Bycatch of rockfish in spot prawn traps and estimated magnitude of trap loss in Washington waters of the Salish Sea

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ABSTRACT

Derelict fishing gear is a known stressor to rockfish populations in the Washington waters of the Salish Sea, including two species currently federally protected under the Endangered Species Act. In Washington and British Columbia, rockfish bycatch in actively fished (non-derelict) prawn traps has been documented in spot prawn test fisheries conducted by state and provincial government, and both live and dead rockfish have been found in derelict prawn traps encountered during derelict fishing gear removal operations in Washington. This study calculates rockfish bycatch rates in actively fishing prawn traps and provides preliminary trap loss rates for both commercial and recreational fisheries. Rockfish bycatch rates were determined through analysis of Washington Department of Fish and Wildlife (WDFW) Spot Prawn Test Fishery Data collected from 2004 to 2013. Data from WDFW creel surveys were used to update preliminary prawn trap loss rates. Interviews with WDFW marine enforcement officers were conducted to estimate the number of lost traps that are recovered before becoming derelict. The overall rockfish catch rates in Washington waters of the Salish Sea were 0.023 rockfish per trap drop, with considerable spatial and temporal variability. The lowest catch rates were consistently seen in Marine Area 7 (San Juan Islands and North Puget Sound); while the highest catch rates were seen in Marine Area 11 (south-central Puget Sound). The trap loss rate estimated for the recreational fishery is 2.33% of all traps fished. We estimate that over the years 2012 and 2013 an average of 653 recreational prawn traps became derelict each year. The accumulation of derelict prawn traps has a mostly unknown effect on benthic habitats of Puget Sound, which warrants additional research. While rockfish bycatch and prawn trap loss rates reported here are low, our findings support evaluating methods to reduce rockfish encounters with prawn traps.

Introduction

In the Salish Sea, recreational trap-based spot prawn (*Pandalus platyceros*) fisheries have increased in popularity in recent decades. Like Dungeness crab (*Cancer magister*) fishing, spot prawn fishing has offered recreational and commercial fishers the opportunity to harvest a quality product in the wake of decreased salmon and groundfish fishery opportunities. Though the spot prawn trap fishery has relatively low bycatch compared to other fishing gear types, in recent years rockfish have been documented in actively fished (non-derelict) (Favaro et al., 2010, 2012; Rutherford et al., 2010) and derelict prawn traps (WA DGDB accessed 9/8/2016).

Increased fishing effort targeting rockfish and other groundfish species in the 1970s and 1980s resulted in the depletion of several rockfish species throughout the Salish Sea (Williams et al., 2010; Yamanaka and Logan, 2010). Three of these rockfish species were listed for federal protection in Puget Sound under the U.S. Endangered Species Act (ESA) in 2010: yelloweye rockfish (*Sebastes ruberrimus*), canary rockfish (*S. pinniger*), and Bocaccio (*S. paucispinis*) (Endangered and Threatened Wildlife and Plants, 2010). These, and 10 other rockfish species have been listed as Washington State Species of Concern (WDFW, 2011, 2014). In 2017, research concluded that canary rockfish in Puget Sound were not a distinct population segment from those off the West Coast, and were therefore delisted from the ESA (82 FR 7711). Though fisheries targeting rockfish are largely closed, rockfish in Puget Sound continue to face a number of threats, ranging from degraded water quality, to derelict fishing gear and fisheries bycatch (WDFW, 2011).

Most rockfish are long-lived with long generation times, and become sexually mature from approximately 4 or 5 years (Bocaccio) to over 20 years old (yelloweye rockfish) (Love et al., 2002). Once mature, individual female rockfish release from thousands to over a million planktonic larvae annually. Most larvae in the Washington waters of the Salish Sea (hereafter referred to as Puget Sound) are released in the spring, from March through May (Greene and Godersky, 2012). Larval survival rates are extremely low, and only a small fraction transition from pelagic habitat to benthic environments where they settle as juveniles (3 cm–9 cm in total length) in the summer and fall. Juveniles gradually move to deeper areas that have rock and/or diverse bathymetry as they grow (Gaines and Roughgarden, 1987; Love et al., 1991). Rockfishes have swim bladders that keep them at neutral buoyancy. As they are brought up from deep water they often suffer from barotrauma that may result in injury or death, making them vulnerable to incidental mortality as bycatch in commercial and recreational fisheries (Pribyl et al., 2011; Sawchuk et al., 2015).

Trap gear such as prawn traps is widely viewed as a lower impact alternative to trawl nets, gillnets, and other gear types because of potentially less bycatch of unintended species, or concurrent habitat damage (Favaro et al., 2012). However, derelict trap gear can continue to catch and kill marine species until it either becomes disabled by disintegration of escape cord, or loses structural integrity (NRC, 2008). Derelict trap gear also alters the character of benthic habitats by adding artificial structure, though habitat effects are less well understood compared to other derelict gear types, especially gillnets (Macfadyen et al., 2009). Impacts to marine species and habitat from derelict traps are also a concern in several fisheries around the world (NRC, 2008; Macfadyen et al., 2009). Within British Columbia waters of the Salish Sea, Breen (1987) estimated a trap loss rate of 11%, accounting for mortality equivalent to 7% of the reported Dungeness crab catch in the Fraser River District. In Puget

Sound, [Antonelis et al. \(2011\)](#) estimated over 12,000 crab traps become derelict each year, causing mortality of over 178,000 Dungeness crab annually (US\$744 K worth based on a price of \$2.19/lb). Additionally, the Northwest Straits Marine Conservation Initiative (NWSI) has reported on the hazards of derelict fishing nets in Puget Sound while conducting surveys and removal of derelict fishing gear in the region since 2002, including impacts to rockfish ([Gilardi et al., 2010](#); [Good et al., 2010](#)). However, little quantitative information is available to evaluate impacts to rockfish and other species from derelict prawn traps. Also the density of lost traps in rockfish habitat, their loss rate, and factors for their loss are unknown. Because of rockfishes' depressed status, long generation times, and vulnerabilities to fisheries; estimating mortalities is important for understanding threats and managing populations to enable rockfish recovery ([Ralston, 2002](#); [Yamanaka and Logan, 2010](#)).

