

Extension Bulletin

SHELL-BORING WORMS ON PACIFIC OYSTER FARMS OF THE U.S. WEST COAST

Prevalence, distribution, and control measures

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Front cover: Oyster farm
Above: Julieta Martinelli clipping a bag of oysters to a flip bag line on a beach.

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Photos throughout report: Courtesy of Julieta Martinelli

TABLE OF CONTENTS

BACKGROUND 1
Introduction 1
Why the interest in shell-boring worms? 1
Shell-boring worm life cycle 2
Infestations globally and in the U.S. 2

IDENTIFYING SHELL-BORING WORMS 3
How to identify shell-boring worms 3
What is and is not a shell-boring worm 3

SHELL-BORING WORM SPECIES ON THE U.S. WEST COAST 3
Species present in CA, OR, WA, and AK 3

PREVALENCE OF SHELL-BORING WORMS IN THE U.S. WEST COAST 4
Overview of results for CA, OR, WA, and AK 4
Conditions that can enhance and reduce worm levels 6

CONTROL MEASURES FOR SHELL-BORING WORMS IN THE US WEST COAST 6
Overview of experimental treatments 6

SUMMARY 8

REFERENCES 9

ACKNOWLEDGMENTS 10

APPENDIX 11
Flyer: How to Identify Shell-boring Worms on Oysters 11

FIGURES
Figure 1. Examples of healthy and infested Pacific oyster shells. 1
Figure 2. Steps of the infestation process. 2
Figure 3. Overall prevalence per state. 3
Figure 4. Seasonality in prevalence. 5
Figure 5. Water pH and infestation by shell-boring worms. 5
Figure 6. Image of *Polydora websteri* found in Washington 7
Figure 7. Live worms found per oyster after treatments were applied. 7

TABLES
Table 1. Shell-boring worm species found per state. 4

FOREWORD

This bulletin is based on a series of peer-reviewed journal articles produced by the research team on the WRAC-funded project, "Detection and Control of Mud Blister Worm (*Polydora* spp.) Infestation on Commercial Oyster Farms Throughout the Pacific Northwest"

The sections in this document summarize the findings of the various research elements explored. For specific detail on the collection, processing and analyses, please review the journal articles linked below.

Identifying shell-boring worms is based on:
Martinelli JC, Lopes HM, Hauser L. Jimenez-Hidalgo I, King TL, Padilla-Gamiño JL, and Wood CL. (2020) Confirmation of the shell-boring oyster parasite *Polydora websteri* (Polychaeta: Spionidae) in Washington State, USA. Scientific Reports, 10, 3961. https://doi.org/10.1038/s41598-020-60805-w

Shell-boring worm species on the U.S. West Coast is based on:
Martinelli JC, Lopes HM, Hauser L, Jimenez-Hidalgo I, King TL, Padilla-Gamiño JL, and Wood CL. (2020) Confirmation of the shell-boring oyster parasite *Polydora websteri* (Polychaeta: Spionidae) in Washington State, USA. Scientific Reports, 10, 3961. https://doi.org/10.10320-60805-w

Martinelli JC, Considine M, Casendino HR, Tarpey CM, Jimenez-Hidalgo I, Padilla-Gamiño JL, King TL, Hauser L, Rumrill SS, and Wood CL. (2024) Infestation of cultivated Pacific oysters by shell-boring worms along the US West Coast: prevalence is associated with season, culture method, and pH. Aquaculture 580:740290 https://chelsealwood.com/wp-content/uploads/2024/01/Martinelli-et-al.-2023.pdf

Prevalence of shell-boring worms on the U.S. West Coast is based on:
Martinelli JC, Considine M, Casendino HR, Tarpey CM. Jimenez-Hidalgo I, Padilla-Gamiño JL, King TL, Hauser L, Rumrill SS, and Wood CL. (2024) Infestation of cultivated Pacific oysters by shell-boring worms along the US West Coast: prevalence is associated with season, culture method, and pH. Aquaculture 580: 740290. https://chelsealwood.com/wp-content/uploads/ 2024/01/Martinelli-et-al.-2023.pdf

Control measures for shell-boring worms in the US West Coast is based on:
Martinelli JC, Casendino HR, Spencer LH, Alma L, King, TL, Padilla-Gamiño JL, and Wood CL. (2022) Evaluating treatments for shell-boring worm (Annelida: Spionidae) infestations of Pacific oysters (*Crassostrea gigas*) in the US Pacific Northwest. Aquaculture 561: 738639. https://doi.org/10.1016/j.aquaculture.2022.738639

Spencer LH, Martinelli JC, King TL, Crim R, Blake B, Lopes HL, and Wood CL. (2021) The risks of shell-boring worms to shellfish aquaculture in Washington, USA: A mini-review to inform mitigation actions. Aquaculture Research 52:438-455. https://DOI.org/10.1111/are.14921

Considine ME, Martinelli JC, King TL, Rumrill SS, and Wood CL. Spatial and temporal variability in infestation of Oregon oyster farms by shell-boring polychaetes. (2024) Aquaculture Reports 35:101929. https://doi.org/10.1016/j.aqrep.2024.101929

