 78 (68.4%) were recovered by divers. Of all crabs tethered in the trawl path, 32.5% were not found. Of the 114 crabs recovered from the trawl path, 5 or 4.4% had new injuries.

Most crab (91.2%) outside the trawl path were recovered (Table 1). Of these crab, 1 (1.6%) sustained a new injury during the recovery process.

B. Problems.

Several difficulties arose that affected the study objectives, methods, and results. Unforeseen problems that resulted in less than satisfactory results in meeting the planned objectives are discussed here. Changes in objectives and changes in methods to meet these revised objectives are discussed in "VI. Evaluation, Section A" of this report.

It was anticipated that results would address the degree of impact on tethered crab by specific gear parts such as mudlines, net footrope, etc. This was not possible for several reasons. First, the skipper could not control the trawl accurately enough to allow confidence in defining the traversed path without additional bottom observations. While the disturbance patterns of the wooden stakes and eggs observed by divers helped estimate each trawl path, the specific path of particular trawl components was not discernable from markings on the substrate. Second, when the spatial pattern of trawl-caught crab was compared to the pattern of disturbed markers, it became evident that the gear was not fishing according to specifications and it may have fished somewhat differently amongst the six trials. Due to these difficulties, results are presented as summaries for the entire trawl tow.

Divers attempted to photograph and observe avoidance behavior of crab as the trawl passed over them. However, continuing poor visibility limited the ability of divers to make these observations. Also, the speed of the trawl created a greater safety concern for the divers than anticipated. Therefore, no observations were made while the trawl was operating. Additional discussion of difficulties in attaining objective three of this study are described in "VI. Evaluation, Section A."

C. Future work.

This study did not attempt to provide answers to all questions regarding "non-observable mortality" of trawling on crab. During the course of the study, we determined that surface observations and manufacturers specifications were inadequate in predicting trawl performance. Detailed mensuration gear measuring door locations, net openings, location of the foot rope, and other parameters would be useful in future studies.

Further studies on effects of trawls would be desirable. Our observations of the sensitivity of newly molted crab to any type of handling suggests animals in this condition may be most vulnerable to impacts of trawls on non-observable mortality. However, this sensitive condition renders soft-shelled crab most difficult to handle during such experiments. Our experience suggests that newly molted red king and Tanner crabs cannot be tethered nor handled out of water without adverse impacts. For example, one softshell crab caught in a commercial crab pot, had seven different injuries to the carapace. An estimated 25% of the pot-caught soft shell crabs had fatal injuries and softshell crabs caught by the trawl incidental to the study had fatal injuries in excess of 80%. Given this constraint, we see the only feasible approach in examining at this problem would be with remotely operated vehicles or piloted submarines directly viewing the impact of a trawl on crab in this condition. It may be possible to concentrate crab in an area by placement of bait stations. Crab could be examined for injuries and enumerated by video immediately before and after trawling through the concentration. Because of the movement of crab during such a study, injury interpretations may be somewhat speculative unless major impacts were observed.

The design of experiments to be conducted at typical trawling depths would also be worthwhile, but this would eliminate the use of divers. The tethering of crab could be done using surface deployment of crab attached to a "long line". A remote operated vehicle deployed from the trawling vessel could parallel the trawl as it moved along the long line and provide direct observations of crab as they contact the trawl. The observations of trawl contact with crab would require interpretation of the potential for injuries, because crab not captured by the trawl but contacted with the gear would probably be freed from their tethers. The deployment of sonic tags on tethered crab may assist in relocating crab that had their tether broken by the trawl. This would provide further insight into the whereabouts and condition of the 32.5% unrecovered by our study. Deployment of sonic tags would be expensive and would require extensive search time. For this approach to work, the ROV would need to operate independently from the trawl and be maneuverable enough to parallel the long line at trawling speeds.

Studies with direct observations of crab by fixed or towed video cameras would offer some insights. However, they do not offer an opportunity to examine the crab for injuries after contact with the gear. Also, without a seeding procedure or other method to concentrate crab in the trawl path, videos of normal trawl operations may provide very few observations per tow due to low crab densities.

At best, any study which addresses the difficult question of "non-observed mortality" will provide only partial answers to the questions raised. The above approaches have a significant risk of failure due to unforeseen circumstances and logistic difficulties. We found it difficult to control the path of a trawl underwater with any precision, even at shallow depths. This problem may be greater at increased trawling depths. All of the approaches suggested above require an extensive use of high technology equipment and would be expected to cost at least an order of magnitude above the costs for this study.

VI. Evaluation

A. Attainment of goals and objectives.

The study was divided into three objectives; two of these were attained for red king crab. Objective one was to identify the catch rate of known tagged crab, "seeded" in the path of a bottom trawl. Objective two was to determine the mortality and injury rate of crab collected in the trawl and of crab that the trawl and associated gear have passed over. Catch, mortality, and injury rates are summarized in Tables 1 and 2.

Objective three was to photograph, and observe avoidance behavior of the crab as the trawl passes over these animals. Inability to attain this objective was described in "V. Findings, Section B." To reiterate, unanticipated low visibility (<3 m) limited the ability of divers to observe avoidance behavior of the trawl during the actual experiments. Also the speed at which the trawl was towed to insure proper net opening and fishing performance prevented divers from riding the trawl. After initial attempts proved too dangerous, divers remained on the surface during each pass of the trawl. However, observations of the behavioral response of crab to an approaching diver suggested the ability of crab to avoid a trawl would be minimal, regardless of the presence of a tether as used in this study.

