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FINAL REPORT

Determining Effectiveness of Dungeness Crab Escapement in Derelict Traps Commonly used in the Washington Waters of the Salish Sea

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Abstract

The prevalence and impacts of derelict crab traps in the Washington waters of the Salish Sea have been well documented by partnering organizations and agencies within the region. Several efforts have been made to reduce trap loss, extract accumulated traps and reduce the impacts (i.e., Dungeness crab mortality, habitat degradation) of traps that become derelict. When properly equipped with legally compliant biodegradable escape cord, a derelict trap becomes "disabled" upon escape cord degradation, allowing an egress route for entrapped crab to escape. However, among the multiple trap designs commonly used in the region, the effectiveness of escapement varies. A laboratory experiment simulating derelict traps was conducted to analyze the escapement effectiveness of 13 trap designs, some equipped with simple modifications. The least successful trap designs in allowing crab escapement were those with escape routes that require crab to push open a door situated on the topside of the trap, offset from the edge. Escapement effectiveness in these traps improved when equipped with a bungee, designed to spring the door open upon escape cord degradation, but escape rates still did not reach the desired 1.00 escapee per crab tested. The traps most successful at allowing crab escapement were those that provided an unobstructed escape panel either on the wall of the trap or along the edge of the topside of the trap. Traps that are not initially designed with this feature can be easily modified by detaching one escape ring, and re-attaching it with escape cord. The opening in the trap following escape cord degradation from the ring falling to the seafloor provides crab the ability to freely escape. This was the first reporting of escapement effectiveness from derelict crab traps of the region, and results can assist in resource management and gear manufacturing decisions.

Introduction

It has been estimated that over 12,000 crab traps are lost each year in the Washington waters of the Salish Sea, mortally entrapping nearly 178,000 harvestable Dungeness crab annually (Antonelis et al., 2011). The Northwest Straits Foundation (NWSF) Derelict Fishing Gear program conducts focused surveys and removals of derelict crab traps, and Washington Department of Fish and Wildlife (WDFW) Marine Enforcement and resource managers conduct on-water surveys during closures of fishing grounds hosting high concentrations of fishing effort. These programs, and others help to reduce the number of derelict crab traps that are persistent in marine waters; reducing the problem but not eliminating it. Additionally, NWSF, WDFW and other groups such as Marine Resource Committee's (MRC) and Washington State University (WSU) Beach Watchers have established ongoing education and outreach programs to inform the public about derelict crab traps and best fishing practices that can reduce trap loss. While difficult to measure, indications are that these programs are effective in certain areas. However, each year approximately 30% of recreational crab harvest endorsements (permits) in the state of Washington are sold to "new" or first-time crab fishers, making it difficult for education efforts to reach all participants of the fishery. With all signs pointing to strong Dungeness crab populations in the Washington waters of the Salish Sea for the foreseeable future, and the associated steady and/or increased opportunities to harvest crab, it is likely that the number of participants in the recreational fishery will remain high; with over 200,000 participants. While gear removal, and outreach and education programs can reduce the number of derelict traps, it is also important to identify ways to reduce the impacts associated with traps after they become derelict.

All shellfish trap fisheries along the North American west coast (WA, OR, CA, AK, BC) require traps to be equipped with biodegradable escape cord (aka: rot cord). In the event that a trap becomes derelict, an egress route held closed by escape cord becomes available upon escape cord biodegradation, essentially disabling the trap. The amount of time it takes for escape cord to biodegrade while underwater is dependent on thickness, thread count and material used, as well as sea water conditions such as temperature, salinity and bacteria concentrations (Redekopp et al., 2006). Regulated escape cord is described in Washington State law as untreated, 100% cotton or other natural fiber with a thread size no larger than 120 (WAC 220-56-320). Studies in the Salish Sea report that it takes between 30 and 148 days for legal escape cord to disintegrate with the most commonly used escape cord styles taking between 90 and 148 days to degrade (Redekopp et al., 2006; Antonelis et al., 2011). Crab traps are also required to have two or more escape rings ($d_i \geq 4.25$ *inches*) located on the upper half of the trap (WAC 220-56-318). This requirement is meant to provide female and sublegal sized males an escape port through the entire soak duration of a trap, whether active or derelict.

Field observations recorded during derelict trap removals conducted by NWSF have shown that disabling mechanisms for derelict crab traps do not always guarantee crab escapement. Dead and dying crab have been found in traps that are technically considered disabled, or "not fishable," meaning that escape cord is gone and the egress route is available. At times this occurs due to biofouling or improper rigging of equipment preventing escape routes from becoming available. Additionally, Antonelis et al. (2011) observed the same escapement failure, where crabs in experimental pots alive at the time of pot disablement or new crabs entering the same "disabled" pot thereafter, could not escape and died within a few weeks. Out of 1,776 derelict traps that were properly equipped with escape cord, the escape cord had disintegrated on 1,572 of them. Of those, 331 traps (21%) were holding 1,077 Dungeness crab at the time of removal, 264 of which were dead. Using calculations reported in Antonelis et al. (2011), the estimated Dungeness crab mortality, in legal sized male equivalents, associated with the extended functionality of these pots could reach 12,000 to 30,000 individuals per year, in addition to the 178,000 already reported. These observations have led researchers to ask: *Why do crab remain held in traps after the trap is technically considered disabled?* And: *Which of the multiple escape mechanisms available are the most effective in allowing crab to escape?*

There are several trap designs commonly used in commercial and recreational Dungeness crab fisheries, with some being more popular than others. Escape mechanisms on these traps vary; however, they often fall within four different categories. In a laboratory study we evaluated six recreational crab trap designs commonly used in the Salish Sea fisheries, and two simple gear modifications, to identify which trap designs are most effective in allowing crab escapement after escape cord degradation. The goal of the study was to evaluate the effectiveness of escape mechanisms found on Dungeness crab traps commonly used in the Salish Sea recreational crab fishery, with the objective to quantitatively inform resource managers, recreational crabbers and trap manufacturers which trap styles are most effective (in terms of least harmful if lost), and offer suggestions for simple modifications to increase the effectiveness of those traps styles that continue to hold crab after becoming disabled.

