Regional surveys and outreach for the non-indigenous burrowing isopod, *Sphaeroma quoianum*

Report Submitted to the Western Regional Panel on Aquatic Nuisance Species,
U.S. Fish and Wildlife Service

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EXECUTIVE SUMMARY

The non-indigenous isopod *Sphaeroma quoianum* has established populations along the west coast of North America from Baja California, Mexico, to central Oregon, USA. This isopod burrows into mud, decaying wood, sandstone, and even Styrofoam, and its extensive burrowing damages shorelines and floats. Most surveys for this isopod are at least 30 years old, and the new, broader surveys for non-indigenous estuarine species have not sampled key *S. quoianum* habitats. Therefore, we surveyed 19 estuaries ranging from central California to Nanaimo, British Columbia for populations of *S. quoianum*. We did not detect a range expansion by *S. quoianum*. The population in Yaquina Bay (northernmost population), however, has increased substantially. It has expanded to occupy more of the shoreline of Yaquina Bay and has caused extensive damage to the docks of an aquaculture facility.

The regional survey also revealed range expansions for two other non-native species, the New Zealand isopod *Pseudosphaeroma campbellense* and the snail *Potamopyrgus antipodarum*. These findings highlight the importance of conducting regional surveys that examine habitats or survey for multiple species rather than focusing on one particular taxon.

We conducted a field experiment to determine the impact of burrows of *S. quoianum* on the erosion rate of saltmarsh habitat in Coos Bay, Oregon. Our experiments examined erosion rate on two scales: 1) within infested marshes, by examining the erosion rate between burrowed and adjacent unburrowed areas, and 2) between marshes, by examining the erosion rate between infested marshes and marshes not infested by *S. quoianum*. Within infested marshes, mean erosion rates were more than 3 times greater in burrowed areas than adjacent unburrowed areas. Erosion rate, the amount of undercutting, and the number of slumped and calved marshes (indicative of marsh breakage and failure) all were higher in infested marsh sites than uninfested reference sites. The between-marsh results could be due, in part, to confounding variables and we are still evaluating the strength of the effects of these possibly confounding variables. The third component of the project is the development of the Non-native Aquatic Species of Oregon website. This website allows visitors to learn about 15 established and potential Aquatic Nuisance Species and to report sightings of new invaders.

The survey of Yaquina Bay showed that *S. quoianum* can spread quickly through a bay once the species establishes locally and the assessment of erosion in the field revealed this species is responsible for substantially increasing erosion of infested marshes. Therefore, we are glad to report no additional range expansion in the past thirty years beyond the recent introduction to Yaquina Bay. The spread to Yaquina could have been due to spread from fouled boat hulls from recreational boats or fishery vessels. We recommend the regional strength of these vectors continues to be assessed for fouling organisms and the associated communities. We also recommend expansion of Johannesson's (1988) work that suggested the threat of spread is greater for species with direct larval development than ones with pelagic larval dispersal. Expanding comparison of direct versus pelagic larval development beyond Littorine snails to a variety of marine and estuarine invasive species would help inform risk assessments and monitoring priorities.

Introduction

The extent and impacts of aquatic nuisance species and other non-native species in coastal marine ecosystems have increased greatly in recent years (Carlton & Geller 1993; Ruiz et al. 2000). These non-native species have caused substantial environmental and economic damage to coastal areas (Carlton 2001) and have cost the US economy billions of dollars (OTA 1993; Pimentel et al. 2005). In marine and estuarine environments, the impacts of biological invasions include dramatic changes to ecological community structure and ecosystem dynamics, parasitism of native species, commercial fisheries stress, and detrimental alterations to physical habitat structure (Carlton 2001, Levin 2002). Although the ecological and economic consequences of species invasions are now recognized and studied more than ever before, we still lack fundamental knowledge about the potential and realized impacts of most non-natives. Moreover, we lack ecological information fundamental to developing management options for these species and the ecosystems they affect. Information as simple as the range and sites of introduction and the impacts is even still lacking for many non-native estuarine and marine species.