Study objectives were to include Tanner crab in addition to red king crab. Tanner crab were not included, because of several unforeseen circumstances: time constraints due to gear malfunctions, unanticipated deployment and recovery requirements, and limitations imposed by the diversion of the R/V Resolution to operations related to the EXXON Valdez oil spill after the study was partially completed; lack of availability of sufficient numbers of hardshell Tanner crab; and the decision to have an adequate sample size for one species, rather than an inadequate sample size for both species. These factors are explained below.

The Exxon Valdez grounded on March 24, 1989. During the course of conducting field work for this project, the R/V Resolution was sent to Prince William Sound to assist in the assessment and cleanup effort for a period of approximately one month. Because of this disruption, the field work, including buoy courses, had to be reset when the R/V Resolution was again available. During the final week of the study, the trawl winch was inoperable for a two day period. This forced the remaining work to be accomplished in 3 days, because the vessel was committed to other projects thereafter. Within these three days, maximum allowable bottom times were approached by the divers beyond which no additional work could be conducted. Also, we found that deploying and recovering the crab took more time than anticipated, and we were unable to deploy 100 total crab for each pass as hoped. The crab were deployed in 2 rows per trial to limit continuous diving time prior to and after trawling over the animals. Given these difficulties, approximately 14 days were spent completing field work, rather than the seven days originally planned.

In addition, it was not foreseen that limited numbers of hard shell Tanner crab would be available to us. Our initial field observations of newly molted crab captured in pots indicated injury rates from collecting the crab to be in excess of 25%, thus effectively eliminating their use in this type of study. An extended period of time would have been required to sort through large numbers of crab and obtain the limited number of hard shell crab available. The commitment of the vessel to other duties precluded this possibility. It was decided to eliminate Tanner crab from study, and to focus the experiments on red king crab to ensure that adequate numbers of crab were used and sufficient numbers of replicate tows were made to provide meaningful results. This decision was made by the project leader onboard the vessel during the last portion of the study, and no other feasible alternative was available. The change was noted to the contracting agency in the first progress report prepared after completion of the field work.

Finally, we had planned to simulate commercial trawling by filling the codend of the trawl to 75% fullness with a mixture of crab and flatfish. Initial attempts to obtain flatfish resulted in high bycatch of molting king and Tanner crab and few flatfish. Also, if crab were used to fill the codend rather than flatfish, the presence of these crab intermixed with the experimental crab may have confounded interpretation of our results. Because of the presence of large numbers of molting red king and Tanner crabs in the area where flatfish were to be obtained, the codend of the trawl was left empty during the experiment. In the professional opinion of the vessel's operator, the shallow depth effect on the trawl's fishing performance would compensate for the lack of fish in the codend. The skipper, who is an experienced trawl fisherman, also stated that the presence of the crab and flatfish in the codend, which would involve retrieving and redeploying the trawl, would not provide realistic fishing conditions nor realistically simulate a 3/4 full codend fishing at depth. It was the skipper's opinion that, with the shallow operational depth of the trawl, the trawl would fish harder than normal on the bottom. Recall that depths chosen for this study were shallower than typical fishing depths, due to the depth limitations of SCUBA divers. Therefore, the decision was made to conduct the trawl experiments without any flatfish in the codend. Thus, the study design was altered to avoid the capture of molting red king crab and to strive for net performance in a manner most typical of realistic fishing conditions. It was felt that this decision was consistent with the intent of original study objectives. Again, the above conditions required an immediate onsite decision to alter the original study plan. This decision was made with no time available for subsequent alterations. Therefore, the contracting agency was notified through the first progress report after completion of the field activities.

B. Industry benefits.

The results of this and future similar studies have significant benefits to the fishing industry, because resultant data bear upon resolution of bycatch deliberations by fishery regulatory organizations. Through studies such as this we can provide initial estimates of a "catchability factor" associated with the capture rate of crab in trawl gear. Our study yielded preliminary estimates of injuries inflicted both on crab captured in the gear and on those struck by the gear but not captured. Injury rates to crab not captured are not available from on-board observers. These injury estimates can be used to assess crab data collected by observations aboard commercial fishing vessels with this type of gear. Within the restrictions applied to this study, it appears that non-observable mortality may occur, but not at a sufficiently high rate to warrant modifying estimates derived by observation of the retained catch in the trawl. Therefore, onboard observations of trawl caught hardshell red male king crab may be more accepted by the public as representative of total crab mortality due to trawling. However, the injury rates found here must be considered with some caution, because 32.6% of the crabs were not recovered and the sample size was relatively small. Further, because this study was limited to hard shell red king crab males, application to other crab, particularly those recently molted, is not appropriate. Our experience in handling crab in this condition during the course of this study suggested mortality rates would be much higher.

Additional benefits resulted from our investigation of new methods. To our knowledge this is the first study to tether experimental animals to insure that they remained within the experimental area. Success in this was critical to analysis of our trawl results. Without knowledge that crab recovered by divers were in the path of the trawl, inferences about results would have been much more speculative. Our underwater diving observations of tethered crab indicated that the behavioral restrictions caused by the tether were minimal. The avoidance ability of a crab approached by a trawl with a speed in excess of 3 knots would be minimal with or without a tether. The tethering techniques were very successful and can be applied to future studies. The full, long-term impact or benefit of this study to industry will largely depend on future efforts that may use the methodology developed here.

C. Dissemination of results.

Copies of the final report will be distributed to the public after approval by the granting agency. Also, limited video tape coverage of above and below water operations is available to the public, upon request.