BACKGROUND

Introduction

Bivalve molluscs have two valves—or shells—and an empty bivalve's shell tells quite a story. The shell documents the history of its life: how it lived, how fast it grew, and what may have attached to the shell as it grew. Generally, people will look at the outside of the shell and see barnacles, periwinkles, little starts of seaweed plants, and perhaps an oyster spat or two. Inside the empty shell, one sees the lustrous, pearly nacre layer, a dark-colored scar where the adductor muscle is attached and maybe a round bump that might be the start of a pearl forming. Sometimes however, the inside of the shells will be duller with dark tracks or burrows that have a thin glassine layer of nacre over them. These are the signs of a shell-boring worm, sometimes also called a mud-blister worm.

Why the interest in shell-boring worms?

Shell-boring worms are not harmful to humans or consumers of shellfish, but they can be unsightly particularly for the half-shell market. The worms burrow in from the outside of live bivalve shells or slip into the soft lip of the open valve and burrow inside, excavating a home that they will occupy and fill with mud and worm feces (Figure 1). Shell-boring worms can cause malnutrition by stealing food intended for the shellfish, and the burrowing activity of these worms puts additional stress on its host by causing it to expend energy for additional shell maintenance, since the shellfish will lacquer over the burrow inside of the shell with nacre to wall off the shell-boring worm, instead of putting energy into growing a bigger shell. In severe infestations, shell-boring worms can kill their shellfish host.

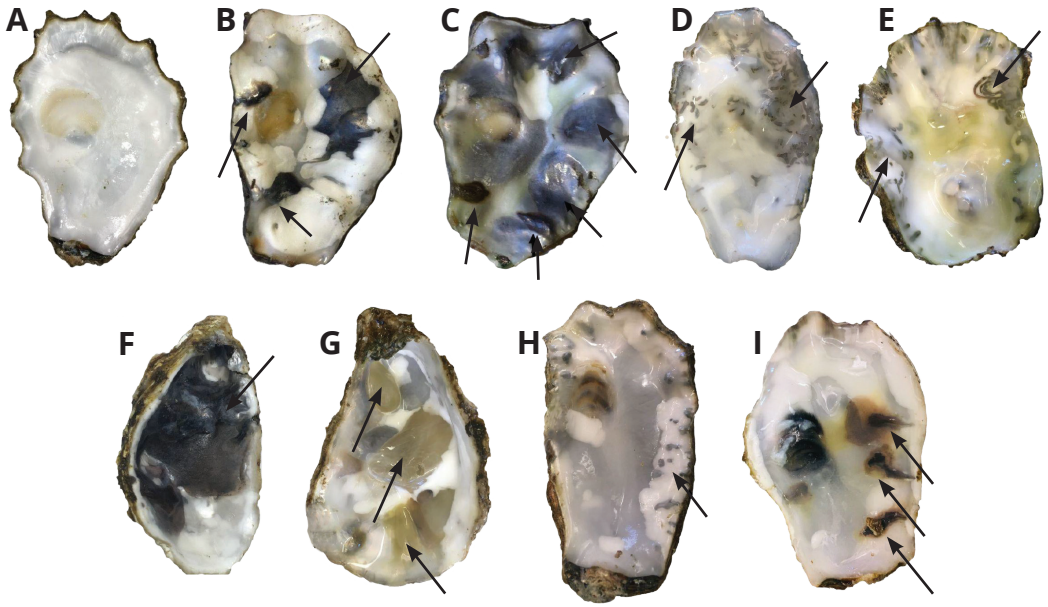


Figure 1. Images of Pacific oyster valves (*C. gigas*) with different levels of infestation: (A) Healthy shell with no signs of infestation, (B-I) Shells infested with shell-boring worms (burrows, blisters, or both), as indicated by the black arrows.

Shell-boring worm life cycle

The shell-boring worm life cycle begins when the male shell-boring worms deposit sperm near a female worm's burrow. She captures and holds onto the sperm until her eggs are ready for fertilization. Once fertilized, the egg is encapsulated. The capsules, containing multiple eggs, are deposited along the side of the burrow. The amount of time from capsule formation to larval emergence can be long – up to 85 days – and is based on water conditions (e.g., temperature) and varies by worm species. Early hatched larvae can sometimes feed on underdeveloped eggs and linger in the burrow, resulting in a later release stage for settlement and recruitment. Once emerged from the capsule, larvae exist as free-floating plankton until they settle out of the water column. Many species of shell-boring worms can spawn multiple times throughout the year. Juvenile and adult shell-boring worms settle onto bivalve shells and begin the burrowing process (Figure 2).

Infestations globally and in the U.S.

