FEATURE

Volunteer Angling and Technology-Based Solutions Provide the First Estimate of Sea Lice Infections for Wild Coastal Cutthroat Trout *Oncorhynchus clarkii clarkii*

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Angler Kathryn Losee inspects a Coastal Cutthroat Trout *Oncorhynchus clarkii clarkii* caught in marine water for ectoparasites to report online

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Anadromous Coastal Cutthroat Trout *Oncorhynchus clarkii clarkii* are one of the least studied salmonids but are a highly prized target in sport fisheries in coastal waters of the Pacific Northwest. Despite an observed high prevalence of ectoparasite infections, described by sport anglers as "sea lice," there is a paucity of data available on the spatial and temporal occurrence of infections on Coastal Cutthroat Trout. We collaborated with the angling community through social media engagement and an online application to report ectoparasites observed on sport catch. In 2018, we received voluntary reports for 1,493 Cutthroat Trout and 416 salmon catch events in marine waters from the province of British Columbia and the states of Washington, Oregon, and California. These data demonstrated that the number of argulids and copepods per trout varied according to body size, capture month, and area. To evaluate accuracy of voluntary parasite counts, we compared results to parasite counts on cutthroat from sampling events conducted by trained biologists. For both voluntary angler reports and those of biologists, spring months had a lower prevalence of argulids and copepods, argulids were common on trout, but absent on salmon, and larger trout were associated with an increased number of argulid and copepod infections.

INTRODUCTION

Coastal Cutthroat Trout *Oncorhynchus clarkii clarkii* are one of seven species of anadromous salmonids in the genus *Oncorhynchus* that inhabit coastal waters of the western United States. Due to their small size, limited commercial value, and low abundance, the biology of Coastal Cutthroat Trout is poorly understood relative to other anadromous salmonid species. To fill the gap in traditional scientific funding, the sport fishing community and local conservation groups in the state of Washington have provided financial and on-the-ground support to conduct research aimed at identifying, prioritizing, and answering key biological questions necessary to improve understanding of this unique species of anadromous fish. These efforts have been led by the Coastal Cutthroat Coalition (CCC; www.coastalcutthroatcoalition.com), a nongovernmental organization located in the state of Washington in close coordination with the Washington Department of Fish and Wildlife (WDFW). Specifically, this work has improved understanding of spawn timing (Losee et al. 2016; Freeman et al. n.d.), marine movement patterns (Losee et al. 2018; Pearcy et al. 2018), genetic structure (Losee et al. 2017), and identified marine survival, predation, and parasitism as key areas for future research (CCC 2022).

For most anadromous species of salmon, trout, and char, characterization of the parasites they host is well developed. For instance, species of parasitic copepod in the genus *Lepeophtheirus* spp. have been shown to slow metabolism, alter migration routes, reduce body condition, and decrease marine survival for anadromous Brown Trout *Salmo trutta*, Atlantic Salmon *S. salar*, Arctic Char *Salvelinus alpinus*, Dolly Varden *S. malma*, and Pacific salmon *Oncorhynchus* spp. (MacKinnon 1998; Costello 2006). Additionally, researchers have reported strong associations between parasite infections and open water fish farming where migration routes overlap with commercial salmon farming operations (Costello 2009; Price et al. 2010; Thorstad et al. 2015). This relationship between rates of parasite infection and fish farming has provided insight into factors limiting survival and productivity of anadromous fishes and has led to regulations on fishing and open water net pen farming to protect native species at risk. Across their range, Coastal Cutthroat Trout are targeted by anglers year-round, reside in close proximity to saltwater net pens, and are known to be a host for *Lepeophtheirus salmonis* (Kabata 1988). Recently, anglers and scientists have reported ectoparasites on the dorsal surface of Cutthroat Trout in marine waters (Figure 1), stimulating research on the topic. Genetic analysis and parasite morphometry studies indicated that an argulid species, *Argulus pugettensis*, and sea louse copepod species, *L. salmonis*, commonly infect Coastal Cutthroat Trout, but researchers examined a limited geographic range across a short time period (Losee et al. 2020).

The benefit of involving anglers and conservation partners in fisheries management activities has been well documented (Lucy and Davy 2000; Quindazzi et al. 2020). These efforts include habitat improvements, fish rescue, catch reporting, and others. In unique circumstances, coordinated effort by the angling and the conservation community have achieved recovery milestones for threatened fish species, such as for Pyramid Lake Lahontan Cutthroat Trout *O. clarkii henshawi* (Al-Chokhachy et al. 2020). However, relying on anglers to collect scientific information brings with it the potential for error and bias associated with fish identification, false reporting, and gear type (Venturelli et al. 2017; Cooke et al. 2021; Page et al. 2021). For these reasons, studies that depend on angler reporting are typically limited in number and scope or are conducted under the direct supervision of professional biologists and technicians. Recent advancement of electronic applications, social media tools and rapid data entry technologies have improved the efficacy and benefit of self-reporting by anglers through improved education, data organization, and reporting accuracy (Quindazzi et al. 2020).