The isopod *Sphaeroma quoianum* is one such non-native species for which much information needed for management is lacking. Extensive burrowing by this introduced isopod damages shorelines and floats and is thought to have caused extensive loss of west coast marshes (Carlton 1979, Cohen and Carlton 1995, Talley et al. 2001). Despite such impacts and being present in numerous Pacific Coast embayments for almost 150 years and being abundant members of some estuarine communities, there are few reports on the present geographic distribution of this species or on what factors affect its local abundance and distribution. Understanding the pervasiveness of this destructive introduced species will better identify the threat this species poses and help elucidate the factors that control its distribution.

Sphaeroma quoianum (H. Milne Edwards 1840; synonymy: *S. quoyanum, S. quoyana, S. pentodon*) was introduced to the Pacific Coast of North America from its native New Zealand and Australia during the late 19th century (Carlton 1979). Arriving initially in San Francisco Bay, *S. quoianum* spread across the coast invading San Diego in 1927 (Johnson & Snook 1927) and Humboldt Bay in 1931 (Iverson 1974). Today, populations of *S. quoianum* can be found in at least 15 embayments ranging from Baja California, Mexico to central Oregon, USA (Menzies 1962, Carlton 1979, Davidson 2008).

More recent studies have documented persisting populations of *S. quoianum* in several bays. The 2002 California Department of Fish and Game survey of non-indigenous aquatic species (with subreports by Fairey et al. 2002, Boyd et al. 2002, and Cohen et al. 2002) identified *S. quoianum* in Alamitos Bay and Los Angeles Harbor (Cohen et al. 2002), in several parts of Humboldt Bay (Boyd et al. 2002), and also in Monterey Bay Harbor, San Francisco Bay and connecting bays, and Tomales Bay (California F&G 2002). However, *S. quoianum* was likely to be undersampled by that survey project because only the fouling community was sampled in minor ports, bays, and marinas, and sampling efforts for the larger bays and ports were not targeted towards prime *S. quoianum* habitats. Other recent surveys have documented *S. quoianum* in temperate west coast bays as well, including San Diego Bay and other southern California bays, Elkhorn Slough, San Francisco Bay, and Coos Bay, OR (Carlton 1996, Talley et al. 2001, Bane 2002, Crooks, unpublished data). Many other bays, however, have not been adequately surveyed.

The range of *Sphaeroma quoianum* appears to be spreading. Although only one specimen was found in Yaquina Bay in March, 2005, a fall survey that same year revealed a number of *S. quoianum* adults and young and their burrows (Tim Davidson, unpublished data). *Sphaeroma quoianum* were not previously reported from this well-studied bay. Therefore, it seems they have newly invaded there.

There is high threat of further spread of *S. quoianum* for two main reasons. First, this isopod has broad environmental tolerances. For example, adult *S. quoianum* can survive 5º C water temperatures (Jansen 1971) and are found in warm back bay waters as well. *Sphaeroma quoianum* live from 3.8 and 33‰ salinity (Riegel 1959), and are occasionally found in up to 40‰ waters (Hass & Knott 1998). They create refuges in a variety of intertidal and shallow subtidal substrata, especially marsh banks (Talley et al. 2001). Second, *S. quoianum* larval development is direct and so lacks pelagic dispersal. Based on his comparative study between two congeneric snails, one a direct developer and one with pelagic larval dispersal, Johannesson (1988) suggests the threat of spread is greater for direct developers. Species with direct larval development and low adult mobility have a high likelihood of establishing new populations because offspring will hatch within the same area and remain as a dense population until sexually mature (Johannesson 1988).

This project had four main components aimed to help increase understanding of the distribution and effects of *Sphaeroma quoianum*. First, we surveyed bays to determine the west coast distribution of this non-native isopod. Second, we evaluated the influence of temperature and salinity on its abundance. Third, we measured the effect of burrows on erosion rate within infested sites and between infested and uninfested reference sites. We tested two hypotheses about the bioerosive effects of these isopods: Hypothesis 1) Within infested marshes, burrowed areas will erode faster than adjacent unburrowed area; Hypothesis 2) Marshes infested by *S. quoianum* will experience greater rates of erosion, exhibit more undercutting, and harbor more marsh slumps and calves than uninfested reference marshes.