Methods and Materials

The study was conducted at the Mukilteo Research Station managed by NOAA Northwest Fisheries Science Center, in Mukilteo, Washington. Thirty small test tanks (*d = 4 feet*) and three large holding tanks (*d = 8 feet*) were each equipped with continuously aerated and circulating sea-water, pumped in from the nearby Salish Sea waters of Possession Sound. The study was conducted in two phases. Phase One followed an initial study design, while Phase Two was conducted to test escape effectiveness of trap modifications that were considered after preliminary analysis of data collected during Phase One.

During Phase One, ten trap styles were tested in triplicate during three separate rounds to achieve the goal of testing 90 crab per trap style. These styles consisted of six unmodified types of commonly used recreational crab traps, and four of those commonly used trap types equipped with Modification #1 (M1). Approximately 350 male Dungeness crab (*Cancer magister*) were collected from the Puget Sound the 3rd of November 2014 using a WDFW Enforcement/ Research vessel. The crab were transferred from the vessel into the Salmon Shed of the NOAA Mukilteo Research Station using large totes. The carapace of each crab was measured with calipers to the nearest millimeter and recorded. Each crab was tagged on its healthiest rear leg with a small disc style tag with a unique number and color combination and placed in one of the three holding tanks. Three distinct rounds, each of 21 days, were conducted in the period of November 2014 to February 2015. A resting period of seven days between rounds allowed for all crab to feed and regain their strength after a 21 day period of starvation. Surplus frozen salmon (*Salmonidae spp.*) from a regional hatchery, provided by WDFW personnel was used to feed the captive crab over the course of the project.

On day one of each round, ten tagged crab were transferred from the holding tanks and placed in each test trap. To avoid size bias, the average carapace size for all tagged crab was calculated (*mean = 6.73 inches, min = 6.26 inches, max = 8.15 inches*) and each group of ten included five "small" crab (*carapace < 6.73 inches*) and five "big" crab (*carapace > 6.73 inches*). Each of the 30 traps (with 10 crab and no bait) were appropriately fitted with escape cord, secured shut, and placed in their assigned tanks to simulate derelict traps holding crab prior to escape cord degradation. To avoid both escapement and re-entry through the entry doors, all entry doors were locked closed with zip-ties. The crab and traps underwent this treatment for seven days. Crab that were not placed into traps remained in the larger holding tanks, and were used to replace any crab lost to mortality during the initial seven-day treatment. For this reason, the replacement crab were also not fed during these seven days. On day eight, a mesh bait bag of cut salmon was placed inside each test tank to entice escapement and encourage escaped crab not to re-enter the trap. Each bait bag was placed out of reach of crab inside the traps, and was weighted to prevent them from moving within reach of the crabs in the trap. The escape cord on each of the 30 test traps was then cut, to simulate degradation, providing access to the escape options afforded by each trap type.

Monitoring crab escapement from traps was conducted for 14 days following the initial seven-day treatment. During the first three days, monitoring occurred over an eight hour period, with each tank checked approximately every 1.5 hours. Thereafter, monitoring occurred one to three times per day. Each crab found outside a trap was removed from the tank immediately upon discovery, and placed in the holding tank with the following information recorded for the individual: Date and Time Escape Observed, Date and Time Last Observed in Trap, General Condition (Good, Fair, Poor), Status (Escape, Held, Dead). Any observed crab mortalities were removed from the traps upon discovery, but not replaced if found after the escape cord had been released. Bait in the bait bags was replaced with fresh bait on Day 12 and Day 16 of each round to continue to entice escapement and encourage escaped crab not to re-enter the trap before they could be observed and removed from the tank as escapees. At the end of 21 days, any remaining held crab in traps were removed and placed in the holding tanks.

In order to counteract potential learned behavior, individual crabs were divided into three groups, and each group of crab were assigned to one of three trap groups with similar escape mechanisms per round. The three trap groups were: 1) non-top door escape route, 2) top door only escape route, and 3) top door with modification #1. Each crab group rotated through the trap groups in subsequent rounds so that each escape mechanism was tested on the same crab more than once. Crabs lost to mortality were replaced with a crab of similar size from the surplus crab and a unique tag in subsequent rounds.

All surplus and escaped crabs in the holding tanks were fed salmon every three days, except for during the initial seven days of each round. The holding tanks were cleaned one to two days after feeding, and test tanks were cleaned at the end of each round.

A summary of the trap designs used during Phase One of this study are as follows (also shown in Table 1) (images shown in Appendix A):