Shell-boring worms, including species in the genera *Polydora*, *Dipolydora*, *Boccardia*, and *Boccardiella*, have a long history of reducing shellfish aquaculture production and value in regions such as Australia, New Zealand, South Africa, Chile, Mexico, Hawaii, the east coast of the United States, Gulf of America, and the east and west coasts of Canada. The primary impact to oyster production is product devaluation due to negative consumer responses to unsightly blisters and burrows within the inner shell, particularly in freshly shucked half shell oysters. If a blister is nicked during shucking, anoxic material can contaminate oyster meat and brine, detracting from flavor and presentation. Burrows can also decrease shell strength, causing cracks during shipping and handling, and making shucking difficult. Since half-shell oysters are the most lucrative product option for oyster farmers, and infested oysters are often not salable on the half-shell market, infestation by shell-boring worms substantially depreciates oyster products.

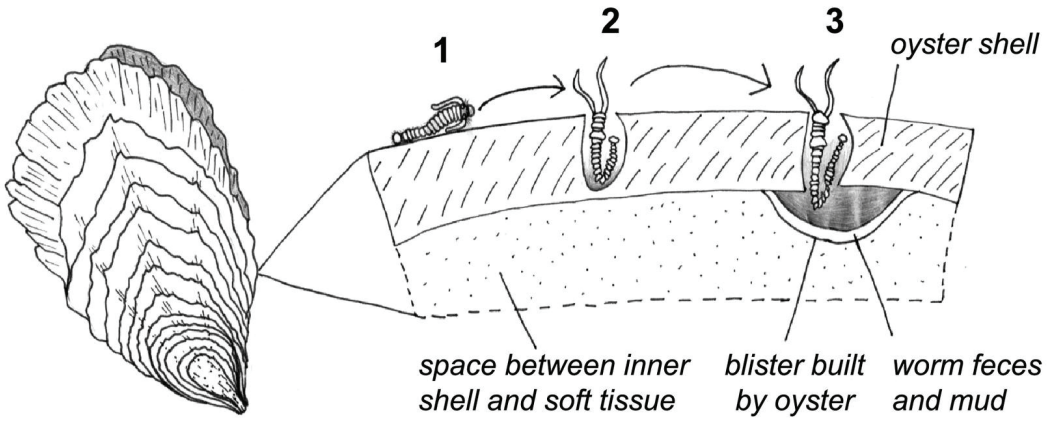


Figure 2. Diagram showing the infestation process by shell-boring worms on oysters. Juvenile larvae settle on the oyster shell and undergo metamorphosis (1), and either the juvenile or the post-metamorphic worm slowly starts dissolving and burrowing into the shell (2). Over time, as worms grow larger, they penetrate the inner layer of the oyster shell, and (3) start accumulating mud, feces, and debris. In response, the oyster creates a blister, which is added layers of shell, to separate the worm and other contents from the oyster soft tissue. Scientific illustration by Dr. Danielle Claar. This figure was originally published in Aquaculture, Vol 561, Martinelli et al., "Evaluating treatments for shell-boring worms (Annelida:Spionidae) infestations of Pacific oysters (*Crassostrea gigas*) in the US Pacific Northwest," 738639, Copyright Elsevier (2022).

IDENTIFYING SHELL-BORING WORMS

How to identify shell-boring worms

You will not see the tell-tale signs of shell-boring worm infestation by looking at the outside of an oyster's shell, as these worms are too small to be seen with a naked eye. Generally, you will need to shuck open the shells and remove the meat to see the burrows and blisters under the thin nacreous layer (Figure 1). Sometimes by carefully tracing and looking at the internal burrow, you can find the opening on the outside of the valve. Most infestations occur through the lip of the shell. As part of our extension work with the Western Regional Aquaculture Center (WRAC) funding, we have created a mud worm identification card to help train industry members and natural resource managers how to identify shell-boring worm signs (see Appendix).

What is and is not a shell-boring worm

Shell-boring worms are small and pink, with two palps, paired sensory appendages on the head that run alongside their body (Figure 3). Because of their small size, they are usually hard to see and identify without a microscope, and the best way to find them is by carefully breaking a shell that has either burrows or blisters (Figure 1). *Polydora websteri*, for example, can measure up to 24 mm long, 1.2 mm wide, and have up to 110 segments (Figure 3). Sometimes shell-borers are confused with other worms, such as the bamboo worms (*Clymenella torquata*), which are much larger in size (50–195 mm long), and darker in coloration.

SHELL-BORING WORM SPECIES IN THE U.S. WEST COAST

Species present in CA, OR, WA, and AK

A variety of shell-boring worms have been found in bivalve shellfish along the West Coast, specifically oyster species in northern California, Oregon, Washington and Alaska. Some species of worms are thought to be indigenous to the region and have been documented in Washington native Olympia oysters (*Ostrea lurida*) back to 80,000 years ago (submitted Martinelli et al., 2025). It is unknown whether these native worms still coexist with native oysters today, or if they also infest Pacific oysters (*Crassostrea gigas*).