Fourth, we created an educational website to provide detailed information on this species as well as other aquatic nuisance species and to allow web visitors to comment and provide information on new sightings.

METHODS

Regional surveys for *Sphaeroma quoianum*

Between June and August, 2007, we surveyed 19 bays along the west coast of North America. These included four California bays, Smith River, Klamath River, Russian River, Tomales Bay; seven bays in Oregon, Youngs River, Nehalem Bay, Tillamook Bay, Siletz Bay, Depoe Bay, Yaquina Bay, Umpqua River; three bays in Washington, Padilla Bay, Gray's Harbor, Willapa Bay; and five bays in British Columbia, Nanaimo Estuary, Port Alberni, Ucluelet Inlet, Portage Inlet, Esquimalt Inlet. In each bay, we surveyed mid to high littoral areas between 5-30 salinity.

We sampled at least 4 sites in small bays (but typically 6-12 sites) and at least 30 sites in large bays. Sites were separated by at least 100m. We focused our surveys on sites with wood, marsh, Styrofoam floats, and friable rock since *S. quoianum* is most often found in those substrata (Davidson 2008). Where accessible, floating docks in harbors were also visually assessed for populations of *S. quoianum*. When individuals of *S. quoianum* were found, we classified their abundance into one of four density levels, low (1-10), medium (100-300), high (500-1000), or very high (3000+) per 0.25 m^3, based on counts of the visible burrows at the surface along a 50m transect. While our surveys focused on *S. quoianum*, we also looked for other non-native species.

Determining environmental correlates

Sphaeroma quoianum was found at high densities in Yaquina Bay so could be used to examine how the environment factors temperature and salinity correlate with the abundance of *S. quoianum*. During our surveys we recorded the salinity and water temperature with a refractometer and digital thermometer at sites where we had access to the water. Of those sites harboring isopods, we obtained 18 and 8 measurements of salinity and temperature, respectively, on 14-17 July 2007. These measurements were taken at approximately 20cm below the water surface at the nearest water to the burrows. These values were related to visual estimations of isopod densities using simple linear correlations.

Determining the effect of burrows of *S. quoianum* on erosion rate in marshes

We examined the relationship between burrows of *S. quoianum* and erosion rate of marsh banks in sites infested with populations of *S. quoianum* (hereafter: infested sites, n=13) and sites without populations of *S. quoianum* (hereafter: uninfested sites, n=12) in Coos Bay, Oregon. We tested two hypotheses: Hypothesis 1) Within infested marshes, burrowed areas will erode faster than adjacent unburrowed areas, Hypothesis 2) Marshes infested by *S. quoianum* will experience greater rates of erosion, exhibit more undercutting, and harbor more marsh slumps and calves than uninfested reference marshes.

The rate of lateral erosion (over one year) was measured in marsh banks by using erosion pins, onshore reference points (wooden stakes), and by measuring the maximum amount of undercutting of the marsh bank (Figure 1A-B). In each infested site, we inserted 20 erosion pins perpendicular into marsh banks. Half of the pins (10) were randomly placed in burrowed areas in densities of at least 10 burrows per 100cm^2 and half were randomly placed in adjacent unburrowed areas. The unburrowed pins were each paired with the burrowed pin within one meter and at similar tidal heights. We used a two-way ANOVA to test if the mean erosion rate in burrowed and unburrowed areas differed (Treatment factor) and if the mean erosion rate differed between infested sites (Site factor). Assumptions of the ANOVA model were visually evaluated using boxplots and frequency histograms. Transformations failed to completely normalize the data and reduce heteroscadacity so we analyzed the raw data and relied on the robustness of ANOVA to account for the minor violations (Underwood 1981).