- **T1:** This is a square-shaped (*s = 24 inches, h = 12 inches*) collapsible trap assumed to be the most common trap design used in the recreational fishery. Four one-way hinged entry doors (*l = 9.75 inches, h = 4 inches)* are in the center of each lower trap wall, reaching the bottom of the trap. Two escape rings are situated in opposite corners, on the top of the trap, one of which is held in place by escape cord. Upon escape cord deterioration, the escape ring falls to the bottom of the trap, leaving an open cross-shaped egress route directly adjacent to the top edge of the trap. Rounds 1 - 3 traps 1, 2 and 3.
- **T2:** This octagonal-shaped trap (*d = 30 inches, h = 12 inches)* with three one way entry doors each inside a ramped-tunnel is a common trap style among the experienced recreational crab fishers, and is also used by a small percentage of the commercial (treaty and non-treaty) fleet. While actively fishing, a hook and bungee attached to the top of the trap with escape cord, holds shut two hinged access doors, one on the top and the other on the side of the trap. Upon escape cord degradation, the bungee releases tension on the hook and the side-door, attached with hinges to the bottom of the trap, falls open onto the substrate; eliminating one wall from the octagonal trap, leaving an open panel (*l = 12 inches, h = 9 inches*). To eliminate the opportunity for escapement from multiple routes, the topside access door was secured with zip-ties. Rounds 1 - 3 traps 4, 5 and 6.
- **T3:** This is a round trap (*d = 30 inches*) with three one way entry doors each inside a ramped-tunnel entries. Two escape rings are situated on the upper half of the trap wall, on opposite sides. While actively fishing a hook and bungee with escape cord holds shut one hinged access door on the top of the trap. Upon escape cord degradation, the hinged access door on the top of the trap is no longer restrained by bungee. It presents an egress route for crab if pushed open from below, and remains shut by gravity otherwise. The topside door is offset from the edge of the trap by two to three inches. Rounds 1 - 3 traps 7, 8 and 9.
- **T3M1:** This is the T3 trap with modification #1 (M1). The modification consists of a section of shock cord (aka: bungee), approximately 16 inches long attached to the top of the trap and the central portion of the escape door under tension. Upon escape cord degradation, the shock-cord releases tension, immediately opening the escape door on the top of the trap. This modification essentially "spring-loads" the escape door, providing an open panel (*12 inches x 9* inches) as an egress route, offset from the edge of the trap by two to three inches. Rounds 1 - 3 traps 10, 11 and 12.
- **T4:** This is a round trap (*d = 30 inches, h = 10 inches*) that is designed similar to, but much smaller than a typical commercial style trap. The rubber-wrapped steel frame is surrounded by steel-wire mesh, with two escape rings situated on the upper half of the trap walls. Half of the topside of the trap acts as a lid, with hinges opposite one another, used to open the lid. While actively fishing, two rubber straps attached to the frame of

the trap connect to a loop of escape cord and a hook, holding the lid closed. Upon escape cord degradation, tension placed on the hook by the rubber straps is relieved and the trap lid becomes available to open, and sometimes cracks open from the tension of the wire mesh. Rounds 1 - 3 traps 13, 14 and 15

- **T4M1:** This is the T4 trap with modification #1. The modification is as explained in T3; however, the only difference is that the shock cord is connected to the wire mesh with zip ties. Upon escape cord degradation, the shock-cord releases tension, immediately opening the trap lid, providing an open half-circle shaped area as an egress route that is directly connected to the trap walls. Rounds 1 - 3 traps 16, 17 and 18.
- **T5:** This is the second octagonal shaped trap style (*d = 30 inches, h = 9 inches*). Two escape rings are situated opposite one another on the upper half of the traps walls. Four one-way hinged entry doors are along the lower trap walls, reaching the bottom of the trap walls. The hinged access door on the top of the trap is also used as the egress route. The door is held shut by bungee material connected to a loop of escape cord and a hook. Upon escape cord degradation, the access door is no longer held shut by the bungee and is available for crab to escape through if they press it open from below. The access door is offset from the edge of the trap by two to three inches. Rounds 1 - 3 traps 19, 20 and 21.
- **T5M1:** This is the T5 trap design with modification #1 arranged to spring open the access door upon escape cord degradation, providing an open egress route (*12 inches x 9 inches*) offset from the edge of the trap by two to three inches. Rounds 1 - 3 traps 22, 23 and 24.
- **T6:** This trap is circular in shape (*d = 30 inches, h = 9 inches*) with four one-way, hinged entry doors, equidistant from one another on the lower half of the trap walls. Two escape rings are situated opposite one another on the upper half of the trap walls. Similar to T4 and T5, the access door on the top of the trap is held closed by bungee material, escape cord and a hook. The closed access door acts as the escape route for entrapped crab after escape cord degradation. Rounds 1 - 3 traps 25, 26 and 27.
- **T6M1:** This is the T6 trap design with modification #1 arranged to spring open the access door upon escape cord degradation, providing an open egress route (*12 inches x 9 inches*) offset from the edge of the trap by two to three inches. Rounds 1 - 3 traps 28, 29 and 30.

Phase Two

Phase Two was developed after preliminary analysis of data and observations collected during Phase One. The main goal of Phase Two was to test the escapement effectiveness of Modification #2 on the three pot styles that showed the least escapement in the initial tests. The methods used to conduct Phase Two of this experiment were very similar to those used in Phase One, with some minor differences. Most notably, Phase Two was conducted in two rounds, Round 4 (R4) and Round 5 (R5).

Dungeness crab remaining at the end of Phase One were returned to the custody of WDFW. An additional 180 legal size male Dungeness crab were collected on April 21, 2015 by WDFW to be used in Phase Two. The crab were delivered to the Mukilteo Research Station where they were measured, tagged, placed in the holding tanks and fed. After an acclimation period of six days in holding tanks, Phase Two began. The goal of testing an equal sample size of 90 crab per pot style was achieved during two rounds by testing two trap styles in six individual traps in Round 4 and in three individual traps in Round 5, while the third trap style was tested in three individual traps in Round 4 and six individual traps in Round 5. Each trap held ten crab per round, as in Phase One. All other procedures were conducted in identical fashion as Phase One.