Species that lack commercial interest or are not given special protection under conservation designation often receive limited scientific attention, which can result in insufficient data to make informed management decisions. In this scenario, the use of angler reported information can be used to fill data gaps and generate attention to future research and conservation needs. The objective of this study was to describe patterns of infection by a poorly understood parasite of Coastal Cutthroat Trout, *A. pugettensis*, and explore the efficacy of angler reporting. Specifically, this study was designed to (1) pilot an online data reporting tool, (2) evaluate the accuracy and dependability of volunteer angler reporting, and (3) describe spatial and temporal patterns of ectoparasite infection on Coastal Cutthroat Trout and other salmonids captured by anglers and scientists.

METHODS

Approach

To describe ectoparasite infections of Coastal Cutthroat Trout and other salmonids in 2018, we relied on collaboration between the WDFW and the CCC to educate and engage the sport fishing community in large-scale data collection. This work was paired with sampling efforts in the study area by WDFW fish biologists using methods described in Losee et al. (2020).

Public Engagement and Communication

Objectives and data collection needs were communicated to the public through presentations to fishing clubs and social media platforms operated by the CCC, including

Figure 1. Anadromous Coastal Cutthroat Trout *Oncorhynchus clarkii clarkii* (length = 385 mm, 15.2 in) infected with argulid and copepod ectoparasites captured by an angler in south Puget Sound, Washington.

Instagram, Facebook, and the CCC website. The CCC website also presented fish and parasite identification tools, a video demonstrating proper fish handling techniques, and a link to an online Web application for entering data. Throughout the life of the study, social media posts provided educational materials and monthly summaries of results and was used to host a monthly raffle that rewarded one or more randomly selected study participants. To encourage both participation and accurate, unbiased results, requirement to enter the raffle was based on participation alone and no prizes were rewarded for number of times entered or whether fish reported were infected with parasites. Prizes were donated by supporters, who included local retailers and members of the conservation community. Names were randomly drawn from monthly participants by well-known anglers, scientists, and conservationists in order to highlight those involved in the work and increase excitement around the study (Figure 2).

Data Collection

The online reporting application was developed using R (https://www.r-project.org/) and the Shiny package (https://www.shinyapps.io/). The application was publicly available and accessed by anglers on the CCC website. Data submitted by anglers were stored in Dropbox. For transparency and to facilitate the promotion of future technology-based management tools, the code for the application developed by the authors is publicly available (https://bit.ly/3VlSRcU).

In the application, users were provided with instructions on how to use the application, parasite identification images for copepods and argulids, and a Washington Marine Catch Area map (Figure 3). Data reported by anglers included name, contact information, catch area (Washington Marine Catch Area, or geographic region of capture such as California, Oregon, Alaska, or Canada), angling method (from shore or boat), date of encounter, hours fished, the number of anglers, total fish count, individual fish species, the number of argulids on each fish, the number of copepods on each fish, and the number of unknown parasites on each fish. Anglers were also prompted to record fish length from a range of categorical options. Fish length was recorded in inches given that the study took place in the United States, where the metric system is not commonly used among anglers. Size bins were defined as:

- <12 in (<305 mm)
- ≥12 in but <16 in (406 mm)
- ≥16 in but <20 in (508 mm)
- ≥20 in but <28 in (711 mm)
- ≥28 in

Expert Surveys

Relying on angler reporting has the potential to introduce bias associated with fish size and under reporting of fish with zero parasites. To understand the potential for bias associated with angler reporting, we conducted monthly beach seining in the state of Washington, Marine Area 13 (Figure 3), led by trained fish biologists employed by the WDFW.

Salmonids were collected by beach seine monthly from January through December 2018. Upon capture, fish were immediately measured for fork length (FL; mm) and placed into a small aquarium with anesthesia (MS-222) to assist with parasite enumeration and identification. A subsample of ectoparasites were carefully removed from anesthetized fish using fine forceps and preserved in 95% ethanol for genetic identification. Results of genetic analysis of parasites are reported in Losee et al. (2020). All fish were released following the examination.