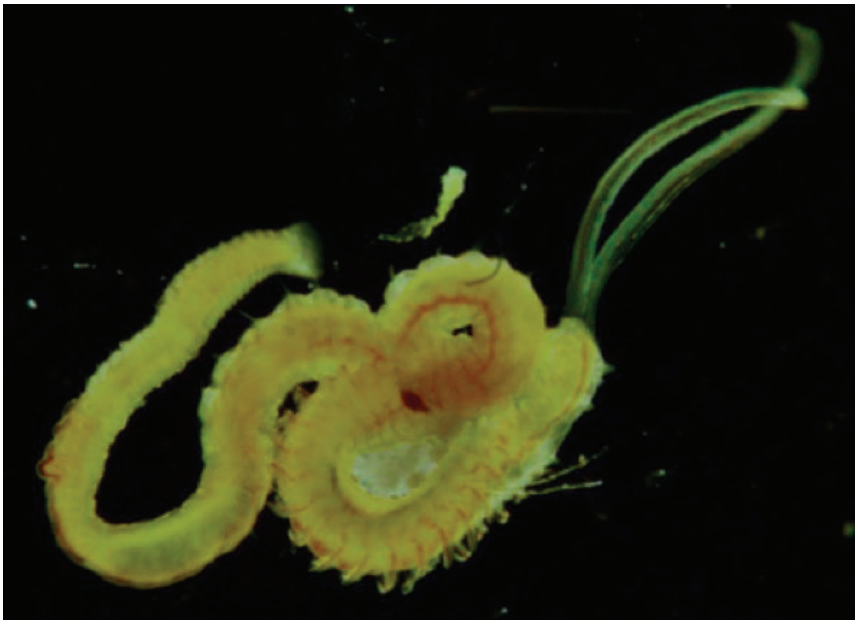


Figure 3. *Polydora websteri* found in *Crassostrea gigas* valve in Puget Sound, Washington, in 2017.

Genetic research has identified a number of shell-boring worm species in Pacific oysters from northern California, Oregon, Washington and Alaska (Table 1). This work has also confirmed the presence of unidentified species. A haplotype is a genetic signature representing a specific combination of linked alleles that can help researchers identify worm lineages and how the various identified and unidentified species may relate to each other.

Using these molecular techniques, *Polydora websteri* was found in Alaska, Washington, Oregon and northern California; *Polydora hoplura* was found in samples from Oregon and northern California, and *Boccardiella hamata* in samples from Washington. Additionally, a cryptic sister species to *P. websteri* was identified in samples from Washington and northern California. For an overview of the species found in each state and other potential new species, see Table 1.

PREVALENCE OF SHELL-BORING WORMS IN THE U.S. WEST COAST

Overview of results for CA, OR, WA and AK

As part of this WRAC-funded project to evaluate the prevalence of shell-boring worms along the US west coast, we collected 4,158 Pacific oysters across four states (CA = 819, OR = 829, WA = 2,023, AK = 487). The overall prevalence was similar in the southern three states (CA = 24%, OR = 24%, WA = 23%), while Alaskan oysters were more heavily infested (AK = 45%, Figure 4). However, these average values mask great variability observed among farms within each state. Farm-level prevalence was either very low (0–10%) or very high (70–90%). Our analysis also found that infestation was higher in larger oysters and in winter months. We did observe some variability between states, as infestation was not higher in winter for Oregon (Figure 5), and oysters that were grown on-bottom had higher infestation rates in all states except Alaska.

Table 1. Shell-boring worm species found per state. Readers can visualize the unique composition per state by viewing each column individually. For details about molecular findings, please see Martinelli et al., 2024 in Aquaculture.

SPECIES/HAPLOTYPE	CALIFORNIA	OREGON	WASHINGTON	ALASKA
Polydora websteri				
Polydora hoplura				
Boccardiella hamata				
Boccardia proboscidea				
Polydora onagawaensis				

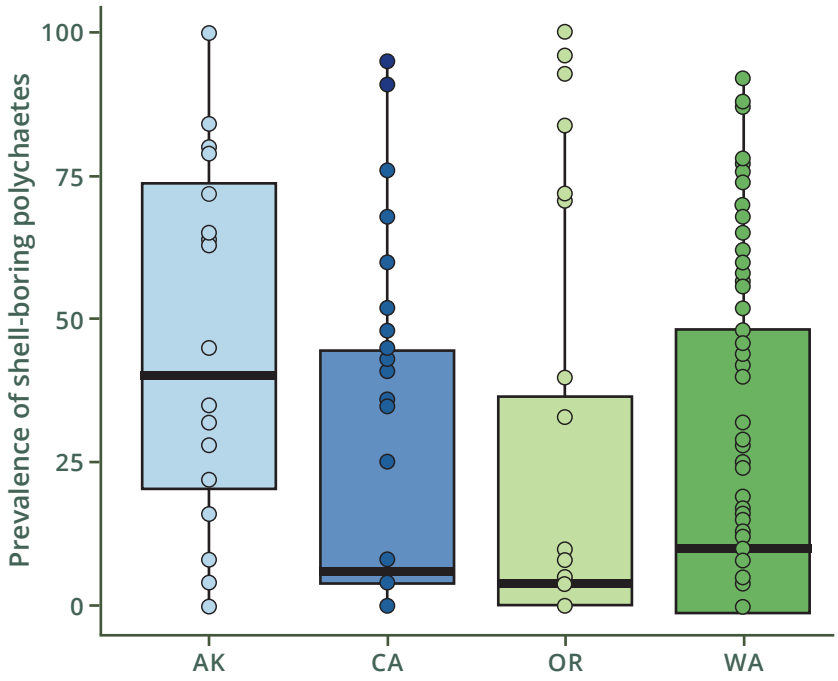


Figure 4. Average prevalence of infestation (% of oysters with blisters or burrows) across all farms sampled in each state (AK = Alaska, CA = California, OR = Oregon, WA = Washington). Each box encloses the 25th to the 75th percentiles. The horizontal line represents the median prevalence value for each state. Data points beyond the whiskers are considered outliers. Each point represents one farm in one season.