Much of the fishing effort for spot prawn occurs in waters ranging from 60 m to 120 m deep, along relatively steeply sloped and rugose benthic areas of Puget Sound ([Martinis, 2015](#)), coinciding with primary habitats of juvenile and adult rockfish, especially deep-water species such as those listed under the ESA ([Endangered and Threatened Species, 2015](#)). A total of 60 derelict prawn traps have been incidentally removed by the Northwest Straits Foundation and Natural Resources Consultants, Inc. during derelict net and crab trap removal efforts in Puget Sound. Three of those derelict prawn traps contained a total of 10 juvenile rockfish (*Sebastes* spp.), two of which were dead. By comparison, only two juvenile rockfish have been found in over 3900 removed derelict crab traps in Puget Sound ([WA DGDB accessed 9/8/2016](#)). Recent studies from British Columbia have reported rockfish bycatch rates in actively fished prawn traps ([Favaro et al., 2010, 2012](#); [Rutherford et al., 2010](#)), and the majority of those rockfish were juveniles. While the bycatch rates in actively fished prawn traps reported in British Columbia were relatively low, the large amount of fishing effort associated with spot prawn fisheries has raised concern about the overall effect of this bycatch on rockfish populations, especially considering the low survival rate of discarded rockfish due to the effects of barotrauma ([Favaro et al., 2010](#)).

In this study we analyzed 10 years of data gathered in the Washington state-managed spot prawn test fisheries to provide an initial evaluation of rockfish bycatch rates in actively fished spot prawn traps in Puget Sound. Additionally, we estimated the density of derelict spot prawn traps in specific locations through sidescan sonar surveys, and we estimated trap loss and deposition rates in Puget Sound through the analysis of creel survey and logbook data collected by Washington Department of Fish and Wildlife (WDFW), including investigating causative factors behind their loss.

Description of the fishery

Puget Sound is a fjord-like estuary covering 6039.3 km² (2331.8 mi²) and the spot prawn fishery occurs at varying levels of effort through all of it. The spot prawn trap fishery consists of recreational, non-treaty commercial, and treaty (i.e., Native American tribal) commercial/subsistence sectors. The 1994 Federal District Court ruling by Judge Edward Rafeedie, known as the Rafeedie Decision, recognized tribal harvest rights to half of all shellfish from treaty tribes' usual and accustomed areas ([U.S. vs. Washington State, 1994](#)). As with other natural resources in the region, the State of Washington and treaty tribes co-manage the spot prawn resource, with yearly harvest quotas split 50:50 between the state (combined recreational and commercial) and the treaty fisheries. Management regions and catch reporting areas are used to geographically divide catch and quota between sectors, while the recreational fisheries are managed by Marine Areas (MA) ([Fig. 1](#)). Seasons and quotas are set using data collected during test fisheries conducted by WDFW and

participating treaty tribes. All fisheries require the use of biodegradable cord to be used on trap escape hatches to ensure that egress routes become available for entrapped animals if the trap becomes derelict.

The non-treaty commercial fishery, limited to 18 licenses, takes place from June through September with a weekly harvest cap of 272 kg (600 lbs) per fisher. Commonly used traps in the commercial fishery are truncated cones surrounded by nylon mesh, weighing approximately 2.3 kg–3.2 kg. Entrance rings are 7.6 cm diameter and aligned with the bait cup, usually containing pellet type bait. Strings of 15–25 traps are attached to a heavy ground line 9 m–30 m apart. Anchors attached to buoys mark the ends of each string, and soak times range from 2 to 48 h. The treaty fishery has grown in the past decade, with just under 200 fishers now participating each year, and employs similar gear as the non-treaty commercial fleet. The treaty fishery occurs over a relatively short period of time, mostly in April and May, oftentimes with openings lasting only a few hours.

The recreational fishery occurs on specific days in the month of May, and the number of days varies between management regions. The maximum trap limit is two traps per licensed fisher, with no more than four traps per vessel, and daily harvest is limited to 80 individual spot prawns per license. Some members of the recreational fleet use web mesh trap designs similar to the commercial fleet, but typically with added weight. More common in the recreational fishery are square, round, and octagonal shaped, wire mesh traps with two to four entry ramps leading to a bait container, often filled with canned cat food or similar bait. Each trap is fished separately, attached to a single buoy line and buoy. Soak times vary depending on the location and timing of the effort, and in the derby-style openings usually last 45 min–3 h. In areas where fishing days are less stringently limited (e.g., South Puget Sound and Straits of Juan de Fuca) soak times may exceed 48 h.

While the limited number of permits allowed prevents growth of the non-treaty commercial fleet, the recreational and treaty spot prawn fleets have increased significantly since the 1990s. Growth in the recreational fleet is likely the result of population increases as well as decreases in harvesting opportunities in the salmon and other finfish fisheries. The growth of the treaty fleet followed the Rafeedie Decision, and more recent growth may likely be influenced by the increase in shellfish product value. From 2002 to 2014 the ex-vessel value of landings from the non-treaty commercial sector alone rose steadily from \$300 K US to \$800 K US (WDFW unpublished data). While there was a slight increase in landings, the majority of this increase can be attributed to the rise in market value.