It is anticipated that industry will use the results of this study in two ways. First, results will help guide the planning of future industry and agency research efforts, because the methods employed in this study have not been attempted previously. Our findings will be useful in designing studies that might use tethering techniques or in developing studies that depend upon accuracy in the positioning of trawl paths on the bottom. Second, our results will provide some additional information for discussion in the establishment of bycatch rates for hard shell red king crab. Both the crab and groundfish fishing industries can use these results, within study limitations, to weigh their prospective concerns on the effect of crab bycatch.

VII. Project sponsorship.

This information was produced with funds provided through the Saltonstall-Kennedy program administered by the National Marine Fisheries Service under Cooperative Agreement NA-89-ABH-00014.

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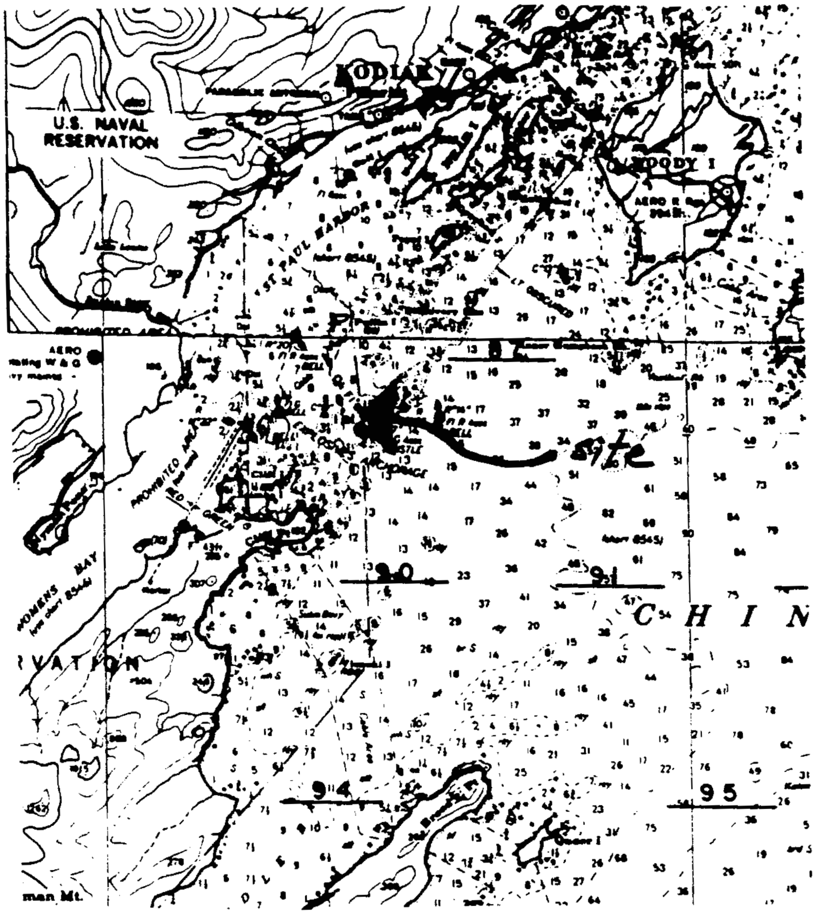
Table 1. Statistics on the recovery of red king crab tethered outside the path of the trawl gear.

Date	Trial	Total number of crab tethered	Number of crab tethered outside trawl path	Number (and percent) of crab recovered outside trawl path	Number (and percent) of crab unrecovered outside trawl path	Number (and percent) of crab with new injuries outside trawl path
April 18	1	39	0	-	-	-
April 18	2	39	8	8 (100.0)	0 (0)	1 (12.5)
April 19	3	39	13	11 (84.6)	2 (15.4)	0 (0)
April 21	4	40	14	14 (100.0)	0 (0)	0 (0)
April 21	5	40	21	17 (81.0)	4 (19.0)	0 (0)
April 21	6	40	12	12 (100.0)	0 (0)	0 (0)
Totals	6	237	68	62 (91.2)	6 (8.8)	1 (1.5)

Table 2. Statistics on the recovery of red king crab tethered within the path of the trawl gear.

Date	Trial	Total number of crab tethered in trawl path	Number (and percent) of crab recovered in trawl	Number (and percent) of crab recovered by divers in trawl path	Total number (and percent) of crab recovered in trawl path	Number (and percent) of crab with new injuries in trawl path
April 18	1	39	5 (12.8)	23 (59.0)	28 (71.8)	2 (5.1)
April 18	2	31	7 (22.6)	15 (48.4)	22 (71.0)	3 (9.7)
April 19	3	26	9 (34.6)	7 (26.9)	16 (61.5)	0 (0)
April 21	4	26	3 (11.5)	13 (50.0)	16 (61.5)	0 (0)
April 21	5	19	1 (5.3)	11 (57.9)	12 (63.2)	0 (0)
April 21	6	28	11 (39.3)	9 (32.1)	20 (71.4)	0 (0)
Totals	6	169	36 (21.3)	78 (46.2)	114 (67.5)	5 (3.0)