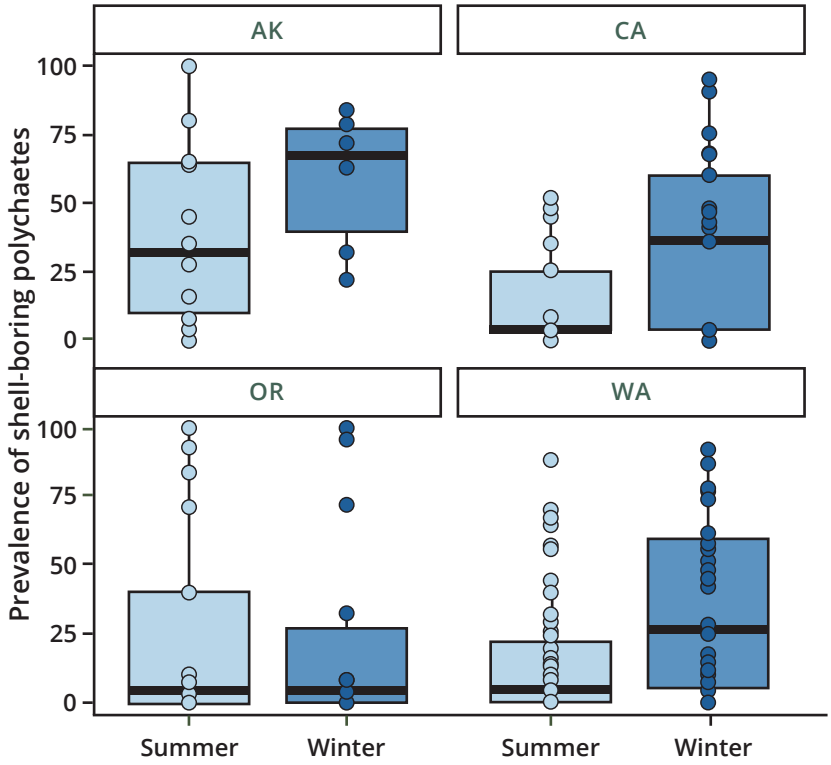
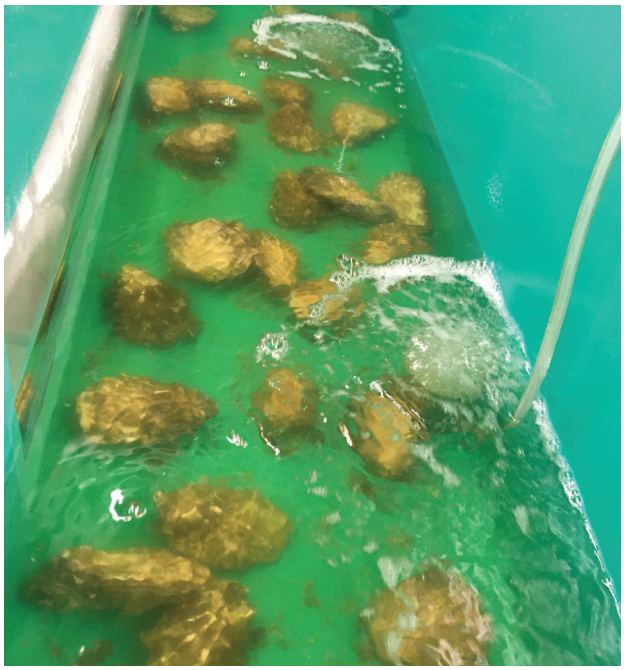


Figure 5. Seasonality in prevalence of infestation across all farms sampled in AK, CA, OR, and WA. Sampling seasons were pooled as follows: "Summer" = Summer 2019 + Summer 2020; "Winter" = Winter 2020 + Winter 2021. Each box encloses the 25th to the 75th percentiles. The horizontal line represents the median prevalence value for each state. Data points beyond the whiskers are considered outliers. Each point represents one farm.