Figure 2. Conceptual diagram highlighting steps to successful community science data collection campaign with (**A**) communication, planning, and coordination with scientists and angler groups, (**B**) promotion via social media on Instagram, Facebook, and Twitter, including highlighting selected winners of monthly raffle drawn by influential supporters to increase participation and awareness. Clockwise from top left: Tom Quinn (University of Washington Professor and salmon ecologist), Keith Robbins (well-known fishing guide, conservationist), Kitty Griswold (Cutthroat Trout researcher, Idaho State University), Andrew Claiborne (fish biologist, Washington Department of Fish and Wildlife), (**C**) parasite identification and fish handling education, (**D**) hook and line sampling consistent with fishing regulations (pictured: Kathryn Losee) and beach seine by expert scientists (pictured: Gabe Madel), (**E**) parasite enumeration, (**F**) data reporting via online web application and collection by experts, and (**G**) real time reporting of results via social media and peer-reviewed journal.

Data Filtering and Analysis

Prior to analysis, records were removed from the angler reported data set if anglers did not properly report catch area or capture date ($n = 8$). A total of 28 "unknown" ectoparasites were recorded by anglers. These were excluded from all analyses. We compared spatial and temporal patterns of parasite abundance (parasites per fish) for Coastal Cutthroat Trout and between fish species reported across the study area. We calculated parasite prevalence, defined as the number of hosts infected by a particular parasite species divided by the number of hosts examined (Bush et al. 1997), and intensity, defined as the number of individual parasites of a given species on a single infected host. Due to small sample size of fish reports >20 in (508 mm; $n = 20$), fish recorded as greater than or equal to 20 in were binned with those recorded as greater than or equal to 16 in (406 mm).

One objective of this study was to evaluate the accuracy and dependability of volunteer angler reporting. To do so, we compared mean parasite abundance and mean fish size between volunteer angler reports vs. beach seine catch from "expert surveys" in the area where beach seining took place (Marine Area 13). To test for differences in argulid and copepod abundance in months when more than 10 fish were sampled (August–January), we used a zero inflated Poisson regression, given the large number of zeros and small sample size. The fit was tested by comparing Akaike scoring criteria against a standard Poisson distribution and examining quantile–quantile plots. This was followed by Tukey's honestly significant difference (HSD) post-hoc test using R statistical software (R Core Team 2012) for comparing between groups while controlling for type I error across multiple comparisons. Differences in the contribution of size classes to catch of volunteer anglers vs. those of biologists was tested using a chi-square test.

RESULTS

Prior to initiating the online data entry application in 2018, we published over 30 social media posts, 1 online educational video, and 9 presentations to fishing clubs. Social media platforms were also used to communicate preliminary results and results from monthly raffles during the study period. Social media posts were also shared by CCC social media network followers during the study period, increasing readership.

In 2018, the online application received reports for 1,909 encounter events reported by 123 individual anglers, of which 1,493 *O. clarkii clarkii* encounters reported and 416 salmon encounters reported that included Chinook Salmon *O. tshawytscha*, Chum Salmon *O. keta*, and Coho Salmon *O. kisutch* (Table 1). Anglers reported parasite counts from Washington, Oregon, California, and British Columbia with 95.4% (1,821/1,909) of catch reports originating from Central and South Puget Sound in the state of Washington, from the entrance of Admiralty Inlet (Marine Area 9) south to Olympia (Marine Area 13).

Angler Scientist Parasite Reporting

There was a maximum of 66 argulids and 30 copepods observed per fish. Average rates of argulid infections per fish were greater than average rates of copepod infections per fish in all study months (Figure 4A). Marine Area 9, located in central Puget Sound had the highest parasite infection relative to the other marine areas (11.38 parasites per fish; Figures 3 and 4B), while Marine Area 2 had the lowest levels of argulid infections (0.33 parasites per fish; Figure 4B). Ectoparasite infections increased with increasing fish size for both Argulid and Copepods with the greatest parasite infections among fish longer than 20 in (Figure 4C). Temporal and spatial patterns of copepod infections were similar to that of argulids (Figure 4A,B). Note that Argulid infections were only observed among Cutthroat Trout while abundance of copepods was consistent across fish species (Figure 4D), but sample sizes of reported Chinook Salmon and Chum Salmon were low (Table 1).

Comparing results of parasite infection between volunteer angler reporting and that of trained biologists in Marine Area 13 revealed similar patterns of infection. Consistent with angler reports, scientists observed zero argulid infections on Coho Salmon, even when caught at the same location in the same haul as infected Cutthroat Trout. In Marine Area 13, volunteer anglers and scientists observed the highest prevalence and intensity for argulid and sea lice increasing with fish size and occurring in the late summer through winter months (August–January; Figure 5). The mean abundance of argulid and copepod infections was different between reports from volunteer anglers and biologists in months where more than 10 reports were received (Tukey's HSD, $P < 0.05$; Figure 5). When comparing fish size reported by biologists versus volunteer anglers in Marine Area 13, significant differences were observed. Specifically, fish size reported by anglers was larger for volunteer anglers vs. biologists with approximately 20% (44/224) of measured fish reported as greater than 16 in, compared to biologists, who reported <5% (8/210) of fish sampled measuring longer than 16 in. In all months where more than 10 fish were sampled, the length of fish reported by anglers was significantly greater than that of biologists (Chi-square test, $P < 0.05$; Figure 6).