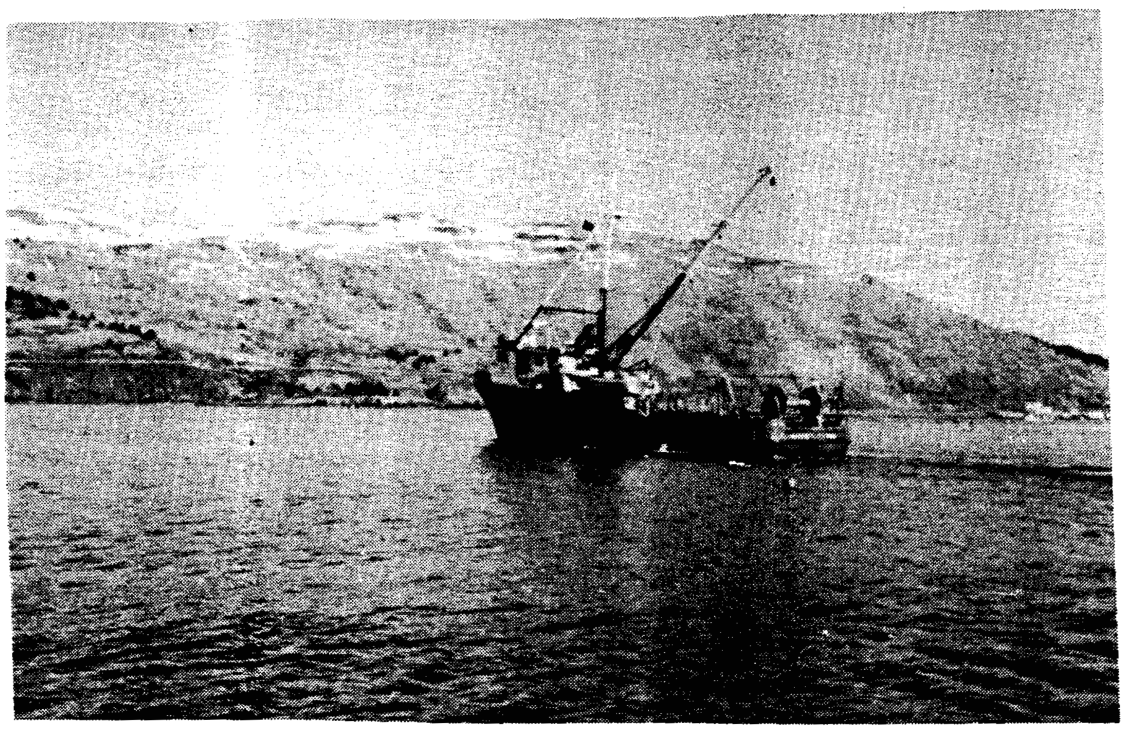


Figure 1. Study area and R/V RESOLUTION trawling through study area.

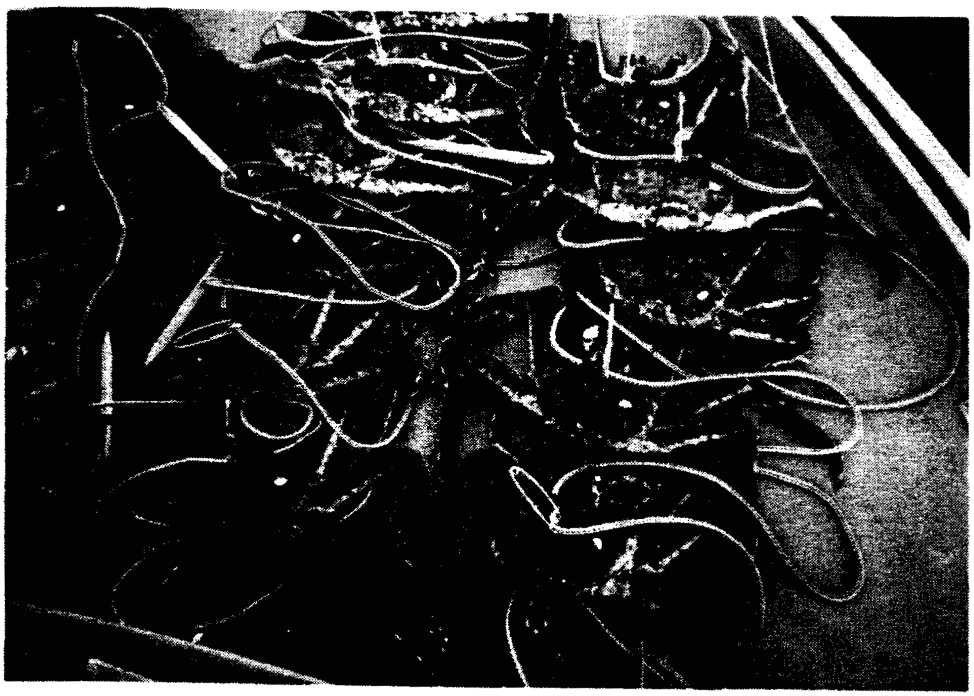
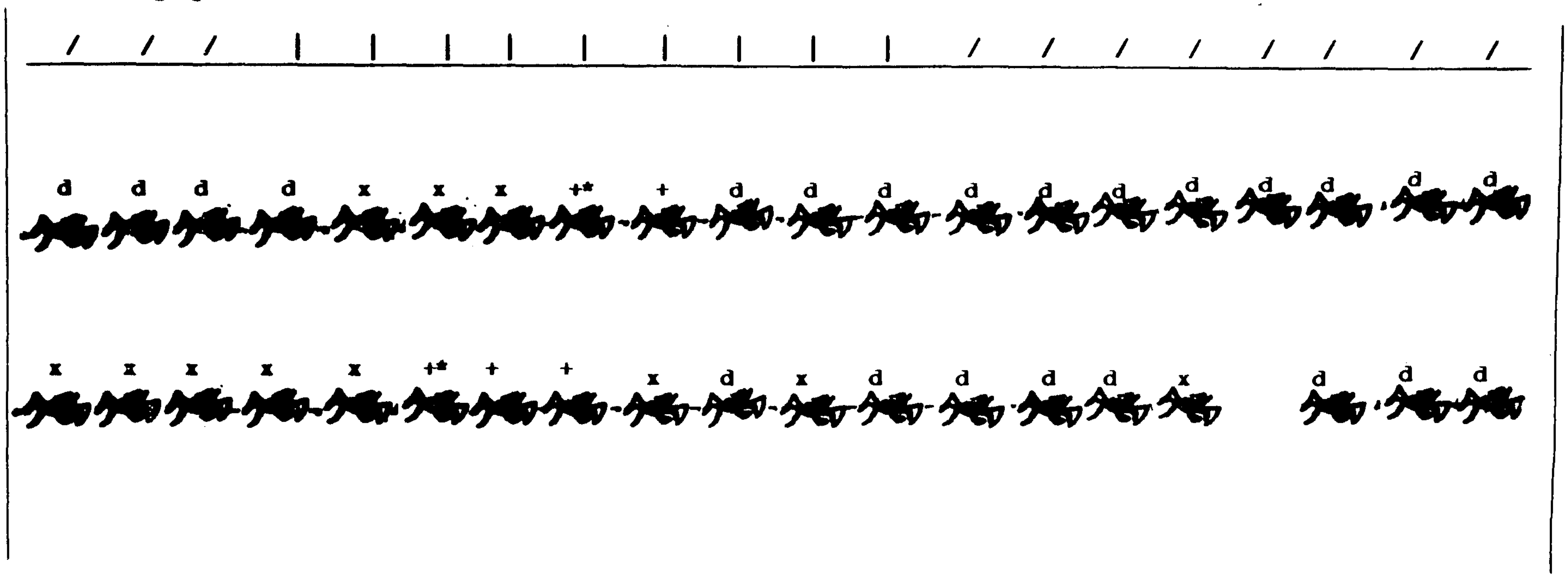