Conditions that can enhance and reduce worm levels

Shell-boring worms are commonly associated with muddy and silty substrates, so elevating shellfish crops off of the substrate can reduce the risk of infestation. Rack and bag culture, stake culture, flip bags, and other similar growing methods elevate the shellfish for the entire life and tidal cycles off the bottom and provide exposure of the shellfish to air with the changing of the tides, thus reducing infestation potential. Additionally, growing shellfish higher in the intertidal can also reduce the chance of intersecting with shell-boring worms, as the worms prefer lower tidal elevations. Relic oysters, reef oysters, or large populations of older infested shellstock can act as shell-boring worm larval reservoirs. Harvesting infested shellstock will help reduce the larval load in the area and the possibility of infestation. Focusing on environmental change conditions such as salinity, sea surface temperature, and pH, we found that only pH had a significant effect on the likelihood of an oyster being infested with shell-boring worms. Interestingly, higher alkalinity waters between pH 8 and 8.2 had a higher probability of being infested than lower alkalinity waters (Figure 6).



Pacific oysters in a raceway of seawater.

CONTROL MEASURES FOR SHELL-BORING WORMS IN THE US WEST COAST

Overview of experimental treatments

Our research focused on control measures that would reduce the burden of shell-boring worms without being overly cumbersome to apply on commercial shellfish farms. The goal for these control measures was that they would kill the worms but not kill Pacific oysters. We also sought control measures that would not impact the oyster's physiology or growth over the long term. We worked closely with our industry advisors to design our experiment. Three simple treatments were then tested:

1) A Dry treatment where shells were removed from the water and placed inside grow-out bags for two days at ambient temperature (10–15 °C),
2) A Fresh-Dry combination treatment where oysters were dipped in a container of freshwater for one hour, followed by drying at ambient temperature for two days (10–15 °C),
3) A Refrigeration treatment where oysters were placed in a refrigerator (4 °C) for three days.

The Dry treatment was the most effective at reducing the number of live worms, but it caused 4% mortality in the Spring (Figure 7). None of the treatments negatively impacted shell growth in the long term. For a full review of the experimental treatments, please see Martinelli et al. 2022.



An open bag of labeled Pacific oysters.

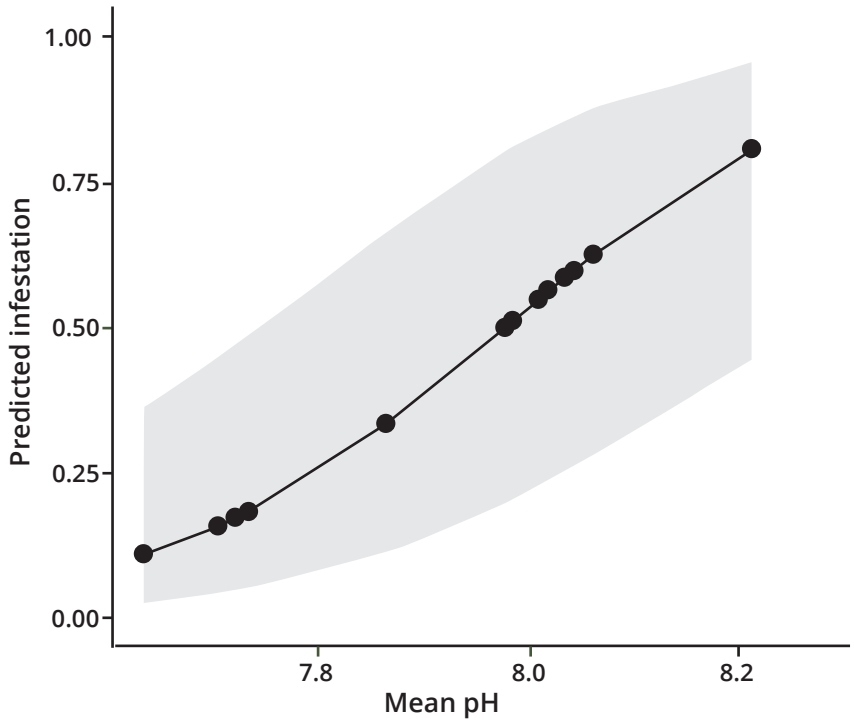


Figure 6. Predicted infestation (0 = not infested, 1 = infested) of an oyster as a function of variability in pH. Oysters in more alkaline water are predicted to have higher chances of being infested than oysters in more acidic waters. Model details can be found in Martinelli et al. 2022.