A summary of the trap designs used during Phase Two of this study are as follows (also shown in Table 1) (images shown in Appendix A):

- **T3M2:** This is the T3 trap design with modification #2. Rather than using escape cord to disable the access door on the top of the trap, modification #2 uses the same escape mechanism as T1, with four loops of escape cord holding one of the two escape rings in place on the side of the trap. Upon escape cord deterioration, the escape ring falls to the bottom of the trap, leaving an open square-shaped egress route (*6 inches x 6 inches*) on the upper half of the trap wall. Round 4 traps 7 - 12, Round 5 traps 7 – 9.
- **T5M2:** This is the T5 trap design using modification #2 leaving an open square-shaped egress route (*6 inches x 6 inches*) on the upper half of the trap wall. Round 4 traps 1 – 6, Round 5 traps 10 – 12.
- **T6M2:** This is the T6 trap design using modification #2 leaving an open square-shaped egress route (*6 inches x 6 inches*) on the upper half of the trap wall. Round 4 traps 13 – 15, Round 5 traps 1 - 6.

Table 1. Commonly used recreational crab traps used in the Salish Sea fisheries and their designated name used in this study.

Trap	Shape	Features	Escape Mechanism	Modification
T1	Square (h=12 in)	Collapsible, 4 doors	Ring-fall; open panel on top, at edge	None
T2	Octagonal (h=12 in)	3 ramped tunnels, topside and wall access doors	Open wall/door; open panel on trap wall	None
T3	Round (h=12 in)	3 ramped tunnels, topside access doors	Closed door; top panel offset from trap edge	None
T3M1	Round (h=12 in)	3 ramped tunnels, topside access doors	Open door; top panel offset from trap edge	Bungee; spring-loaded door opening
T3M2	Round (h=12 in)	3 ramped tunnels, topside access doors	Ring-fall; open panel on trap wall	Detach escape ring, re-attach with escape cord
T4	Round (h=10 in)	Commercial style, open lid access	Lid, including half-perimeter of trap top	None
T4M1	Round (h=10 in)	Commercial style, open lid access	Open lid, including half-perimeter of trap	Bungee; spring-loaded lid opening

			top	
T5	Octagonal (h=9 in)	4 doors, topside access door	Closed door; top panel offset from trap edge	None
T5M1	Octagonal (h=9 in)	4 doors, topside access door	Open door; top panel offset from trap edge	Bungee; spring-loaded door opening
T5M2	Octagonal (h=9 in)	4 doors, topside access door	Ring-fall; open panel on trap wall	Detach escape ring, re-attach with escape cord
T6	Round (h=9 in)	4 doors, topside access door	Closed door; top panel offset from trap edge	None
T6M1	Round (h=9 in)	4 doors, topside access door	Open door; top panel offset from trap edge	Bungee; spring-loaded door opening
T6M2	Round (h=9 in)	4 doors, topside access door	Ring-fall; open panel on trap wall	Detach escape ring, re-attach with escape cord

Data analysis

To determine the most effective trap designs and associated escape mechanisms, we calculated a frequency of crab escapement per trap style across Rounds 1 through 3 combined (n = ~*90*), and Rounds 4 and 5 combined (n = ~*90*). Crab that died during the 14 day period following escape cord release were excluded from the analysis. Escapement rates are reported as proportion of escaped crab per total crab tested per trap (escapee per crab tested, n = ~*10*). To identify potential significant differences between Rounds 1 through 3, an initial ANOVA was used to compare frequency of escapement per individual trap style per round. The final ANOVA analysis excluded trial rounds to compare frequency of crab escapement between all trap styles from both Phases. Escapement success was also evaluated temporally as the number of days from trap disablement until crab escapement. Carapace length was also analyzed as a potential covariate for escapement.

Results

Of the 350 crab initially collected, a total of 31 mortalities occurred by the completion of Phase One; an 11 week period. While health of crab were not quantified during the study, a decrease in movement and excitement within the crab was observed, coinciding with continued mortalities. During Phase Two, 161 of the 183 crab remained alive at the end of the eight week period, with similar compromise in health observed as time progressed. The majority of crab mortalities occurred in the holding tanks among the surplus crab during rounds, or between rounds. A total of three crab were replaced during the initial seven day treatment of rounds, and six crab died during the 14 day trap disablement period. Dead-loss equated to a total of 53 (10%) of the 530 Dungeness crab captured and held for the study. All remaining live crab at the end of both Phases were transferred to WDFW custody.

Initial analysis found that differences in Dungeness crab escapement success between trap styles was significant (*$p < 0.001$)* with a high proportion of the data explained by trap style (*F-ratio = 150.486*). Analysis of escapement rates in Phase One showed a statistically significant interaction between trap style and rounds (*$p = 0.013$, F-ratio = 1.895*). This interaction effect was significant amongst the trap style with top-door escape routes, both unmodified (T3, T5 and T6) and modified (T3M1, T5M1 and T6M1), yet non-significant amongst the other trap styles (T1, T2, T4, T4M1). The final ANOVA, testing escape per trap style for all crab tested in both phases (*n = 1164; 6 mortalities removed)* also proved to be significant (*$p < 0.001$, F-ratio = 174.223, $R^2 = 0.645$*) while crab carapace length was determined to be insignificant (*$p < 0.176$*).

The effectiveness of Dungeness crab escapement from T1 and T2 traps was very high in both the proportion of the tested population that escaped, and the speed in which they escaped. In T1 traps, the proportion of escaped crab per trap (escape rate) was 0.989 (95% CI = 0.968-1.00; Table 2; Figure 1), and 81% of crab that escaped did so within three days after escape cord release (range = < 0.001 - 11.04 days; Figure 2). Very little difference in escapement occurred between R1, R2 and R3, as the escapement rate was 0.966, 1.00 and 1.00, respectively (Figure 1). The escape rate of crabs in T2 traps was 1.00 (Table 2; Figure 1). All 90 crab escaped from T2 traps within four days (range = < 0.001 - 3.99 days), 79% of which escaped within the 24 hours after escape cord release (Figure 2). No difference between escapement proportions existed between R1, R2 and R3 (Figure 1).