DISCUSSION

The potential to involve anglers and conservationists in fish science has grown with increased use of social media and engagement in outdoor activities by the public (Venturelli et al. 2017; Valenzuela 2020). However, promoting meaningful, accurate, and unbiased data collection while also ensuring safe fish handling has prohibited broad application of angler data collection. In this study, strong collaboration between government and nongovernmental organizations combined with focused and frequent communication with the angling public resulted in the first description of ectoparasite infection rates on a wild anadromous Coastal Cutthroat Trout and real-time education to the angling community. We highlighted the cutthroat-specific nature of an argulid ectoparasite and identified Central Puget Sound as a parasitic "hot spot" in the Salish Sea.

Data collected from anglers and scientists revealed a positive relationship between fish size and parasite infection consistent with other studies (Tucker et al. 2002; Peacock et al. 2019). In estuarine and marine waters of Scotland, Todd et al. (2000) attributed the positive relationship between *L. salmonis* intensity and anadromous Brown Trout size to fish age, due to the extended residence time in marine waters of older, bigger fish, increasing exposure to ectoparasites. Anadromous Cutthroat Trout regularly return to freshwater during the summer, winter, and spring (Claiborne et al. 2020). However, the fall represents the time period when most Cutthroat Trout have spent the longest duration in the marine environment and coincides with the highest levels of parasite infection as observed in this study.