Fig. 1. Map of the study area in Puget Sound with Marine Areas (MA) used for fishery management. Binned bycatch rates of rockfish in spot prawn traps from test fisheries performed by the Washington Department of Fish and Wildlife from 2004 to 2013 reported per MA by shaded color. Test fisheries did not occur in MA 13.

Materials and methods

Rockfish bycatch estimates in active spot prawn traps

Two geographically distinct spot prawn test fisheries are conducted by WDFW in Puget Sound. The Hood Canal test fishery, established in the late 1970s, includes bi-annual sampling in Hood Canal, Discovery Bay, Port Angeles, and Port Townsend. The Puget Sound test fishery, established in 2002, includes biannual sampling from all other regions of Puget Sound, including the San Juan Island area, but excluding the South Sound (MA 13) (Fig. 1). Sampling locations are identified to “represent the extensively fished populations of spot prawns” during spring (March or April) and fall (September or October) season (WDFW, 2012).

Procedures vary slightly between the two test fisheries. In the Puget Sound test fishery two or three strings of five traps are deployed at each site with a target soak time of 24 h (prior to 2007 each string consisted of 10 traps). Strings are set perpendicular to depth contours, and generally cover approximately 30.5 m of vertical change within the approximate depth range of 60.0 m–106.7 m. Traps are approximately 30.5 m apart along each groundline containing five traps, and 15.2 m apart along each groundline containing 10 traps. In the Hood Canal test fishery, three strings of three traps are deployed at each site with a target soak time of 18 hrs–24 h. Each string is approximately 45.7 m in length, with three baited traps set at 15.2 m intervals along anchored groundlines parallel to three depth contours of 18.3 m, 49.4 m, and 76.8 m (WDFW, 2010). Test fisheries employ the commonly used truncated cone traps consisting of 1.3 cm nylon mesh surrounding a frame of three stainless steel rings, and having three, 7.6-cm diameter cone shaped entrance tunnels (Favaro et al., 2010; WDFW, 2010, 2012). Each test fishery uses the same commercially designed, oiled, pellet style bait; similar to styles commonly used in the commercial fisheries of the region. Strings are retrieved via hydraulic winch at the end of each sampling period. Data collected for each string include location, date, time, depth, waypoint numbers, catch data, pull date and time, spot prawn weight, and the count and identification of any non-target species contained in each trap (WDFW, 2010, 2012). Attempts were made to access similar datasets that include this suite of information, but they were either unavailable or did not exist at the time of the study.

Raw data were analyzed from 20 sampling periods (10 spring periods and 10 fall periods) collected at 105 discrete sites, in 17 locations throughout seven Marine Areas (MA 6–MA 12) from 2004 through 2013. A total of 4231 sampling units (trap drops) from the combined test fisheries were examined. Due to the relatively small number of traps with rockfish, and rare occurrences where more than one rockfish was present in a single trap, a presence/absence analysis of rockfish was used to provide bycatch rates as the frequency of individual trap drops capturing ≥ 1 rockfish. These capture rates are reported here as frequency of rockfish caught per trap. While sample size between variables was not equal, a General Linear Model ANOVA to test for interaction effects was initially used to help explore the data, but the model was simplified to remove variables that were not significant, recognizing that some data within variables were not normally distributed.

Although the WDFW test fisheries were not designed to target rockfish presence, this retrospective review of data was conducted to summarize available information on the frequency and variability of rockfish capture rates in spot prawn traps.

Prawn trap loss rates and density estimates

Recreational prawn trap loss rates were estimated from data collected by WDFW during creel surveys of recreational prawn fishers in 2012 and 2013. Prior to the 2012 fishing season, creel survey forms did not include directed questions regarding trap loss. In 2012 and 2013, two questions were added to the survey: “*Did you lose any traps? Y or N*”, and “*If yes, how many?*” The loss rates were calculated per year as the percentage of traps lost per traps fished.

To establish whether lost traps were later recovered prior to becoming derelict, personal accounts were collected from WDFW Marine Enforcement officers who perform patrols following recreational shrimp fishery openings. Relatively few prawn traps are encountered and removed during patrol surveys and little to no associated data is collected. Therefore, a semi structured interview technique was used to elicit responses to a few specific questions focused on the frequency of encountering and recovering prawn traps (lost or abandoned) outside prawn fishing season, and the amount of rockfish encountered within those recovered prawn traps. A total of five WDFW enforcement officers were interviewed, whose combined areas of operation cover all major recreational fishing grounds. All those interviewed explained that the number of prawn traps recovered during patrols varies by year, but their reported numbers were what they consider to be the average of recent years. Additionally, conversations with recreational prawn fishers suggest that some traps reported as lost during creel surveys are recovered by their owners, or somebody else other than WDFW Marine Enforcement officers, within a few days after trap loss (M. O’Toole, WDFW, personal communication).

To estimate how many lost traps actually become derelict, we subtracted the estimated average number of traps removed per year by WDFW Marine Enforcement from the yearly estimates of traps lost. Information obtained through the interviews was also used to gain a better understanding of the frequency of occurrence of the rockfish bycatch in derelict prawn traps. All comments pertaining to number of rockfish encounters from interviewees were recorded such that they correspond with the amount of traps recovered per year during WDFW patrol surveys.

There is a lack of existing or available data for trap loss from the treaty and non-treaty commercial prawn fisheries. Review of commercial logbook entries, and conversations with resource managers and fishers suggest that trap loss from the commercial sectors is extremely low ($< 0.1\%$ of traps fished). Because this rate is very low and no specific datasets are available to refine this estimate, no further analysis of trap loss within the commercial fisheries was conducted.