In both infested and uninfested sites, we also estimated the amount of lateral erosion by placing ten reference stakes 1.25m from the marsh edge and by determining the maximum undercutting of the marsh bank in ten random locations. Undercutting was measured by inserting a pole at the marsh edge and measuring the maximum horizontal distance between the pole and the bank. The distance between the stakes and marsh edge were measured initially and after one year to estimate erosion rate.

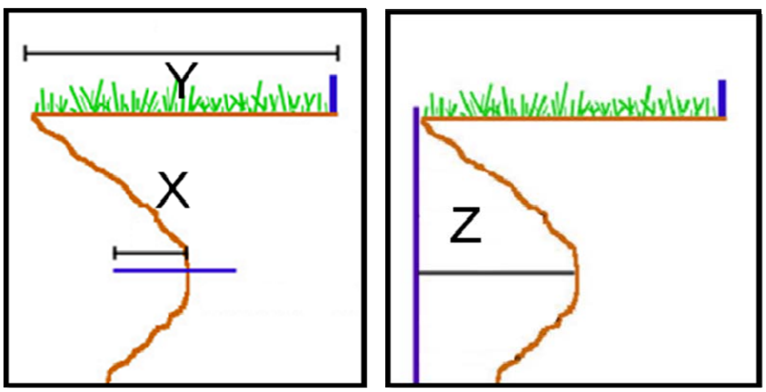

Figure 1A-B. Methods to assess erosion in marsh banks. X is the distance between the marsh bank and end of the erosion pin (pin shown in blue); Y is the distance between the onshore reference point (in blue) and marsh edge; Z is the maximum undercutting. Erosion rate was determined from initial measurements and measurements taken 1 year later.

We used a nested ANOVA to test if the mean amount of lateral erosion (measured with onshore reference points) and undercutting differed significantly between infested and uninfested sites. Transformations failed to normalize the lateral erosion data (from onshore reference stakes) and we continued the analysis using untransformed data, but a 4^{th}-root transformation of the undercutting data improved both normality and heteroscadacity.

In all sites, we noted the presence and size of slumped and calved marsh bank sections and photographed the sites at fixed positions before and following erosion monitoring. We tested if there was a mean difference in the number of slumped and calved marsh sections between infested and uninfested sites using a Mann-Whitney test (due to the non-normality of the data).

We also recorded the relative amount of water movement by measuring the dissolution of calcium-sulfate clod cards at each site and analyzed the difference using a t-test. We obtained sediment cores within all sites to determine the % water, % sand and clay, and % organic matter between sites. In addition, the overlying vegetation was identified and burrow density estimated by 10 randomly placed quadrats ($0.25m^2$) in each site.

RESULTS & DISCUSSION

***Determining the west coast distribution of* Sphaeroma quoianum *and factors correlated with densities of* S. quoianum**

Sphaeroma quoianum was found in all sampled bays where it had previously been identified but not in any new ones. It was absent from surveyed sites north of Oregon's Yaquina Bay (Oregon sites: Depoe Bay, Siletz Bay, Tillamook Bay, Nehalem Bay, and Youngs River; all Washington and British Columbia sites). Populations of *S. quoianum* also were not found in the Smith River, Klamath River, or Russian River, CA or in the Umpqua River, OR (Figure 2). However, populations of *S. quoianum* in Tomales Bay (noted first in 1929) persist within wood and marsh banks.

While *S. quoianum* has not spread to these new areas and the northern limit remains where it was identified in 2005 (Yaquina Bay, Oregon; Davidson 2008), the populations in Yaquina Bay appear to have expanded since 2005. *S. quoianum* was found in 42% (21/50) of surveyed sites in Yaquina Bay and some sites hosted very high densities of the isopod, similar to densities found in Coos Bay (thousands per $0.25m^3$). In addition, *S. quoianum* is now potentially impacting the local economy of Yaquina Bay: Oregon Oyster replaced their dock floats recently and nearly every one of the 60 one-meter long newly removed Styrofoam billets were riddled with *S. quoianum* burrows (Figure 3A-B).