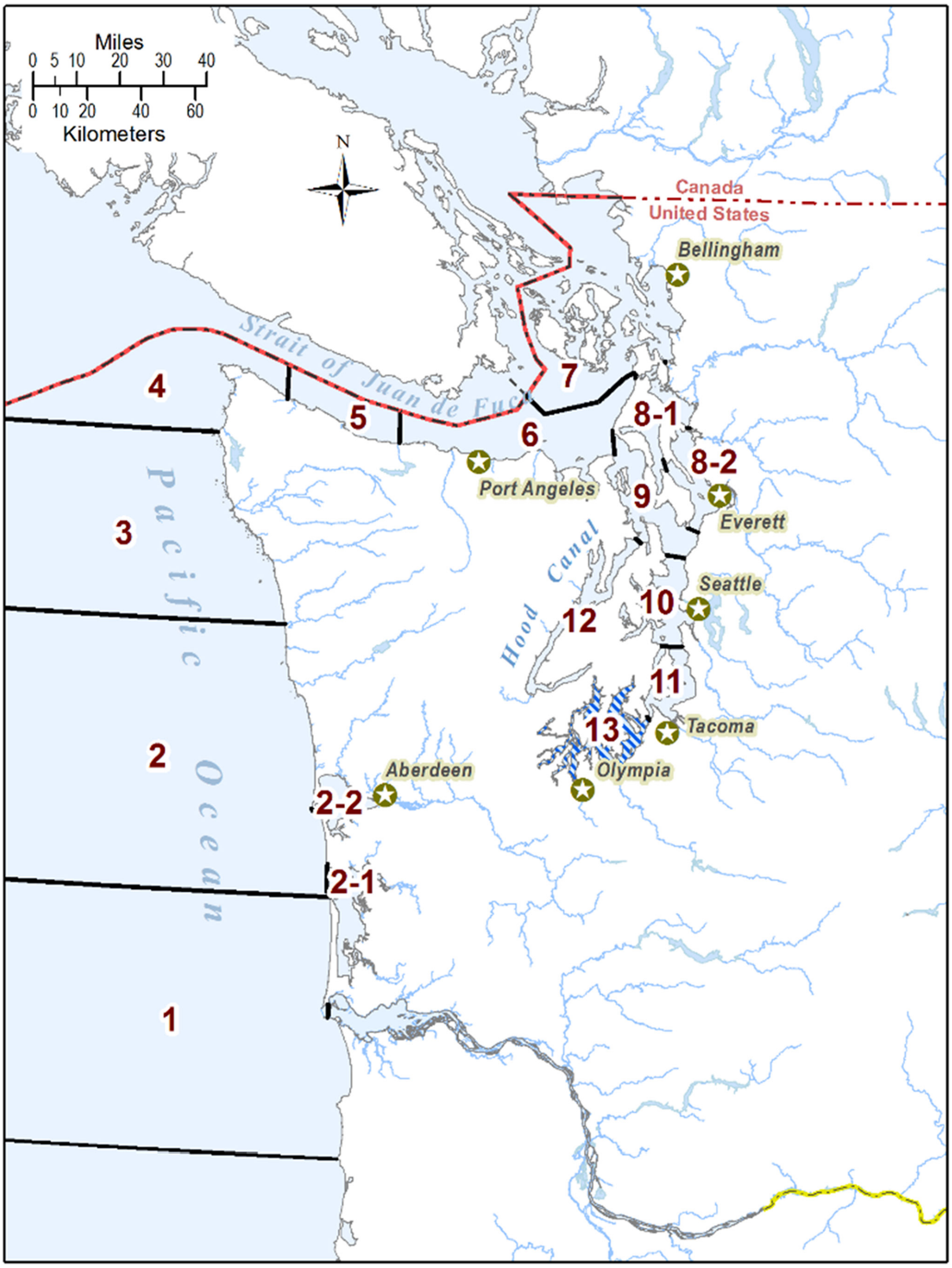

Figure 3. Study area on the West Coast of the United States with the state of Washington marine catch areas used to designate fishing areas for angling sea lice reporting. Blue hatched area (Marine Area 13) represents the area trained biologists sampled salmonids for sea lice.

Table 1. Sample size (*n*), prevalence, mean intensity, and standard deviation (±SD) of ectoparasites observed on the body for Coastal Cutthroat Trout *Oncorhynchus clarkii clarkii*, Coho Salmon *O. Kisutch*, Chinook Salmon *O. tschwatyschca*, and Chum Salmon *O. Keta* in south Puget Sound, Washington, in the winter of 2017/2018.

		Argulus pugettensis			***Lepeophtheirus salmonis***		
	n	**Prevalence**	**Intensity**	**SD**	**Prevalence**	**Intensity**	**SD**
Coastal Cutthroat Trout	1,493	0.52	7.14	7.11	0.24	2.66	2.77
Coho Salmon (Silver)	388	0.00	0.00	0.00	0.23	2.20	1.97
Chinook Salmon (King)	24	0.00	0.00	0.00	0.17	2.50	1.12
Chum Salmon (Dog)	4	0.00	0.00	0.00	0.25	2.00	0.00