Figure 2. Male king crabs arranged on leadline and ready for deployment (above), and tethering technique.

Trial 1
4-18-89
Crabs tethered = 39
+ = Crabs recovered in trawl = 5
(d) = Crabs recovered free by divers = 0
d = Crabs recovvered on tethers = 23
x = Crabs not recovered = 11
*** = New injury = 2**

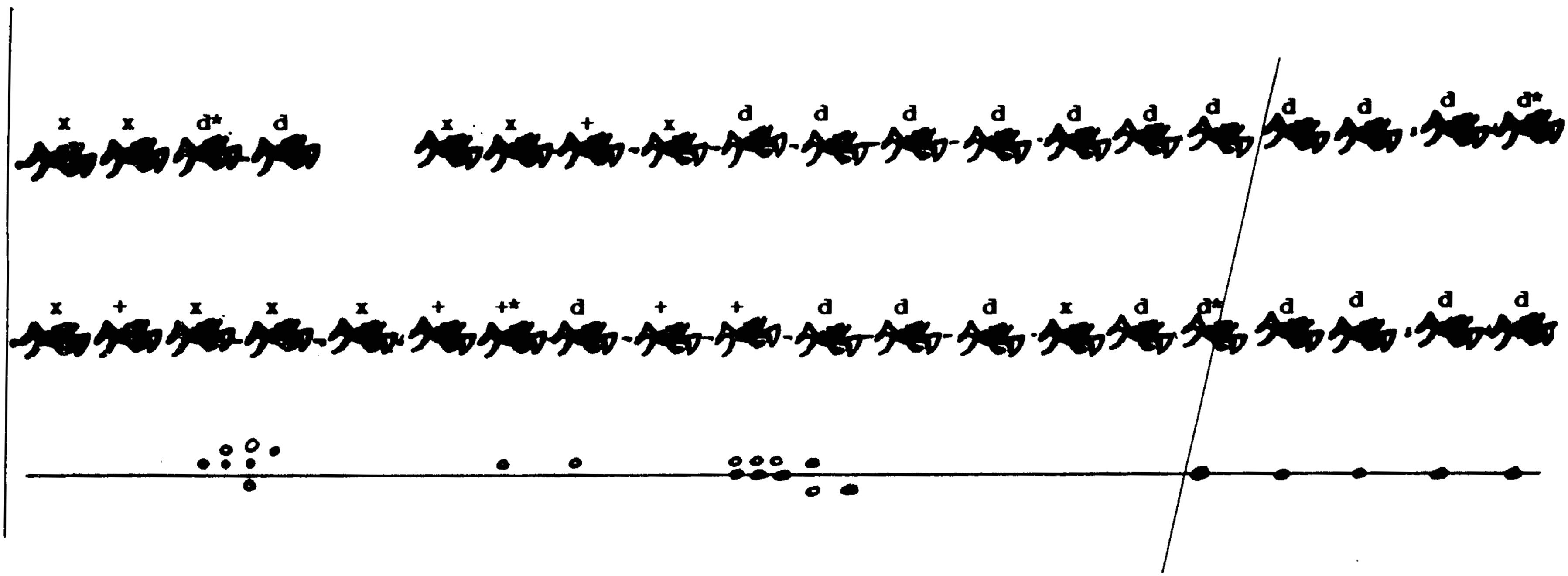
| = Undisturbed stake
/ = Disturbed stake
o = Egg



Appendix Figure 1. Schematic of the results of trial No. 1. Long vertical lines bracket the estimated path of trawl.