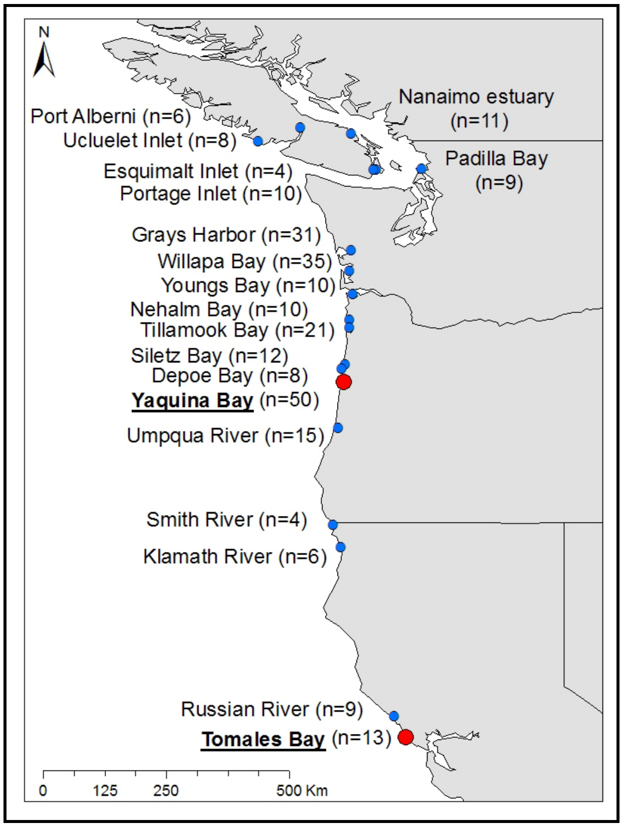

Figure 2. Regional surveys for *S. quoianum* in estuaries of British Columbia, Washington, Oregon, and California. Blue circles denote estuaries where *S. quoianum* was not found; Larger red circles and bolded underlined text indicate estuaries were *S. quoianum* was detected; n= the number of locations examined within each estuary.

We did not detect a significant correlation between salinity (r^2= 0.002, df=18, *P*=0.87) or temperature (r^2= 0.07, df=7, *P*=0.50) and the abundance of *S. quoianum*.

Figures 3A-B: Extensive burrowing by populations of *S. quoianum* (left) virtually destroyed the Styrofoam billets (right) in the floating docks used by Oregon Oyster (Newport, OR).

The survey of Yaquina Bay also revealed the presence of *Pseudosphaeroma campbellense* (=*P. campbellensis*), another sphaeromatid from New Zealand. This represents a new northern limit for this species and confirms a recent sighting by John Chapman (OSU). Furthermore, surveys revealed a new northern limit for the invasive New Zealand Mud Snail (*Potamopyrgus antipodarum*). New Zealand mud snails were found in low densities in Port Alberni, British Columbia. The previous northern most record was Columbia River, Oregon. We communicated our findings with resource managers in British Columbia who have undertaken additional surveys and are developing public education material to limit the spread of this invader. Finally, we collaborated with additional scientists from several institutions including Fisheries and Oceans Canada, the Center for Lakes and Reservoirs at PSU, and the Department of Environmental Science and Policy at UC Davis to produce a manuscript describing the range expansion and distribution of *P. antipodarum* in the Pacific Northwest. The manuscript, Davidson et al. (2008), was recently published in the journal *Aquatic Invasions (Appendix A)*.

Determining the effect of burrows of *S. quoianum* on erosion rate in marshes

Hypothesis 1, within a marsh, comparing burrowed to unburrowed areas: Lateral erosion, as measured by paired erosion pins, was three times greater in burrowed areas than adjacent unburrowed areas within infested marshes (Table 1, Figure 4). This estimate may be conservative since some pins were lost in some sites when an entire marsh bank collapsed.