The unmodified commercial style sport traps (T4) tested during the study provided escapement rates of 0.910 escapee per crab tested (95% CI = 0.822-0.998; Table 2; Figure 1), where 84% of the 81 escapees escaped within the initial three days after escape cord release (range = 0.07 – 8.10 days; Figure 2). Escapement success in these traps retrofitted with the spring-loaded lid opening (T4M1) increased to 1.00 escapee per crab tested (Table 2; Figure 1), and 97% of the 89 crab that escaped did so within the first three days of trap disablement (range = < 0.001 – 3.16 days; Figure 2). It should be noted that during the seven day holding period prior to escape cord release, several crabs escaped from T4 and T4M1 traps. During this period in R1, a total of 32 crab escaped before the traps were equipped with several zip-ties to block or close potential "leaks" in the traps. Seven crab escaped during the seven days prior to disablement in R2, and three escaped in R3. Therefore, with what we believe to be very low likelihood, the potential exists for crab to have escaped from an egress route other than the designed escape mechanism being tested during the 14 day disablement periods.

The overall escape rate for T3 traps was 0.101 escapee per crab tested (95% CI = 0-0.212; Table 2; Figure 1), as only nine of 89 tested crab escaped during the treatment period of 14 days following trap disablement. Of the few crab that escaped, all escapement occurred within 13.25 days (range = 0.92 - 13.23 days), 44% of which escaped within the initial three days after escape cord release (Figure 2). These traps exhibited greater effectiveness in allowing escapement in R1 than in R2 and R3, as the escape rate went from 0.267 to 0.033 to 0.000, respectively (Figure 1). Escapement success in T3 traps increased with the spring-loaded access door retrofit, as overall crab escapement in T3M1 was 0.811 escapee per crab tested (95% CI = 0.716-0.906; Table 2; Figure 1), where 73 of 90 crab escaped during the treatments. During R1 the escapement rate in T3M1traps was 0.933, which dropped to 0.733 in R2, followed by 0.767 in R3 (Figure 1). Of the escaped crab, 56% escaped within the initial three days of trap disablement (range = 0.07 – 8.10 days; Figure 2). Crab escapement rates increased even further as the T3 traps were equipped with the ring-fall modification (T3M2). In T3M2 traps, the escapement rate was 1.00 escapee per crab tested (Table 2; Figure 1), and 98% of the 89 crab that escaped did so within the first day of escape cord release (range = < 0.001 – 1.92 days; Figure 2).

Table 2. Estimated legal-sized male Dungeness crab escapement rates by trap and escapement mechanism design, in simulated derelict recreational crab traps used in Washington waters of the Salish Sea (CL = confidence limit).

Trap	Escape Mechanism	Escapement Rate (escaped crab per crab tested)	95% CL Lower	95% CL Upper
T1	Ring-fall; open panel on top, at edge	0.989	0.968	1.000
T2	Open wall/door; open panel on trap wall	1.000	1.000	1.000
T3	Closed door; top panel offset from trap edge	0.101	0.000	0.212
T3M1	Open door; top panel offset from trap edge	0.811	0.716	0.906
T3M2	Ring-fall; open panel on trap wall	1.000	1.000	1.000
T4	Lid, including half-perimeter of trap top	0.910	0.822	0.998
T4M1	Open lid, including half-perimeter of trap top	1.000	1.000	1.000
T5	Closed door; top panel offset from trap edge	0.100	0.008	0.192
T5M1	Open door; top panel offset from trap edge	0.544	0.433	0.656
T5M2	Ring-fall; open panel on trap wall	1.000	1.000	1.000
T6	Closed door; top panel offset from trap edge	0.056	0.011	0.102
T6M1	Open door; top panel offset from trap edge	0.633	0.492	0.774
T6M2	Ring-fall; open panel on trap wall	1.000	1.000	1.000

Crab escaped from the T5 traps at a rate of 0.100 escapee per crab tested (95% CI = 0.008-0.192; Table 2; Figure 1), as only eight of the 90 tested crab escaped. All crab escaped within 12 days after trap disablement, 44% of which escaped within the first three days (range = 0.92 – 11.98 days; Figure 2). Similar to T3 traps, escapement success was significantly higher in R1 (0.267) than in R2 (0.000) and R3 (0.033); however in T5 traps, the escape rate in R3 was higher than the null value in R2 (Figure 1). The T5 traps showed some improvement in escape effectiveness when equipped with the spring-loaded access door, as 49 of 90 crab escaped, producing an overall escape rate in T5M1 traps of 0.544 escapee per crab tested (95% CI = 0.433-0.656; Table 2; Figure 1). Just over half (51%) of those that escaped did so within the initial three days of escapement (range = 0.20-13.23 days; Figure 2). Escapement from T5M1 traps in R2 and R3 were significantly lower than those in R1, where they dropped from 0.733 (R1) to 0.467 (R2) to 0.433 (R3) (Figure 1). Similar to T3 style traps, the escapement success in T5 traps equipped with the ring-fall modification (T5M2) increased to 1.00 escapee per crab tested (Table 2; Figure 1); and 96% of the 90 crabs escaped during the first day of trap disablement (range = < 0.001 – 1.92 days; Figure 2).