Trial 2
4-18-89
Crabs tethered = 39
+ = Crabs recovered in trawl = 6
(d) = Crabs recovered free by divers = 0
d = Crabs recovered on tethers = 23
x = Crabs not recovered = 10
* = New injury = 4

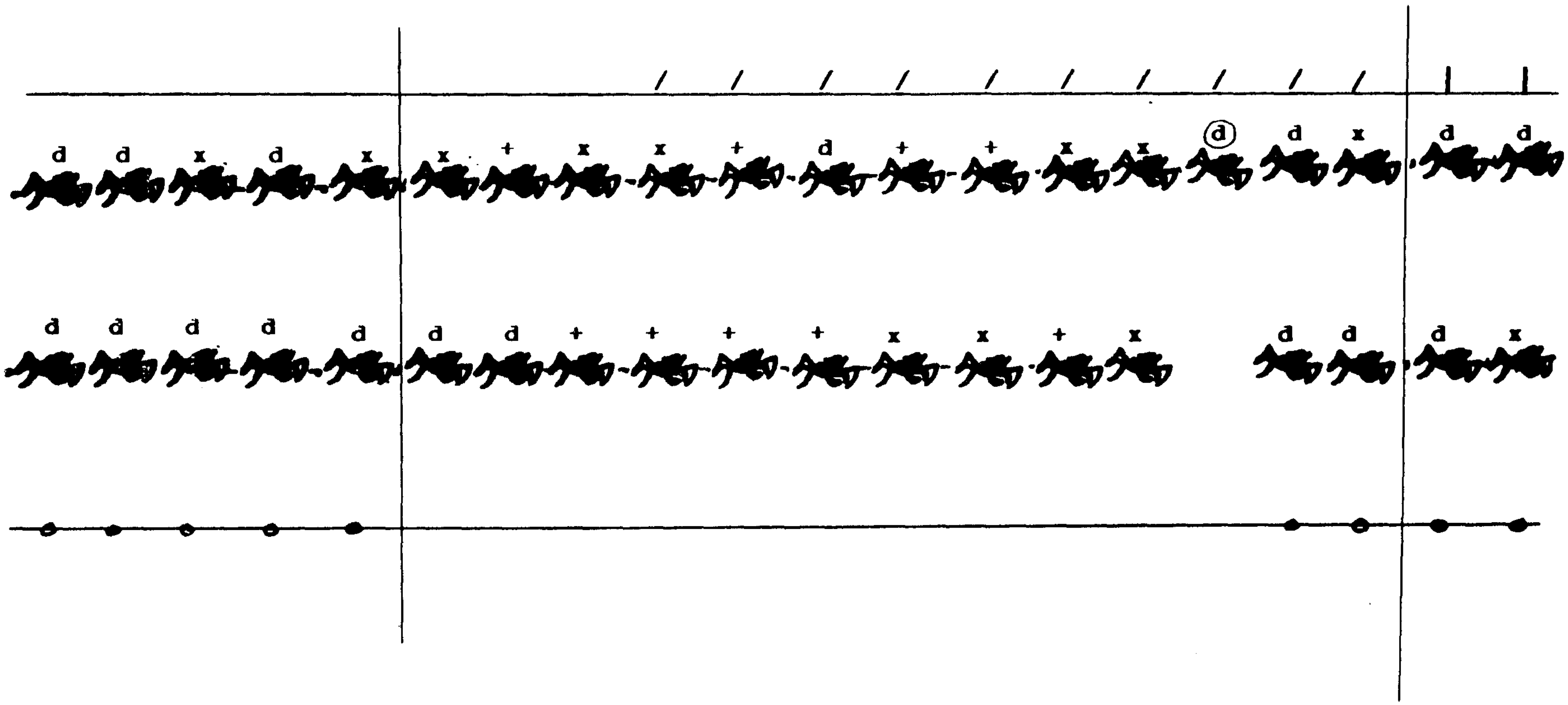
| = Undisturbed stake
/ = Disturbed stake
o = Egg



Appendix Figure 2. Schematic of the results of trial No. 2. Long vertical lines bracket the estimated path of trawl.

Trial 3
4-19-89
Crabs tethered = 39
+ = Crabs recovered in trawl = 9
(d) = Crabs recovered free by divers = 1
d = Crabs recovered on tethers = 17
x = Crabs not recovered = 12
* = New injury = 0