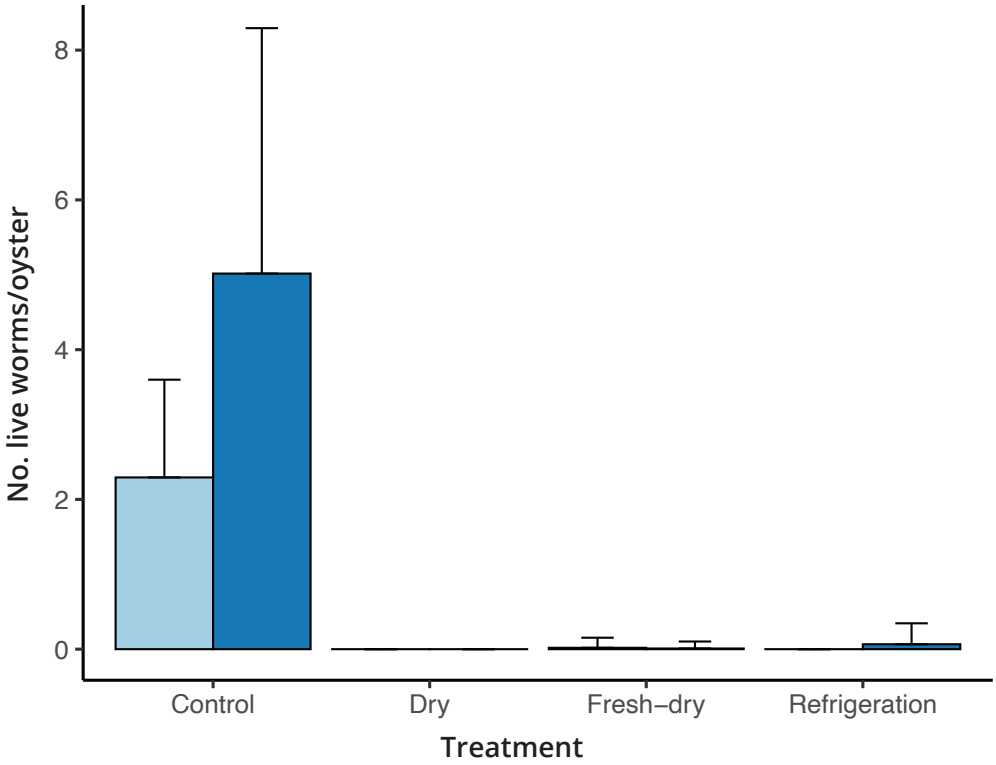


Figure 7. Barplot showing the number of live worms per oyster after each of the treatments. Seasons are color-coded: fall 2020 is shown in light blue and spring 2021 in dark blue.

SUMMARY

Shell-boring worms have contributed to the collapse of several oyster aquaculture operations around the world. These pests burrow into the shells of bivalves, creating mud blisters that are unappealing to consumers, and which make oysters less valuable on the half-shell market. The US Pacific region produces 38% of the farmed shellfish in the US, making it important to understand the prevalence and drivers of parasite infestation in this region. In addition to conducting sampling from 35 shellfish farms over four seasons and four states (CA, OR, WA and AK), we also collaborated with local shellfish growers to develop treatments that could be practically deployed on oyster farms. Our sampling confirmed the presence of *Polydora websteri* in the study region, in addition to four other species of shell-boring worms and several unidentified haplotypes. The mean prevalences across all shell-boring worm species ranged from 23–45% across seasons between states. In general, prevalence was higher in the winter and among oysters cultured on the bottom versus in tumbled bags, but these results varied across states. We also found greater infestation by shell-boring worms at less acidified sites (pH = 8-8.2). The experimental treatments developed to control shell-boring worms showed that drying and using a freshwater dip plus drying for two days are both highly effective at killing worms without negatively impacting oyster survival. This work is the most comprehensive dataset to characterize shell-boring worms along the US West Coast, providing an important baseline of prevalence, species distribution, environmental associations, and control measures.



Person walking on a beach carrying a bucket and collecting oysters at low tide.

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Martinelli JC, Lopes HM, Hauser L, Jimenez-Hidalgo I, King TL, Padilla-Gamiño JL, and Wood CL. (2020) Confirmation of the shell-boring oyster parasite *Polydora websteri* (Polychaeta: Spionidae) in Washington State, USA. Scientific Reports, 10, 3961.

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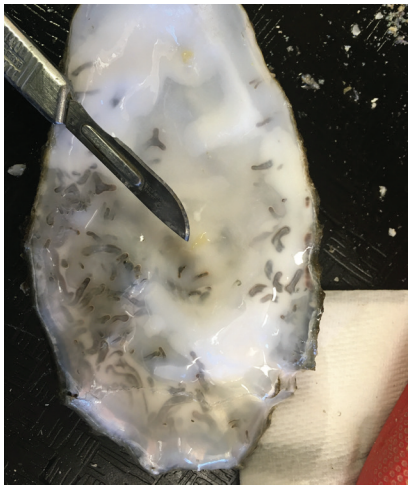
Martinelli, JC, Considine M, Casendino HR, Tarpey CM, Jimenez-Hidalgo I, Padilla-Gamiño JL, King TL, Hauser L, Rumrill SS, and Wood CL. (2024) Infestation of cultivated Pacific oysters by shell-boring worms along the US West Coast: prevalence is associated with season, culture method, and pH. Aquaculture 580:740290.