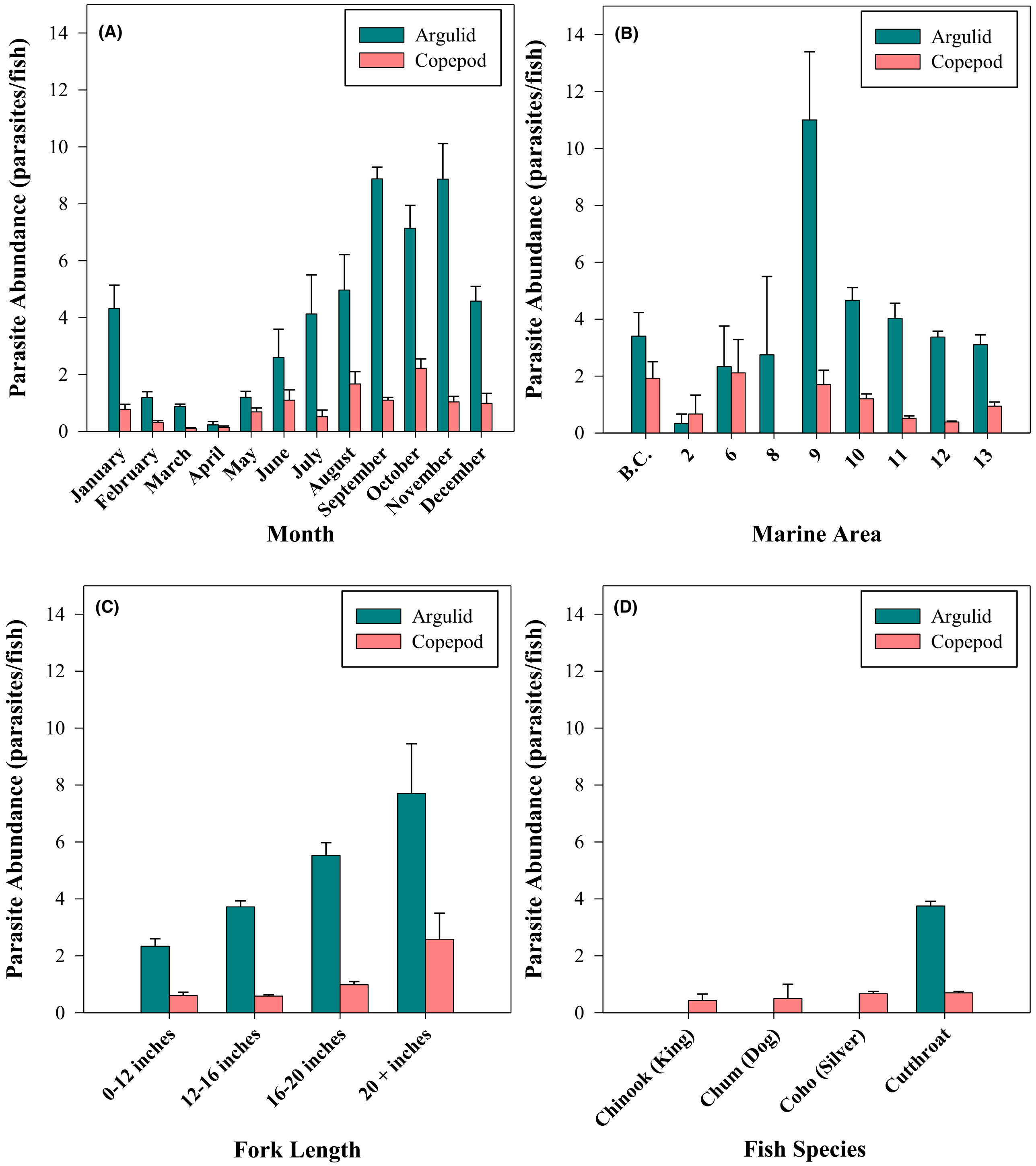

Figure 4. Abundance of parasitic argulids (blue) and copepods (pink) comparing patterns of infection on anadromous Coastal Cutthroat Trout *Oncorhynchus clarkii clarkii* in 2018 between (**A**) months, (**B**) marine areas (see Figure 3), (**C**) size-classes, and (**D**) host species.

An additional finding of note was the lack of argulids on Coho Salmon reported by biologists and volunteers. This result has important implications for the ability of anglers to identify parasites and properly report counts to the sea lice reporting application including those fish with zero parasites. The fact that Coho Salmon of the same size as Cutthroat Trout live sympatrically but remain uninfected with the argulid parasite highlights an important difference in the host selection of parasite species (MacKenzie 1987). While the mechanism for this differential infection is unknown, it is plausible that Coho Salmon have developed a physiological or behavioral trait that makes them unsuitable for the parasite. Alternatively, it is possible that the argulid parasite prefers Cutthroat Trout or that fine-scale ecological or behavioral differences between Cutthroat Trout and salmon (foraging behavior, habitat use, etc.) provides different susceptibility to argulid infections. Both