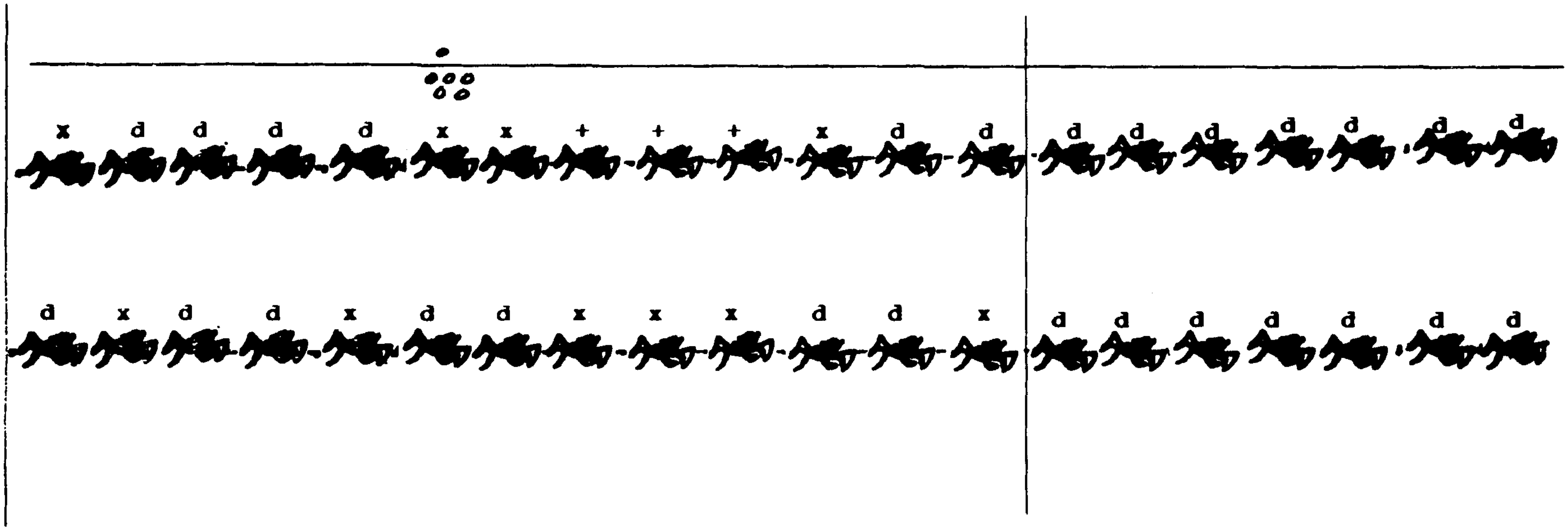
| = Undisturbed stake
/ = Disturbed stake
o = egg



Appendix Figure 3. Schematic of the results of trial No. 3. Long vertical lines bracket the estimated path of trawl.

Trail 4
4-21-89
Crabs tethered = 40
+ = Crabs recovered in trawl = 3
(d) = Crabs recovered free by divers = 0
d = Crabs recovered on tethers = 27
x = Crabs not recovered = 10
* = New injury = 0

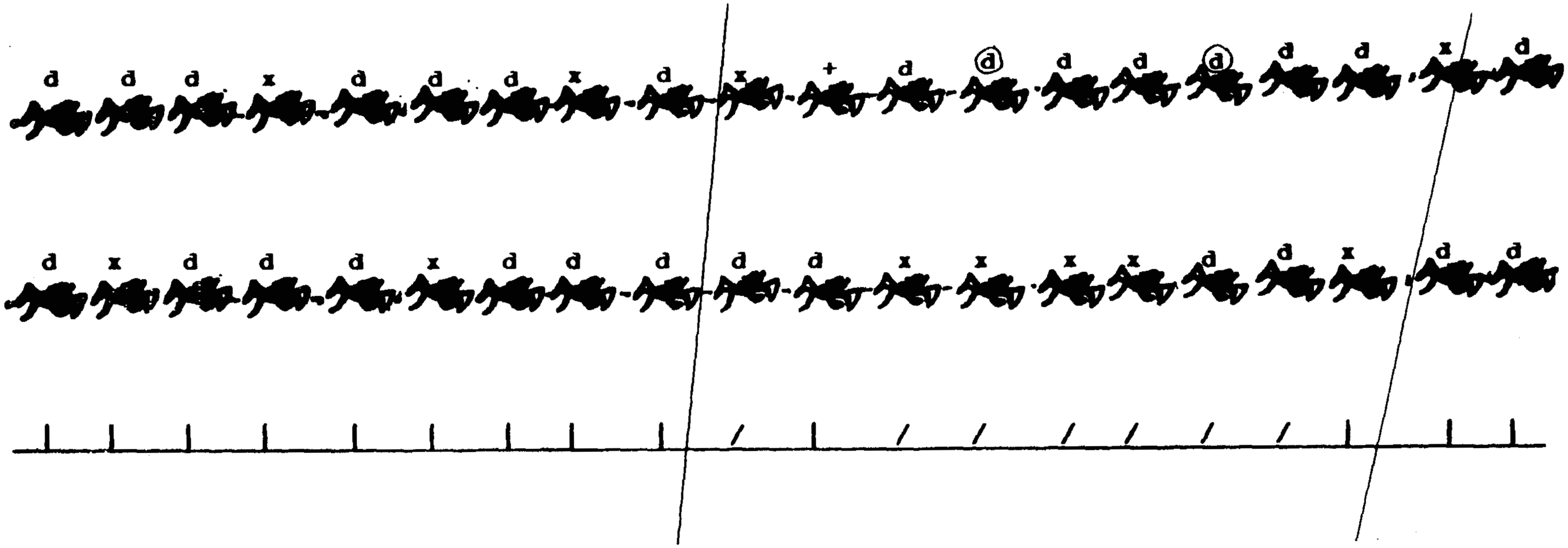
| = Undisturbed stake
/ = Disturbed stake
o = Egg



Appendix Figure 4. Schematic of the results of trial No. 4. Long vertical lines bracket the estimated path of trawl.