To estimate the density of existing derelict prawn traps in rockfish habitat areas, we conducted sidescan sonar surveys in three locations along the eastern shore of central Puget Sound at Edmonds, Mukilteo, and Pipers Creek ([Fig. 3](#)); where documentation of ESA listed rockfish overlap prawn trap fishing grounds. Surveys were conducted between the 32 m and 107 m depth contour with a swath width of 100 m. Sidescan sonar images were examined during post-survey processing and precise locations of derelict shellfish trap targets were recorded. Due to overlap between prawn trap and Dungeness crab trap fishing grounds, and the similar size and shape of traps amongst the two fisheries, we assume a portion of the survey targets were crab traps. Video footage from remote operated vehicle (ROV) surveys conducted by WDFW near these areas showed a 7:12 ratio of derelict prawn traps to crab traps, suggesting that approximately 37% of derelict traps in the sidescan sonar survey area

were prawn traps, and the remainder were crab traps (R. Pacunski, WDFW, personal communication). This ratio was applied to the total number of derelict trap targets to estimate the total count and density of derelict prawn traps present within the sidescan sonar survey areas.

Results

Rockfish bycatch estimates in actively fished (non-derelict) traps

Of the 4231 samples examined from the WDFW test fisheries, 97 traps contained 119 rockfish. The number of rockfish caught per trap ranged from one individual in 78 traps, to two rockfish in 16 traps, to three individuals in 3 traps. Species composition of the individual rockfish caught consisted of; 56 copper rockfish (*S. caurinus*), 25 quillback rockfish (*S. maliger*), 20 unidentified rockfish (*Sebastes* sp.), 9 brown rockfish (*S. auriculatus*), 8 Puget Sound rockfish (*S. emphaeus*), and 1 greenstriped rockfish (*S. elongates*) (Table 1). The vast majority of traps (97.7%) caught no rockfish.

Basic descriptive statistics were reviewed prior to analyzing the data. Initial model variables included year, season, Marine Area, soak time, and depth. All parameters were determined to be categorical. Year was not continuous for data collected, soak times fell into general bins before or after a set number of hours, and depth also could be separated by depth ranges. Soak times fell into two bins, ranging from 3 to 5 h and 17 to 28 h, where traps were either pulled after a few hours or left overnight. Depth of trap deployment generally clustered within 15.2 m strata, from 15.2 to over 137 m. Using a backward stepwise approach in a General Linear Model, capture rates of rockfish were analyzed by binned spatial and temporal variables. Soak time (p-value = 0.607) and depth (p-value = 0.672) were removed from the analysis after no significance was found in determining rockfish bycatch. However, year (p-value = 0.013), season (p-value = 0.003), and MA (p-value = 0.011) were all found to be significant variables, with no significance between interaction effects (p-value > 0.6).

The overall rockfish catch rate for the combined dataset from 2004 to 2013 was 0.023 rockfish per trap. A Pearson Chi-squared test was used to evaluate significance for rockfish catch rate since the frequency of catch was low (Chi-squared p-value < 0.001), using a two-way Fisher's exact test for rockfish catch rate by year. Catch rates for rockfish varied considerably by year, from a low in 2013 when no rockfish were caught, to a high in 2009 of 0.058 rockfish per trap (Table 1). Seasonal differences in rockfish bycatch rates appear, as the fall rate of 0.034 rockfish per trap is significantly higher than the 0.012 in the spring (p-value = 0.003, Fig. 2). Differences in rockfish bycatch between Marine Areas was also evaluated. The lowest catch rates are consistently seen in MA 7 (San Juan Islands and North Puget Sound), with 0.005 rockfish per trap; while the highest catch rates of 0.048 exist in MA 11 (south-central Puget Sound) (Table 2 and Fig. 1). Catch rates in MA 12 (Hood Canal) are slightly less than the overall rates, but are closer to the overall rates than any other Marine Area. This is not surprising, as test fishery effort in MA 12 makes up 42% of the total effort.

A variety of additional non-target fish and invertebrates were captured in the spot prawn test fisheries with similar composition to those reported by Favaro et al. (2010). Squat lobster (*Munida quadraspina*) and hermit crabs (*Pagurus hirsutiusculus*) were the most commonly captured animals by total number of individuals, followed mostly by other shrimp and crab species. Ronquil (*Ronquilis jordani*) were the most common finfish captured, with 369 individuals found in 245 traps. Combined rockfish species (*Sebastes* spp.) were the second

most common finfish captured. Other finfish included flatfish, sculpins, perch, dogfish, ratfish, walleye pollock, and more (Appendix A).

Table 1

Total number of individual rockfish by species caught in Washington Department of Fish and Wildlife spot prawn test fisheries, 2004–2013.

Year	Total count of rockfish per species						Total rockfish	Traps with rockfish	Number of trap drops	Frequency of rockfish occurrence
	Unidentified <i>Sebastes</i> spp.	Quillback <i>S. maliger</i>	Copper <i>S. caurinus</i>	Brown <i>S. auriculatus</i>	Puget Sound <i>S. emphaeus</i>	Greenstriped <i>S. elongatus</i>				
2004	2	1	0	0	0	0	3	3	310	0.010
2005	1	0	0	1	0	0	2	2	484	0.004
2006	7	6	9	7	0	0	29	21	696	0.030
2007	9	1	2	1	2	0	15	13	369	0.035
2008	0	1	2	0	0	0	3	3	432	0.007
2009	5	4	15	0	0	0	24	22	382	0.058
2010	0	4	16	0	1	1	22	16	408	0.039
2011	0	4	6	0	0	0	10	8	411	0.020
2012	1	4	6	0	0	0	11	9	394	0.023
2013	0	0	0	0	0	0	0	0	345	0.000
Total	25	25	56	9	3	1	119	97	4231	0.023

Fig. 2. Occurrence of rockfish bycatch per trap drop in Puget Sound spot prawn test fisheries conducted by Washington Department of Fish and Wildlife (2004–2013). Means are shown ($\pm$ SE) per trap drop. Black circles represent fall sampling, and white squares represent spring sampling.