Table 1. Results from a Two-way ANOVA analysis examining the mean difference in erosion between burrowed and unburrowed areas (treatment) and between infested sites (sites).

Factor	Df	MS	*F*-value	*P*
Treatment	1	12953	33.083	**<0.001**
Site	12	2206	5.633	**<0.001**
T*S	12	392	1.002	0.45
Residual	208	392		

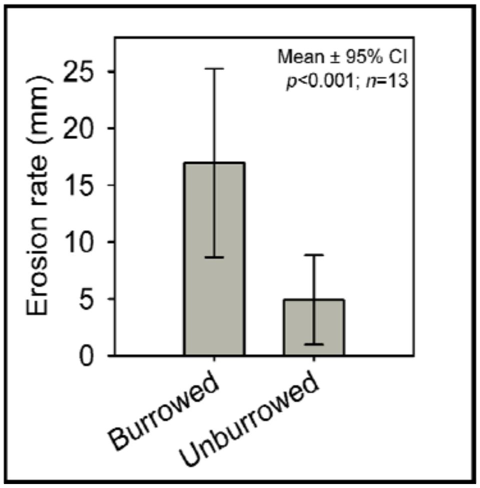

Figure 4. Lateral erosion (measured by paired erosion pins) in burrowed and unburrowed areas within infested marsh banks

Hypothesis 2: All measures of erosion were higher in infested sites than uninfested reference sites. We observed significantly more marsh breakage and failure (more slumps, calves) in infested than uninfested marshes (W=120, P=0.003; Figure 5). Estimates of erosion were highly variable and may have been underestimated due to the loss of stakes from when large sections of marsh failed. Similarly, maximum undercutting was higher in infested than uninfested marshes ($F_{1,23}$=8.31, P=0.008; Figure 6A). Shoreline loss, measured using onshore reference points, was higher in infested than uninfested marshes but was not statistically significant ($F_{1,22}$= 2.94, P=0.10; Figure 6B).

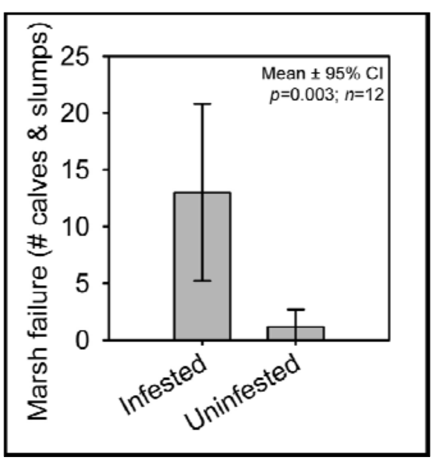

Figure 5. Mean number of calved and slumped marsh sections in saltmarshes

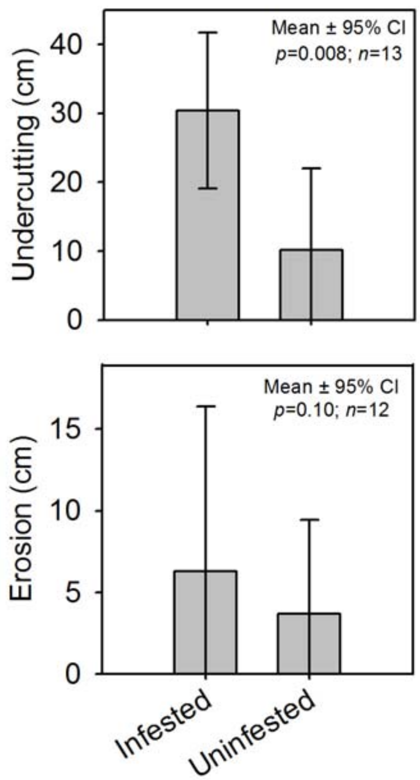

Figure 6A-B. Lateral erosion measured by onshore reference markers and maximum undercutting in marsh banks in Coos Bay, OR.