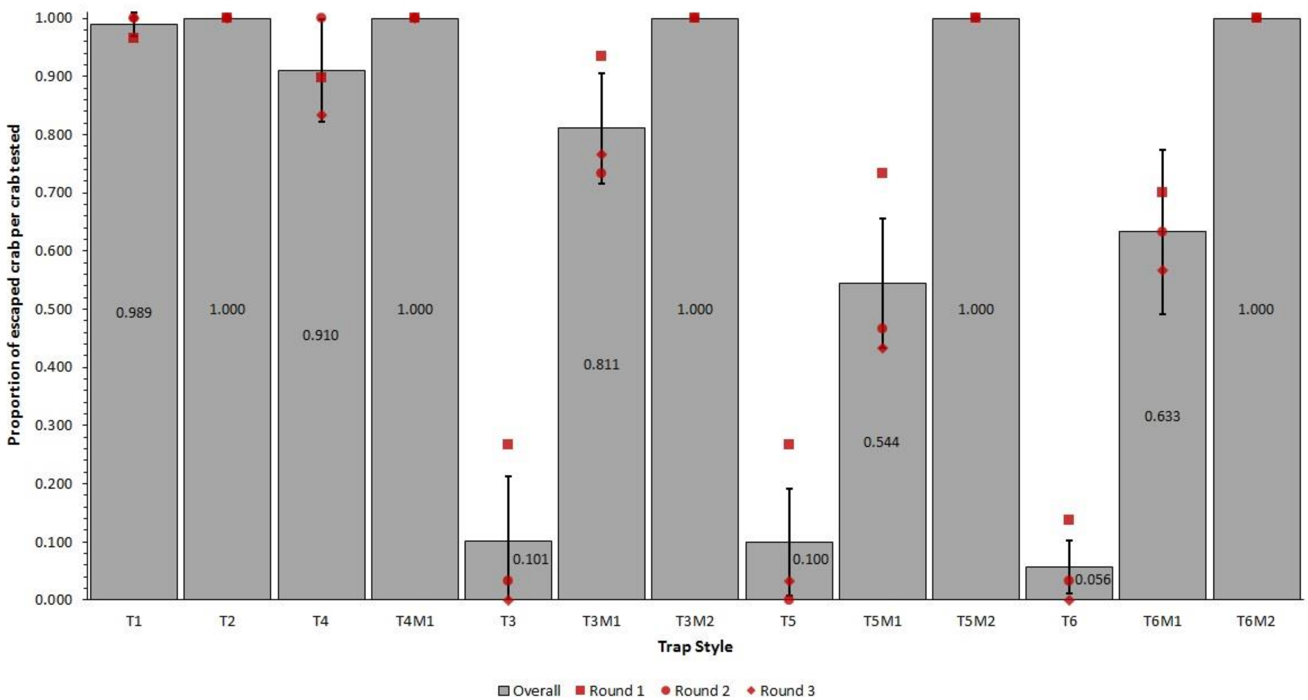

Figure 1. Estimated legal-sized male Dungeness crab escapement rates by trap design, overall and per round, in simulated derelict recreational crab traps commonly used in Washington waters of the Salish Sea (Error bars shown in 95% confidence intervals).

The overall escapement rate from T6 traps was 0.056 escapee per crab tested (95% CI = 0.011-0.102; Table 2; Figure 1); with only four of 89 test subjects escaping. The four crab escaped between 4.04 and 13.97 days, and none escaped within the initial three days after trap disablement (Figure 2). The proportion of escaped crab per crab tested was much higher in R1 (0.138) than in R2 (0.033) and R3 (0.000) (Figure 1). The spring-loaded access door modification on the T6 traps (T6M1) increased the escapement rate to 0.633 escapees per crab tested (95% CI = 0.492-0.774; Table 2; Figure 1). A total of 57 crabs escaped, 61% of which escaped within the initial three days of trap disablement (range = 0.04 – 13.97 days; Figure 2). The differences in escapement effectiveness from R1 to the following rounds were more gradual and less dramatic than those observed in the other traps with topside access doors (T3 and T5). In T6M1 traps the escapement rate in R1 was 0.700 escapees per crab tested, followed by 0.633 in R2 and 0.567 in R3 (Figure 1). Similar to both T3M2 and T5M2, the escapement rates in T6 traps equipped with the ring-fall modification (T6M2) were 1.00 escapee per crab tested (Table

2; Figure 1), and 96% of the 90 crabs escaped during the first day of trap disablement (range = < 0.001 – 1.78 days; Figure 2).