Prawn trap loss rates and density estimates

The recreational trap loss rate in 2012 was 2.01% of all traps fished, equating to 608 traps lost out of the estimated 30,217 total traps fished. In 2013, the loss rate was 2.56%, with an estimated 978 traps lost from the total estimated traps fished of 38,152. The combined loss rates for the 2012 and 2013 seasons equated to 2.33% of traps fished being lost throughout

Puget Sound, or an average of 793 traps lost per year ([Table 3](#)).

Recreational trap loss by MA was relatively consistent between 2012 and 2013. The largest differences occurred in MA 6 and MA 9 where trap loss rates decreased by 83% and 80%, respectively. The smallest variance was observed within the two Marine Areas where the highest trap loss rates occur ([Fig. 3](#)). In MA 11, loss rate decreased by 4%, and MA 7 loss rate decreased by 5%.

WDFW Marine Enforcement officers who patrol MA 7 reported removing, on average, approximately 30 prawn traps per year since 2010. In MA 6 and MA 12, officers estimated recovering approximately 40 traps per year; all of which are recovered within a day or two after a fishery opening. Officers that frequently patrol MA 8, 9, 10, and 11, recovered approximately 70 traps per year. We estimate that approximately 140 lost or abandoned prawn traps are recovered by marine patrol surveys prior to their becoming derelict. Only one of the officers reported rockfish bycatch in recovered prawn traps, saying he encountered about one rockfish per year of approximately 10 prawn trap removals. All other interviewees explained that they did not encounter rockfish in the traps that they recovered.

Accounting for those removed by marine enforcement patrols, we estimate that in 2012 a total of 468 traps became derelict, and in 2013 the number rose to 838, with an annual average rate of 653 recreational prawn traps becoming derelict in the Puget Sound ([Table 3](#)).

During the sidescan sonar surveys, track lines totaled 39.14 linear km, covering 2.90 km² of prawn trap fishing grounds and rockfish habitat. A total of 165 derelict shellfish trap targets were identified during post-survey processing. Surveys in the Mukilteo area covered 0.85 km² of seafloor between the depths of 14 m and 108 m, detecting 107 derelict trap targets, 39 of which were likely to be prawn traps; resulting in an average prawn trap density of 45.9 prawn traps/km². The Edmonds survey covered 1.36 km² between the depths of 18 m and 149 m. A total of 45 trap targets were detected in the Edmonds survey area, 17 of which assumed to be prawn traps, with a density of 12.5 prawn traps/km². At the Pipers Creek area a total of 13 derelict trap targets were found in the survey covering 0.69 km² in the depth range of 13 m–141 m, for an estimated total of 5 derelict prawn traps, and a density of 7.2 prawn traps/km². The overall estimated derelict prawn trap density of the three survey areas combined is 13.7 prawn traps/ km². Target depths ranged from 27 m to 95 m, and averaged 59 m.

Fig. 3. Recreational trap loss rate shown as percentage of traps fished by Puget Sound Marine Area (MA) based on creel survey data collected by Washington Department of Fish and Wildlife in 2012 and 2013 (data not available for MA 13). Also included are the three areas where sidescan sonar surveys were conducted to quantify derelict trap presence in areas where spot prawn trap fisheries and rockfish habitat overlap.

Table 2

Effort and rockfish bycatch caught in WDFW's trap prawn test fisheries by Marine Area (2004–2013).

Marine Area	Total rockfish	Traps with rockfish	Number of trap drops	Frequency of rockfish occurrence
MA 6	24	18	675	0.027
MA 7	3	3	632	0.005
MA 8	8	8	444	0.018
MA 9	4	4	85	0.047
MA 10	3	3	75	0.040
MA 11	36	26	547	0.048
MA 12	41	35	1773	0.020
Total	119	97	4231	0.023

Table 3

Results, by year, of recreational prawn trap loss estimates from data collected during Washington Department of Fish and Wildlife creel surveys in 2012 and

2013.

Year	Number of recreational trap days	Percent of traps lost	Projected number of traps lost	Traps removed by area sweeps	Number of traps becoming derelict
2012	30,217	2.01	608	140	468
2013	38,152	2.56	978	140	838
Annual Average	34,185	2.33	793	140	653

Discussion

Results of data analysis of the WDFW spot prawn test fisheries suggest that rockfish bycatch within spot prawn trap fisheries in Puget Sound shows considerable annual and geographical variability, similar to what has been reported in British Columbia ([Favaro et al., 2010](#);