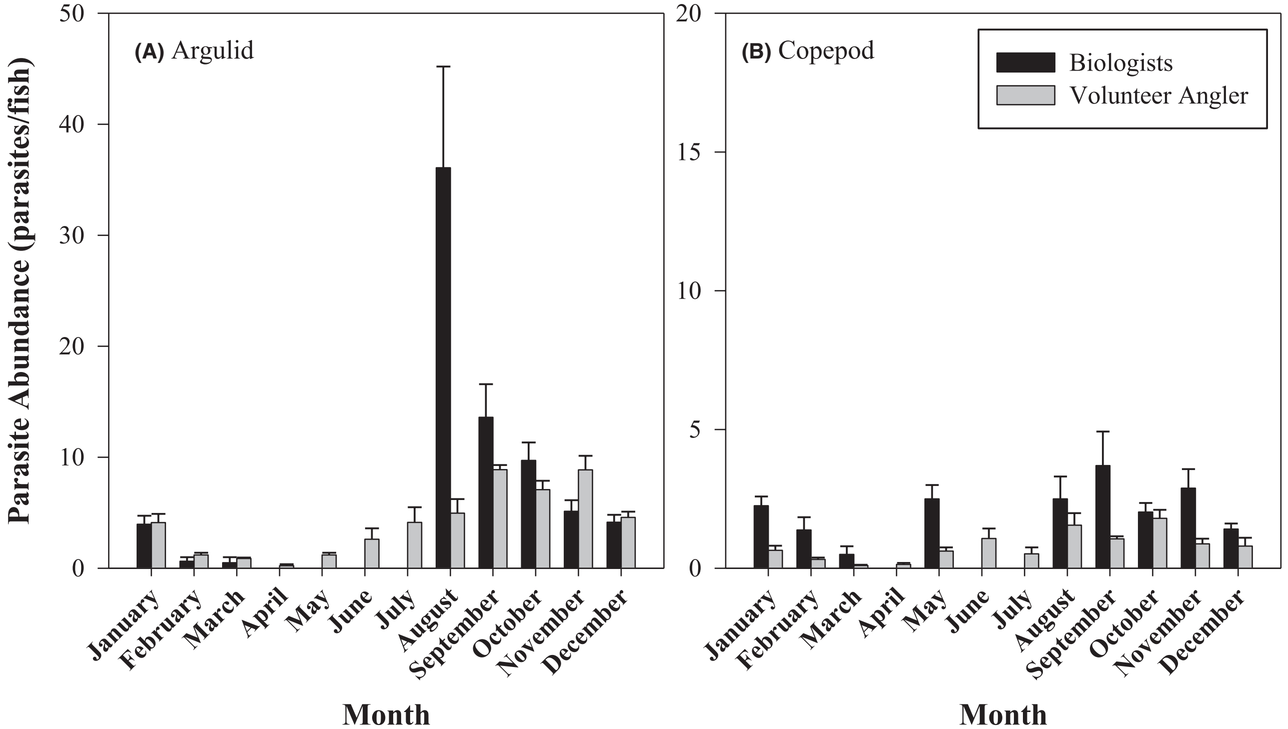

Figure 5. Estimates of (A) argulid and (B) copepod abundance reported by biologists (black) vs. volunteer anglers (gray) observed on anadromous Coastal Cutthroat Trout *Oncorhynchus clarkii clarkii*. No samples were collected by biologists in June or July.

host behavior and parasite preference have been attributed to differences in parasite infections between fish species that occupy similar habitat (Rohde 1982; Trudel et al. 2007; Losee et al. 2014). Argulids have been documented on Cutthroat Trout (Losee et al. 2020) and Coho Salmon (Kent 1992) previously, but additional research is needed to understand determinants of infection. Future research focused on the interaction between this relatively unstudied parasite would improve our understanding of Cutthroat Trout behavior and the effect these infections have on their hosts.

Comparing parasite counts of volunteers vs. trained biologists provided important insights and areas for future work. Volunteer anglers reported parasite counts for more than 1,500 fish sampled in Washington, Oregon, and California,

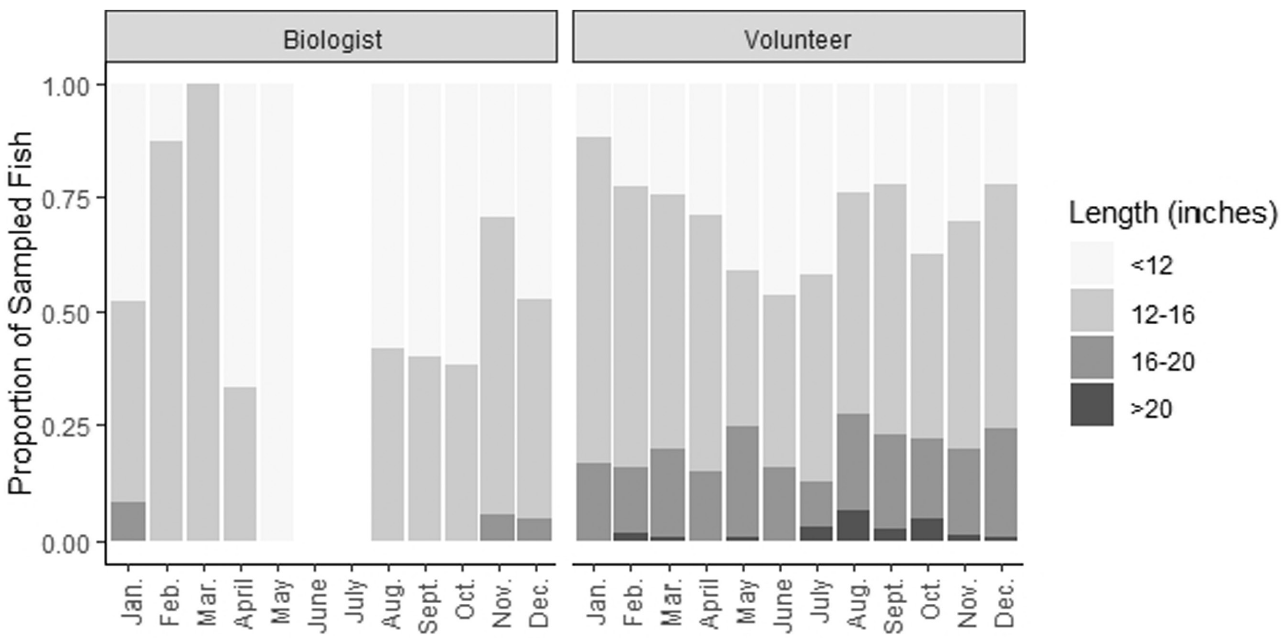

Figure 6. Proportional contribution of size classes of anadromous Coastal Cutthroat Trout *Oncorhynchus clarkii clarkii* by month captured and reported by fish biologists using beach seine and volunteer anglers using hook and line, both in Marine Area 13, Puget Sound, Washington. No samples were collected by biologists in June or July.