Trial 5
4-21-89
Crabs tethered = 40
+ = Crabs recovered in trawl = 1
ⓓ = Crabs recovered free by divers = 2
d = Crabs recovered on tethers = 26
x = Crabs not recovered = 11
* = New injury = 0

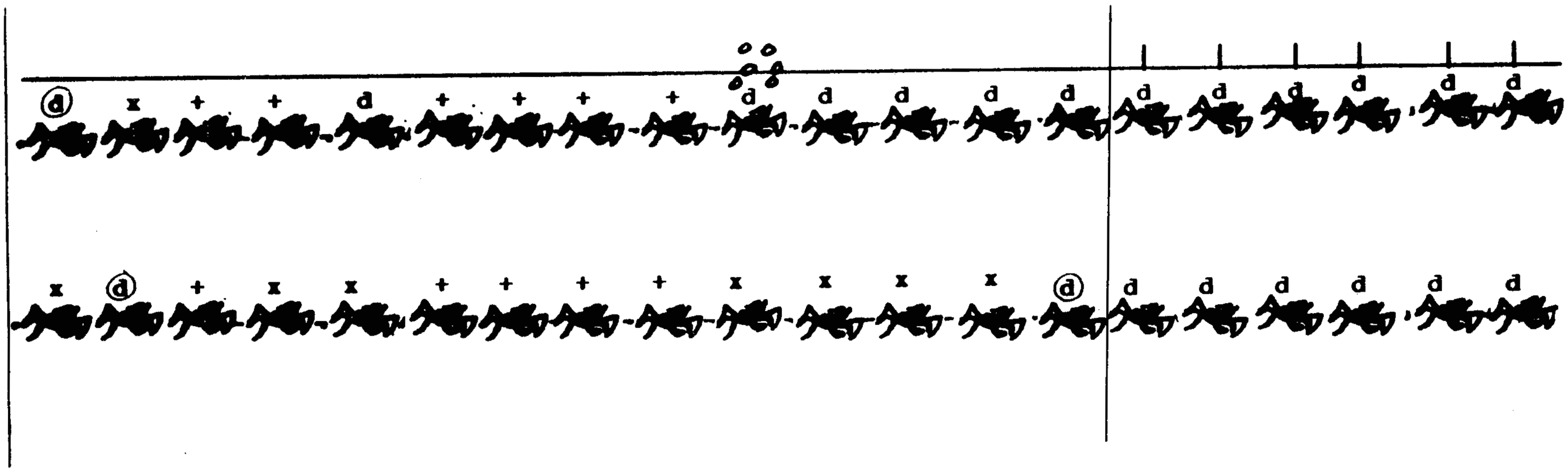
| = Undisturbed stake
/ = Disturbed stake
o = Egg



Appendix Figure 5. Schematic of the results of trail No. 5. Long vertical lines bracket the estimated path of trawl.

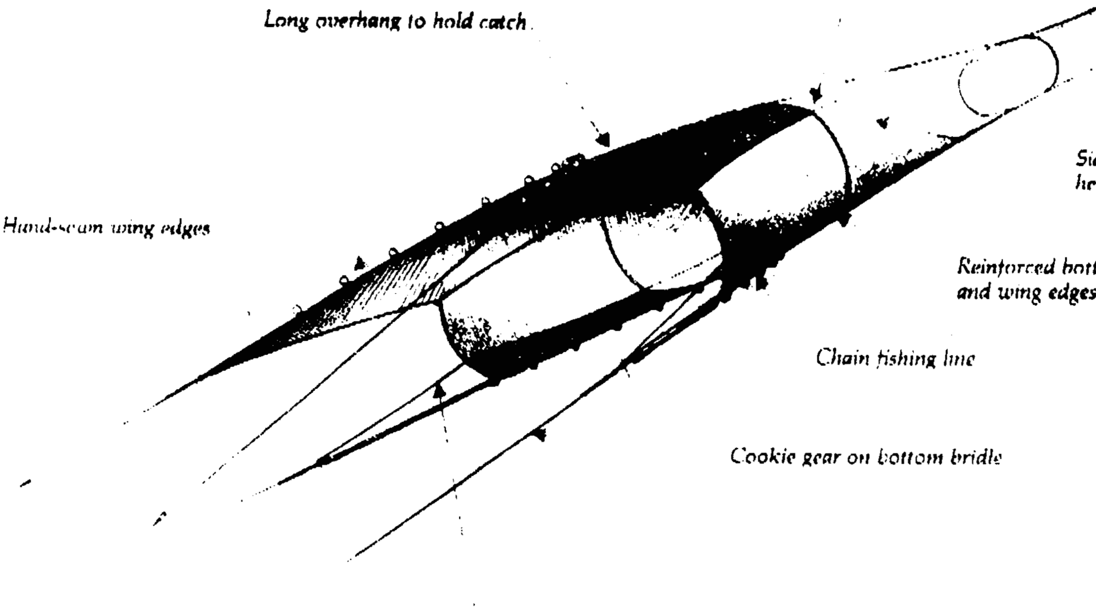
Trial 6
4-21-89
Crabs tethered = 40
+ = Crabs recovered in trawl = 11
(d) = Crabs recovered free by divers = 3
d = Crabs recovered on tethers = 18
x = Crabs not recovered = 8
* = New injury = 0

| = Undisturbed stake
/ = Disturbed stake
o = Egg



Appendix Figure 6. Schematic of the results of trial No. 6. Long vertical lines bracket the estimated path of trawl.

ALEUTIAN COMBINATION TRAWL



4-seam design gives this net more vertical height than the Codfish version, while the net retains many of the good features of the Aleutian design.

High speed net for codfish and other strong-swimming species.

Large overhang holds fish better.

Large mesh options help maximize the mouth opening at higher speed.

Small bottom wings for low maintenance.

Hand sewn edges and double-mesh tear stop strips to reduce repairs.

Many footropes options available.

7910 N.E. Day Road West Bainbridge Island, WA 98110 · 206-842-5623 FAX: 206-842-5832

Appendix Figure 7. Aleutian Combination Trawl

ACE 9121713