Rutherford et al., 2010). We do not estimate rockfish bycatch rates by species due to the low sample size; however, copper and quillback rockfish make up the majority (68%) of the total observed bycatch, while 17% of the rockfish encountered were unidentified. Rockfish and other finfish found in test fishing traps are often partially eaten by prawns or other scavengers, making it difficult to identify individuals to species (M. O'Toole, WDFW, personal communication). The summaries provided here assist in understanding the overall effects of spot prawn trap fisheries on rockfish populations, but do not include information directly related to the two ESA listed rockfish species in Puget Sound. Nevertheless, similarities in preferred habitat and juvenile behavior between many of the rockfish species in the Salish Sea, including ESA listed species ([Endangered and Threatened Species, 2015](#)), indicate a strong overlap of the spot prawn fishery and areas used by rockfish. Because quillback and copper rockfish are the most commonly encountered rockfish in Puget Sound, it is to be expected that they would represent a large proportion of bycatch in any fishery affecting rockfish. Likewise, because ESA-listed rockfish are, by definition, rare, their absence in actively fished and derelict prawn traps in this study should not be assumed to mean the species are not affected by the prawn fishery. Juvenile rockfish occupy a wide range of depths ([Love et al., 2002](#)), but juvenile yelloweye rockfish, in particular, primarily occupy depths fished in the spot prawn fishery in Puget Sound. Development of gear modifications and bycatch reduction devices (BRD) could reduce rockfish bycatch and associated mortality. Specifically, modified tunnel entries designed to reduce bycatch have been developed and tested in British Columbia ([Favaro et al., 2012](#)), and were successful in reducing rockfish bycatch in field experiments. However, they also produced a decrease in spot prawn catch per unit effort (CPUE) versus an unmodified trap; for this and other reasons they have not been implemented into the fishery. Artificial lights in the form of LED attached to trawl gear have recently been successful in reducing bycatch of several fish species including rockfish in the ocean shrimp trawl fishery off the Oregon coast, with no effect on shrimp catch ([Hannah et al., 2015](#)). We believe it would be worthwhile to test prawn traps equipped with LEDs in Puget Sound as a potential rockfish BRD. Rockfish descending devices have been shown to increase the survival of discarded rockfish suffering from effects of barotrauma ([Hochhalter and Reed, 2011](#); [Hannah et al., 2012, 2014](#)) and are promoted or required in several fisheries along the U.S. and Canadian west coast to mitigate mortality associated with discarded rockfish bycatch ([Theberge and Parker, 2005](#); [WDFW, 2013a,b](#); [CDFW, 2014](#)). We suggest consideration for descending devices to be promoted within the prawn trap fisheries for the same reason.

The overall rockfish per trap rate of 0.023 in Puget Sound test fisheries from 2004 to 2013 is higher than the 10-year average reported by [Favaro et al. \(2010\)](#) of 0.015 from 1999 to 2008 in Howe Sound, British Columbia. Comparisons of rockfish catch rates in Puget Sound and British Columbia over the 5-year span where data temporally overlaps show considerable variance between studies. Of particular interest is the difference in trends, or lack thereof in Puget Sound. Rockfish bycatch in Howe Sound, British Columbia shows an apparent non-linear, positive trend from 2004 to 2008, whereas the Washington bycatch rates are sporadic and show no trends. Years with increased rockfish bycatch could be the result of episodic increases in local populations of juvenile rockfish, as suggested by [Favaro et al. \(2010\)](#). This concept is supported by observations of large-scale recruitment of rockfish in the summer of 2006 in central and south Puget Sound, and the Strait of Juan de Fuca ([LeClair et al., 2007](#); [Palsson et al., 2011](#)), where much of the bycatch occurred (MA 11 and MA 6). A similar recruitment event occurred in Hood Canal in 2008 ([Palsson et al., 2011](#)), possibly reflected in the spike in rockfish bycatch seen in 2009 in MA 12. In addition, an absence of adequate food sources could also increase rockfish attraction to baited prawn traps, leading to increased catch rates. These and other reasons may contribute to the significant differences between rockfish bycatch rates by MA ($p\text{-value} = 0.011$). Marine Area 7 (San Juan Islands) has the most rocky habitat and often has been considered to host the greatest numbers of rockfish in

the Puget Sound region ([Palsson et al., 2009](#)), yet the rockfish bycatch rate in MA 7 is substantially lower than those in all other MAs. This could be the result of juvenile rockfish being less attracted to prawn traps in an area where food sources and preferred habitat is abundant in the high-relief rocky substrate of the San Juan Islands. In contrast, rockfish bycatch rates were highest in MA 11 where much less rocky habitat is present, and the seafloor often consists of sand, mud, cobble, and intermittent boulders ([Palsson et al., 2009](#)). In habitats such as this, juvenile rockfish may be more attracted to prawn traps by the scent of the bait, as preferred habitat, or both. The number of samples between MA did vary, with the lowest sampling rates in MA 9 and 10 (85 and 75 respectively); comparative sampling between MA 6, 7, 8, and 11 (675, 632, 444, and 547 respectively); and the most samples from MA 12 (1773). The timing of the fisheries in the spring months could result in less bycatch because it is possible fewer young-of-the-year rockfish are present in benthic environments compared to the fall. Overall seasonal differences ($p\text{-value} = 0.003$) were analyzed independently as no significant interaction effect with year or MA was found ($p\text{-value}$ for both interactions > 0.6). This seasonal difference in bycatch rates implies that juvenile rockfish in the Salish Sea are more commonly found in habitat utilized by the prawn trap fisheries during the fall months, or that if the rockfish are present, they are less attracted to prawn traps during the springtime.