as well as British Columbia, and in South Puget Sound, and produced results that closely matched data collected by trained fish biologists across the study period. As mentioned above, both volunteer anglers and trained biologists reported zero argulids on Coho Salmon, Chum Salmon, and Chinook Salmon, highlighting the species-specific nature of this parasite and ability of anglers to successfully identify two species of ectoparasites on various species of salmonid hosts. However, significant differences were observed when comparing parasite counts of biologists versus those reported by anglers in Marine Area 13. These results highlight the fine-scale differences in parasite abundance within an area sampled by anglers which encompasses approximately 108,574 acres. While significant cost savings were achieved by utilizing free social media outlets and a Web-based online reporting app, we required anglers to report their parasite counts into large marine area assignments to reveal broad patterns of infection and maximize efficiency and accuracy for volunteers. Our web-based tool required less than 10 h of development at a cost of US$35 per month. Complimentary efforts by trained fish biologists in this study in one area of South Puget Sound (Marine Area 13; Figure 3) using beach seine required two fish biologists, four scientific technicians, and a significant investment in equipment (boat, beach seine, nets, etc.). By conducting this work simultaneously with volunteers, we showed that volunteer anglers recorded parasite abundance accurately for a low cost, but spatial resolution was limited. Future studies utilizing volunteer anglers and Web-based tools should tailor the study design and associated reporting technology to the specific study question in order to balance simplicity in reporting and complexity of data received.

An additional source of uncertainty identified when comparing reports from volunteer anglers with those of biologists sampled in the same marine area was the potential for anglers to overestimate the body size of fish sampled. The notion that anglers overestimate the size of their fish has been well documented in scientific literature and popular press; therefore, it is likely that differences in size are the result of inaccuracies in data reported by anglers due to overestimation of fish size or failure to report small fish (Andersen 1973; Greenlaw 2004). Other potential reasons for the discrepancy in size between these two independent data sources could include differences in gear type (beach seine vs. hook and line), small sample size, or small-scale differences within Marine Area 13, as noted above. To better understand the discrepancies between data from volunteer anglers and biologists reported here, future research should rely on a comparison of catch between volunteers and trained biologists in a smaller geographic area utilizing similar gear type.

The effect of argulid parasites on anadromous salmonids is not known. This is due partially to the fact that marine argulids are much less common than members of the same genus inhabiting freshwater and estuarine environments (Walker et al. 2004), but also because marine ectoparasites in Puget Sound are not well studied. In northern parts of the Salish Sea and elsewhere, research has highlighted the negative effect parasitic copepods have on salmon and associations with net pens, including secondary infections (Johnson et al. 2004), change in behavior (Gjelland et al. 2014; Halttunen et al. 2018), changes in diet (Godwin et al. 2015), and reduced survival (Gargan et al. 2003). Within the current study area, numerous net pen operations have existed for decades (Mahnken 1975; Rensel et al. 1988) and are comprised in large part of those raising juvenile Coho Salmon, which are known as a host for argulid and copepod parasites (Kent 1992). While argulid infections were not observed on more than 400 Coho Salmon sampled in the current study, the infection status of pen-reared Coho Salmon in Puget Sound is unknown; therefore, an association between net pens and argulid infections is unknown.

Argulids consume blood and tissue of their host (Walker et al. 2004) and, in extreme cases, intensities were observed to exceed 60 parasites per individual fish. While the potential deleterious effects of high intensity ectoparasite infections are unknown, it is plausible that Coastal Cutthroat Trout may be negatively impacted by the observed high infection rates. A comprehensive management approach focused on long-term sustainability of the anadromous life history of Cutthroat Trout should include well-designed studies aimed at a better understanding of the interaction between Cutthroat Trout and their parasites. Comparing ectoparasite hotspots reported in this study, such as Marine Area 9, with those where parasite prevalence is relatively low (e.g., Marine Area 6) could serve as a good starting point.

CONCLUSION

Regardless of the fact that argulids were reported on the back of "a small silver salmon" more than 100 years ago (Wilson 1908) and sport anglers have been encountering them during this time period, descriptive information on this parasite has been absent in the scientific literature until recently. This is partly due to inadequate funding for Coastal Cutthroat Trout research relative to their anadromous salmonid cousins. Through the use of online reporting and involvement from the angling community, results from this work corroborated previous results showing that community data collection has a role in science, including the goal of filling data gaps at a low cost. This approach has the added benefit of increasing awareness for conservation issues and improving engagement of those that interact with the focal species the most. The use of online data reporting should continue to be explored for other species that are targeted by sport fishers and have complex management questions that have remained unanswered by relying on traditional methods.

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