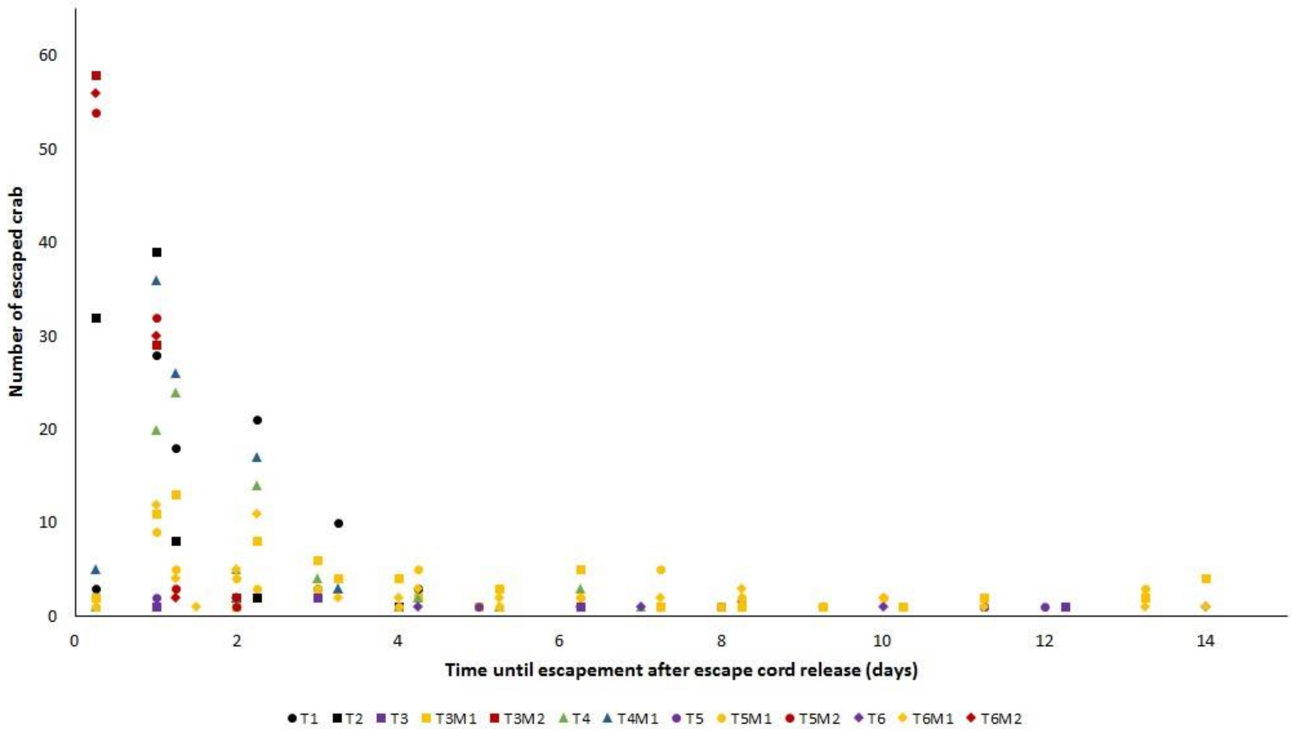

Figure 2. Observed time from trap disablement to crab escapement per trap design in simulated derelict recreational crab traps commonly used in Washington waters of the Salish Sea.

Discussion

This study represents the first description of the escape mechanism effectiveness in traps commonly used in the recreational Dungeness crab fisheries of the Salish Sea and elsewhere. The variance of escapement success between different trap designs and escape mechanisms clearly shows which traps are most effective at allowing crab to escape after escape cord degradation, and which could be improved upon to allow for easier crab escapement. Additionally, findings provide descriptions of simple trap modifications that can increase crab escapement after trap disablement, and in turn reduce ghost fishing in trap designs that are difficult for crab to escape from.

We assume that the rotation of crab through different trap design groups between rounds eliminated learned escapement behavior. Regarding crab health, while predation on entrapped crab from sunflower stars (*Pycnopodia helianthoides*) and other Dungeness crab cohorts in derelict traps has been documented (Antonelis et al., 2011), it is evident that much of the mortality is simply due to starvation and degraded health resultant from being entrapped for a long period of time. At the time of this study, there was not an established protocol for grading the stages of Dungeness crab health. However, development of protocols for Reflex Action Mortality Predictors (RAMP) in Dungeness crab is currently underway in Oregon (Noelle Yochum, OSU, personal communication), which could be used in the future to evaluate stages of Dungeness crab health while in captivity. If we assume that observations of diminishing movement and activity among the crab tested over time correlated to diminishing health over time, then the statistically significant interaction between trap style and rounds may assist our understanding of how crab in various stages of health escape from disabled derelict traps. The effect of rounds was not the same for each of the trap styles, as inspection of the escape rates (Figure 1) show that the effect of rounds (associated with length of time in captivity) only occurred in traps with top-door escape routes, whether equipped with modification or not. The round effect was non-existent for the other, more successful traps that reached escapement rates of 0.989 to 1.00 escapee per trap (T1, T2, T4M1, T3M2, T5M2 and T6M2). We note that the degree of significance in escapement success between rounds is consistent with expectations, and conclude that it bolsters the two prominent findings that (a) open access escape routes on the wall or topside edge of trap are most effective, and (b) obstructed escape routes, even with doors sprung open are less effective when offset from the edge of the trap. Most simply put, healthy and unhealthy crab alike escape from traps with unobstructed escape routes, while some healthy and fewer unhealthy crab escape from traps with obstructed escape routes. Additionally, re-using the crab population across experiments reduced the total number of samples taken from the Salish Sea to conduct the study.

Of the unmodified traps that were tested, the clear leaders in escapement effectiveness after disablement were the square-shaped Danielson® collapsible trap (T1) and the octagonal-shaped Danielson® trap with three ramped tunnels. Upon initial inspection, other than the material used to make them, these two trap designs do not show any apparent similarities, nor do their escape mechanisms. The T2 traps provide an open wall on the side of the trap at ground-level for crab to simply walk out of, whereas the T1 traps have a smaller escape hatch that is on the top of the trap. There are obvious reasons why these are different from the least effective unmodified traps, as the octagonal Danielson without ramps (T5) and the round SMI traps with (T3) and without (T6) ramps all provide an escape door on the top of the trap for the crab to find and press open from below in order to escape. With such success in the traps with passive egress routes, those that do not require the opening of a door (T1 and T2), the initial assumption was adding a spring-loaded component to the topside access doors (M1) on T3, T5 and T6 would provide similar open access to the escape hatch. However, while escapement effectiveness increased with this modification, it was still highly variable between rounds, and the overall escapement rates in spring-loaded modified traps ranged from 0.544 in T5M1 to 0.811 in T3M1, far from the desired 1.00. One similarity with these traps is that their access doors on the top of the traps are offset from the edge of the trap by two to three inches. This offset seems to be enough to truly effect the ability for crab to identify and access the escape route, as an escaping crab would need to climb up the trap wall and then invert itself to negotiate the offset from the trap edge. Whereas on the T1 style escape route, which is also on the top of the trap, the escaping crab has a direct route up the wall and out of the trap, and the same applies for the commercial style sport traps with the M1 modification (T4M1).

The second modification (M2), tested during Phase Two, was essentially testing the escapement effectiveness of the combination of the two most effective escapement designs seen in T1 and T2. The ring-fall concept is a simple modification following the design of the T1 trap, while providing an unobstructed escape route on the wall of the trap is similar to that of the T2 trap design. Traps tested with the M2 modifications all reached escapement rates of 1.00 escapee per crab tested, all of which occurred within the first two days after initial trap disablement. This supports the concept that the unobstructed egress route, similar to those in T1 and T2 traps, allowing for passive escapement is the most effective escape mechanism that a crab trap can be equipped with.