The WDFW spot prawn test fishery data is the only known dataset available that contains records from several years of spot prawn fishing effort with documentation of rockfish (and other) bycatch. The test fishery methods used are not exactly the same as methods used by commercial or recreational harvesters. Nevertheless, we believe test fishery methods are similar enough to harvester methods to allow us to extrapolate test fishery bycatch data to the recreational and commercial fisheries in Puget Sound. We estimate the annual average rockfish bycatch from 2004 through 2013 within the Puget Sound spot prawn trap fisheries using bycatch rates from the WDFW test fisheries and trap drop summary data provided by WDFW statistical summaries. Such data on trap drops from the treaty fishery were not available, and therefore we limit this extrapolation to only the state managed commercial and recreational fisheries. The total number of commercial trap drops over the 2004 through 2013 period was 270,385 and the total number of recreational trap days were 295,396. Because our analysis showed no significant difference in catch rates between short (< 5 h) and long (> 17 h) soak times, calculations were based on traps fished rather than trap hours. With these assumptions, we estimate an average annual capture of 1274 rockfish in state commercial and recreational prawn trap fisheries over the 10-year period from 2004 through 2013. Landings data from WDFW statistical summaries show that treaty fisheries landed approximately 48% of the total Puget Sound spot prawn harvested those years. Assuming the rockfish bycatch rate from the WDFW test fishery is similar across all sectors, and that state commercial and treaty prawn CPUE is similar, then the total (state and treaty combined) number of rockfish caught each year in prawn traps in Puget Sound could be 2600. These estimates are based on the assumption that in general, rockfish are attracted to and enter spot prawn traps at the same rate regardless of which fishery the traps are deployed from. Naturally, certain details such as timing and intensity of effort, and trap design may influence the rates of rockfish bycatch.

Regarding trap loss, we propose that the preliminary loss rate for the recreational fishery is based on the most accurate data available, as creel surveys during both 2012 and 2013 included questions specific to the number of traps lost per fisher interviewed. Additionally, the number of prawn traps retrieved by WDFW patrols assists in calculating the number of prawn traps that actually become derelict each season. These trap loss rates are relatively low in comparison to other trap fisheries in Puget Sound ([Antonelis et al., 2011](#)) and elsewhere ([Bilkovic et al., 2012](#); [Arthur et al., 2014](#)). Assuming the loss rates within the fisheries and patrols conducting trap recovery remain consistent, average loss rate from 2012

and 2013 can be used to estimate number of derelict prawn traps deposited in future years, since the two questions related to trap loss were taken out of the creel survey questionnaire after the 2013 season. Therefore unless they are added again, the 2012 and 2013 average will be the most accurate available trap loss rate to be applied to future years.

Though we were unable to estimate annual trap loss in the commercial sector, we presume that loss rates in the recreational sector are much larger. Recreational fishers are limited to single trap deployments, and if not augmented by additional weight, the relatively light-weight traps commonly used by recreational fishers can be prone to drag or drift during heavy tidal exchange periods common during the month of May when the fishery typically occurs. Commercial traps are also relatively light-weight; however, they are fished in strings from a common groundline that is anchored at each end, providing additional stability and reducing loss rate for these traps.

Reasons for prawn traps becoming derelict vary, and are similar to reasons for loss of crab traps in Puget Sound. Causes for loss generally fall into three categories, all of which include a degree of user error: vessel interaction (both recreational and commercial vessels), improperly configured gear, and improperly placed gear. The user errors involved in trap loss include badly tied knots, using lines too short for the fishing depth, using unweighted gear (which can be swept off position by currents and wind), and placing traps in vessel traffic lanes or too close to other fishing gear ([Drinkwin, 2016](#)). Many of the reasons for trap loss in Puget Sound, and elsewhere, can vary in magnitude depending on geographic location, particularly those resulting from forces of nature, such as strong tidal currents, unexpected water depth, and high winds/rough sea conditions ([MacFadyen et al., 2009](#)). Gear may become impossible to retrieve if it becomes snagged on underwater obstructions, natural or man-made, and can also be related to a fisher's level of experience and familiarity with a given location and associated conditions ([Gilman, 2015](#)). In the derby-style recreational fishery openings that are common in Puget Sound, effort is extremely dense in the popular fishing grounds, which increases the risk of entanglements with other gear that could lead to gear loss.

The only WDFW enforcement officer interviewed who encountered rockfish in recovered prawn traps explained that they were newly lost and still freshly baited. All other respondents had not encountered rockfish in traps removed during patrols. Therefore, evidence supporting rockfish impacts in derelict prawn traps remains limited to the occurrences observed during derelict fishing gear removal operations conducted by NWSI, where 3 of 60 recovered, un-baited, derelict traps contained a total of 10 rockfish (eight live and two dead). This limited sample gives a relatively high rockfish bycatch rate for derelict traps (0.167 rockfish per trap) and provides speculative estimates suggesting that 5% of all derelict prawn traps contain ≥ 1 rockfish, 0.20 of which could be mortally entrapped. In one instance a dead rockfish was partially decomposed, and being eaten by spot prawns in the trap; evidence that the fish died in the sedentary trap rather than as a result of barotrauma from trap removal. It was also noted by the onboard biologist that some of the rockfish were too large to exit through the trap entrance, implying that the entrapped fish had grown since entering the trap. Full investigations of derelict prawn traps in their environment, or simulated derelict traps in laboratory settings, may prove to be the most effective way of informing us on the subject of rockfish impacts from derelict prawn traps. The density of derelict prawn traps where sidescan sonar surveys were conducted should be further investigated with visual surveys to distinguish between prawn and crab traps, and it would be helpful to investigate the length of time that prawn traps remain structurally viable and continue fishing after becoming derelict.

Prawn trap entrance tunnels are too small for large mature rockfish to enter ([Favaro et al.,](#)

2010, 2012). Therefore, the impacts of bycatch and trap loss rates reported here are assumed to affect only juvenile rockfishes. The accumulation of derelict prawn traps, in addition to the more abundant loss of crab traps, has a mostly unknown effect on benthic habitats of Puget Sound, which warrants additional research. Additionally, there is the potential for derelict prawn traps to affect localized, isolated populations of rockfish in areas where effort and trap loss are high. Therefore, continued investigation is warranted, considering the depleted status of many rockfish species throughout the Salish Sea.