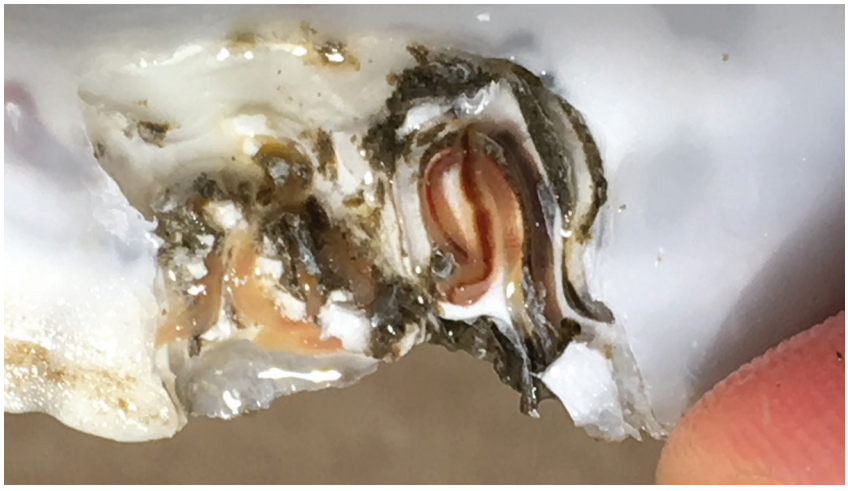
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Left: Scalpel pointing to mud blister worm burrows on the inside of a Pacific oyster.
right: Close-up of a pink mud blister worm underneath the exposed nacre layer in the inside of a Pacific oyster.

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Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and should not be construed to represent any official USDA or U.S. Government determination or policy.



Oyster flip bags piled on a beach with oyster flip bags in the foreground hung on lines.

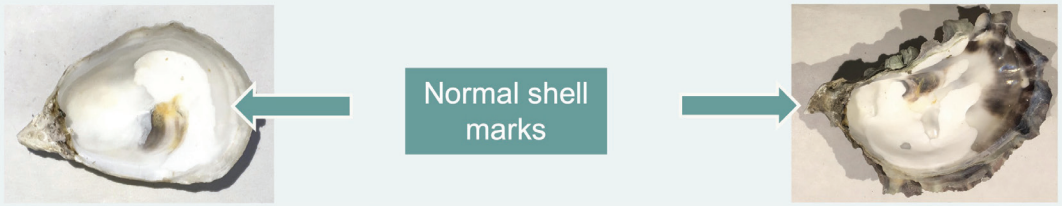
APPENDIX: FLYER TO SHARE AT OYSTER FARMS

Do you know how to identify shell-boring worms?

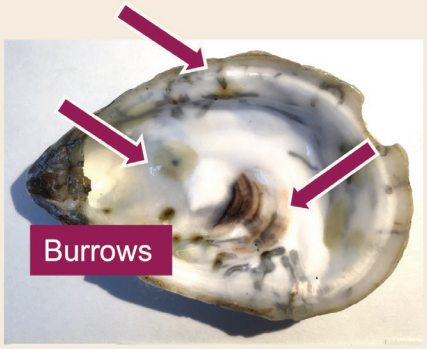
Shell-boring worms, such as *Polydora websteri*, live in the water column as larvae before settling onto the outer surface of oyster shells. Once there, they burrow into the inner shell, creating burrows and blisters filled feces and mud, making shucked oysters unappealing to consumers. Use the images below to identify the signs of investation.

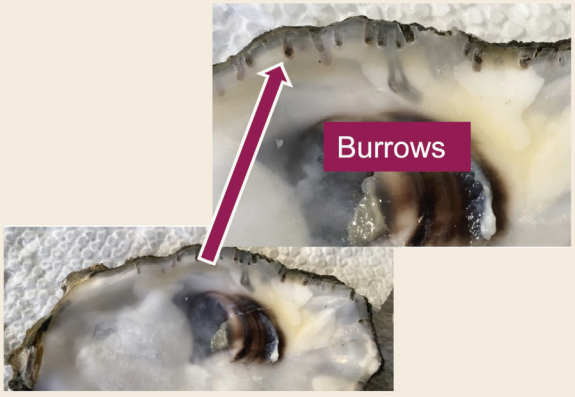


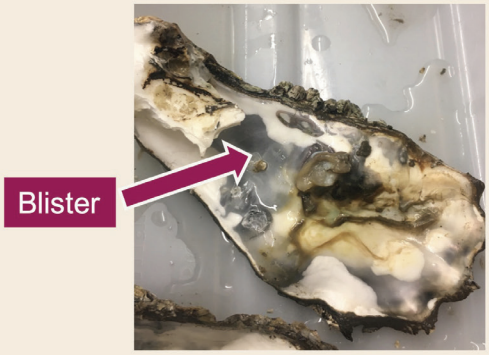
Examples of healthy shells



Examples of infested shells









Polydora infestations occur on shellfish farms all along the US west coast. While harmless to the consumer, the presence of these marks make half-shell products unattractive. If you'd like to know more, or how to treat these pests, contact Dr. Chelsea Wood (chelwood@uw.edu) at the University of Washington. This project was funded by the Western Regional Aquaculture Center from the USDA National Institute of Food and Agriculture, grants 2018-38500-288889 and 2020-38500-32561.



Oyster beach at low tide.

The Western Regional Aquaculture Center (WRAC) is one of five centers in the United States. Developed to take advantage of the best aquaculture science, educational skills, and facilities within a twelve-state area, WRAC works to enhance viable and profitable commercial aquaculture production in the U.S. for the benefit of producers, consumers, and the American economy.

To learn more about WRAC, go to the website at https://wracuw.org.

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