Effectiveness of escapement determined in this study was based on the proportion of live crab that escaped from a crab trap over the course of a 14 day period, and by the amount of time it took for those crab to escape after trap disablement. The most successful traps had escape rates of 1.00 escapee per crab tested, with nearly all escapement occurring within the first three days after escape cord release. In the least successful traps, while the total number of escapees were few, they continued to escape into days 13 and 14, suggesting that longer treatment period may result in greater total escapement in the T3, T5, T6, T3M1, T5M1 and T6M1 traps. Therefore, while we cannot say that crab don't escape from these traps, we can confidently say that they are much less effective in terms of duration of entrapment than the other traps with alternate escape mechanisms that provide unobstructed egress routes on the trap wall or along the top edge of the trap. Whether by predation, starvation or other forms of degraded health, the longer a crab remains entrapped in a derelict trap, the greater the chance of mortality, as reported in Antonelis et al. (2011), where the average number of days until death for an entrapped crab was 51.5 days (range = 6 – 320 days). This emphasizes the importance of crab having escape routes that are easily accessible, allowing for rapid escapement.

The study did not take into consideration any of the other reasons why traps remain actively fishing after escape cord degradation. This typically happens due to biofouling, such as plumose anemones (*Metridium giganteum*) growing on the traps and holding the escape mechanism shut, or barnacles (*Semibalanus spp.*) and algae (*Saccharina spp.*) interfering with the hinge action of an access door (Antonelis et al., 2011; Maselko et al., 2013). This is also caused by improper setup of fishing gear, when bridles or clips are attached in ways that connect the escape mechanism to the trap frame, keeping it closed even though the escape cord has deteriorated. Therefore, while a modification or re-design of a trap style can increase crab escapement in derelict traps, and reduce the associated mortality, it remains extremely important that fishers are conscientious of how they configure their trap gear so that the escape hatch will become available to crab upon escape cord degradation. Another consideration not tested during the study was trap sedimentation. Most all popular Dungeness crab fishing grounds within the Salish Sea region host a mud and/or sand substrate, where traps, particularly those that are derelict, can become partially or completely buried over an unspecified amount of time. Such sedimentation could cause failure of escape mechanisms, such as those provided on the T2 traps, where a layer of sediment could prevent the bottom-hinged sidewall door from falling open. The ring-fall escape design, whether on the top-edge of the trap, or on the upper half of the trap wall would be less likely to fail due to sedimentation unless the trap became completely buried in sediment, in which case any escape mechanism would fail. We believe that the ring-fall design, especially on the upper half of the trap wall, provides the most effective escape mechanism, while also minimizing opportunities for improper gear set-up that would cause the escapement mechanism to fail when triggered.

Degradable escape panels, made of biodegradable polymers originally developed for traps in the Chesapeake Bay blue crab (*Callinectes sapidus*) fishery have proven successful in disabling derelict traps (Bilkovic et al., 2012), and they have been modified to be tested in other fisheries, such as the Dungeness crab fishery in Southeast Alaska. During the early stages of planning for this project, we considered testing similar biodegradable escape panels that would be specifically designed for the Salish Sea fisheries. However, after consideration, it was decided to focus on solutions that would be readily available to regional crab fishers, by utilizing the traps and materials that are commonly being used within the local fishery. Results reported here suggest that the biodegradable escape cord, when configured properly with appropriate escape mechanisms, is an effective material to be used for disabling crab traps. Regardless, considering the degraded health and mortality caused by entrapment, we continue to recommend the use of relatively thin escape cord that can biodegrade within a shorter duration that what is commonly used today. We believe that this type of change would not significantly affect costs per fisher within the recreational crab fishery since recreational effort is relatively low in comparison to the commercial fleet, where such changes would require analysis of increased expenses caused by additional rigging of gear and potential loss of gear components.

Testing commercial style traps was beyond the scope of this study, and plans for future studies to test the escapement effectiveness of commercial style traps are currently under development. Findings reported here will not only assist in reducing ghost fishing in recreational traps by modifications in gear design, but several points can be considered in the commercial fisheries as well. Most notable, is the limited escapement success among traps with obstructed escape routes, offset from the trap edge, and the high escapement rates in traps with unobstructed escape routes. This information can be of value to commercial fishers and resource managers when identifying ways to limit the loss of resource associated with derelict traps.

Finally, it should be noted that it was beyond the scope of this project to test all possible traps available to the Dungeness crab fisheries in the region. For this reason, the traps chosen to be tested were done so by committee, keeping in mind the features of the traps that are similar between different manufacturers and users. For example, other traps with hinged access doors as their main form of escape, use different style hinges and material that could reflect slight differences in functionality between traps. However, we believe the effectiveness of an open panel either on the wall of a trap or on the top edge of the trap connected to the edge is universal in concept, and can be applied to most, if not all, trap styles used within the region.

Recommendations

Based on observations and results of the crab trap escapement study, the following are recommendations to further reduce the impacts of derelict crab traps on the marine environment, particularly those hosting Dungeness crab fisheries.

- Consider adjusting the language in trap gear regulations requiring open-access, unobstructed escape routes to become available on trap walls or along the topside edge of traps upon escape cord deterioration.
- Consider management measures that reduce the size of legally compliant escape cord that will deteriorate at a faster rate than those that are most commonly used
- Include information about the ring-fall modification in ongoing education and outreach programs targeting Dungeness crab fishers.
- Provide trap gear manufacturers with the findings reported here, and suggest modifications in design of top-door style traps to include a less obstructed escape route (i.e., ring-fall modification).
- Conduct similar studies that test the escapement effectiveness of commonly used trap designs in the commercial Dungeness crab fisheries of Washington State and elsewhere.

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