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Appendix A

Total list of species other than spot prawns captured in WDFW shrimp trap test fisheries with corresponding number encountered.

Group	Common name	Scientific name	Occurences in traps	Total individuals	Group	Common name	Scientific name
Crustaceans	squat lobster	Munida quadraspina	594	6218	Fish - other than rockfish	northern ronquil	Ronquilusjordani
	hermit crab	Pagurus hirsutiusculus	148	2818		shiner perch	Cymatogaster ag
	pink shrimp	Pandalus jordani	235	2780		pacific sanddab	Citharichthys sor
	(smooth)						
	dock shrimp	Pandalus danae	431	2274		staghorn sculpin	Leptocottus arma
	humpback shrimp	Pandalus hypsinotus	361	2210		sanddab	Citharichthys spp
	red rock crab	Cancer productus	461	1312		sculpin	Cottoidei spp.
	pink shrimp	Pandalus eous	291	1025		sailfin sculpin	Nautichthys ocul
	decorator crab	Oregonia gracilis	210	877		flatfish	Pleuronectiforme
	slender cancer crab	Cancer gracilis	350	813		spiny dogfish	Squalus acanthias
						shark	
	eualid shrimp	Eualus spp.	97	394		walleye pollock	Gadus chalcogran
	Dungeness crab	Metacarcinus magister	72	193		great sculpin	Myoxocephalus
							polyacanthoceph
	lebbeid shrimp	Lebbeus spp.	49	86		spotted ratfish	Hydrolagus collic
	crangon shrimp	Crangon spp.	14	31		plainfin	Porichthys notatu
						midshipman	
	Heptacarpid shrimp	Heptacarpus spp.	11	20		speckled	Citharichthys stig
						sanddab	
	sidestripe shrimp	Pandalopsis dispar	5	18		blackfin sculpin	Malacocottus kin
	spiny lebbeid	Lebbeus groenlandicus	13	13		threadfin sculpin	Icelinus filament
	kelp crab	Pugettia producta	2	9		buffalo sculpin	Enophrys bison
	Pandalid shrimps	Pandalidae spp.	1	8		greenling	Hexagrammidae
	scaled crab	Placetron wosnessenskii	5	5		red irishlord	Hemilepidotus
							hemilepidotus
	black clawed crab	Lophopanopeus bellus	4	4		gunnel	Pholidae spp.
		bellus					
	coonstripe Shrimp	Pandalus goniurus	2	2		tom cod	Microgadus tomc
	box crab	Lopholithodes	1	1		whitespotted	Hexagrammos ste
		foraminatus				greenling	
	deep blade shrimp	Spirontocaris prionota	1	1		red brotula	Brosmophycis ma
	horned shrimp	Paracrangon echinata	1	1		irish lord	Hemilepidotus sp
	rough patch shrimp	Pandalus stenolepis	1	1		northern sculpin	Icelinus borealis
	shrimp	Spirontocaris	1	1		pacific hake	Merluccius produ
		lamellicornis					
	tanner crab	Chionoecetes bairdi	1	1		poacher	Agonidae spp.
	miniature spinyhead shrimp	Mesocrangon munitella	1	1		lingcod	Ophiodon elonga

						snailfish	Liparis spp.
Echinoderms	Sunflower star	Pycnopodia helianthoides	710	898		decorated warbonnet	Chirolophis decoratus
	vermilion star	Mediaster aequalis	233	627		pacific cod	Gadus macrocephalus
	urchins	Echinoidea spp.	17	45		arrowtooth flounder	Atheresthes stomus
	brittlestar	Ophiurida spp.	6	6		cabazon	Scorpaenichthys marmoratus
	green urchin	Strongylocentrotus droebachiensis	3	6		english sole	Parophrys vetulus
	starfish	Asteroidea spp.	3	3		kelp greenling	Hexagrammos decagrammus
	spiny red star	Hippasteria spinosa	2	2		needlefish	Belonidae spp.
	pink sea star	Pisaster brevispinus	1	1		perch	Perca spp.
	basket star	Euryalida spp.	1	1		pileperch	Rhacochilus vaccae
	blood star	Henricia leviuscula	1	1		rocksole	Lepidopsetta bilineata
	mottled star	Evasterias troschelii	1	1		rough back sculpin	Chitonotus pugetensis
Mollusc	pink scallop	Chlamys rubida	78	234		silver surfperch	Hyperprosopon elongatum
	Oregon triton	Fusitriton oregonensis	12	67		sturgeon	Acipenser medirostris
						sturgeon	Podothecus accipitrinus
						poacher	
	red octopus	Octopus rubescens	50	52	Fish - rockfish	copper rockfish	Sebastes caurinus
	octopus	Octopus spp.	36	42		quillback	Sebastes maliger
	scallops	Pectinidae spp.	9	17		rockfish	
	weathervane scallop	Patinopecten caurinus	1	8		rockfish	Sebastes spp.
	squid	Teuthida spp.	4	6		brown rockfish	Sebastes auriculatus
	giant Pacific octopus	octopus dofleini	4	5		Puget Sound rockfish	Sebastes emphaeus
	nudibranch	Opisthobranchia spp.	2	4		greenstriped rockfish	Sebastes elongatus
	stubby squid	Rossia pacifica	3	3	Other		
	snails	Gastropod spp.	1	2		jellyfish	Cnidaria spp.
	abalone	Haliotis spp.	1	1			
	striped nudbranch	Armina californica	1	1			
	white nudibranch	Dendronotus albus	1	1			
	frilled dogwinkle	Nucella lamellosa	1	1			
	northern moon snail	Euspira heros	1	1			

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