While we detected significant differences between infested and uninfested sites, we recognize that there may be confounding factors that may be responsible for the differences in erosion rate across different marshes. The first aspect of this experiment (Hypothesis 1) controlled for these confounding factors by examining erosion rate between paired burrowed and unburrowed areas (within 1 meter) within infested sites. The additional factors that affect erosion likely caused the high observed variability in erosion between the sites. We measured many of the potential confounding factors that may affect erosion rate across between marshes (Hypothesis 2) such as: water flow, vegetation type, and sediment characteristics (% sand, % organic matter, % water). We are still processing these data; preliminary results indicate few systematic differences between the water flow and vegetation type between treatments (infested vs. uninfested sites). The rate of dissolution of clod cards (a proxy for water movement) was not significantly different between infested and uninfested sites (t = 0.99, df = 19, P = 0.33). The vegetation type also did not differ between sites; most sites were dominated by *Salicornia* *virginica*. Infested marshes were taller than uninfested ones (Mann Whitney, W=132, P=0.003), which potentially could influence the erosion rate at the measurement sites although pins were deployed at similar elevations within sites.

Create a website to inform the public and allow the reporting of new invaders.

We have developed an educational website that describes 15 estuarine and brackish non-native species in Oregon (and species to watch out for). For each species profile, we describe the identifying characteristics, biology, life history and ecology, vectors, invasion history, threats/implications, and possible management options. In addition to the 15 species profiles, we included a comprehensive list of species reported as established in Oregon and, as applicable, hyperlinked those species to the appropriate profiles described on other websites. The website includes a link to report new sightings. We are reformatting the Non-native Aquatic Species of Oregon website to fit the new required Portland State University format; it will be hosted under the Portland State University domain.

CONCLUSIONS

Sphaeroma quoianum is a significant agent of erosion and can have detrimental impacts on the integrity of saltmarsh ecosystems and marine structures. This invader is present in at least 15 estuaries on the Pacific Coast of North America ranging from Baja California to Yaquina Bay. Fortunately, we did not detect new populations of *S. quoianum* in our 19 surveyed estuaries. Our surveys also detected range expansions for 2 other invaders: *Pseudosphaeroma campbellense* and *Potamopyrgus antipodarum*. Thus, our results highlight the importance of conducting regional surveys that examine habitats or survey for multiple species rather than focusing on one particular taxon.

Populations in Yaquina Bay appear to have expanded since surveys in 2005 and isopods have extensively damaged the floating docks in at least one marine facility. The spread to Yaquina Bay could have been due to spread from fouled boat hulls from recreational boats or fishery vessels. We recommend the regional strength of these vectors continues to be assessed for fouling organisms and the associated communities.

Our erosion experiments quantified the erosive impact of isopods on saltmarshes. Despite high variability between sites in all erosion measurements, we found clear evidence that *S.*

quoianum measurably accelerate erosion of marsh sites in Coos Bay. Within infested marshes, areas burrowed by *S. quoianum* experienced mean erosion rates more than 3 times greater than adjacent unburrowed areas. Future studies should attempt to evaluate the relationship between burrows of *S. quoianum* and erosion rate. Future work will attempt to quantify the erosive effect of *S. quoianum* on Styrofoam floating docks and assess the resulting economic impacts.

We recommend expansion of Johannesson's (1988) work that suggested the threat of spread is greater for species with direct larval development than ones with pelagic larval dispersal. Expanding comparison of direct versus pelagic larval development beyond Littorine snails to a variety of marine and estuarine invasive species would help inform risk assessments and monitoring priorities.

PRODUCTS

Publications

Davidson TM, Brenneis VEF, de Rivera CE, Draheim R, Gillespie GE (2008) Northern range expansion and coastal occurrences of the New Zealand mud snail *Potamopyrgus antipodarum* (Gray, 1843) in the northeast Pacific. *Aquatic Invasions* 3: 349-353

Available online:
http://www.aquaticinvasions.ru/2008/AI_2008_3_3_Davidson_etal.pdf

Davidson TM, de Rivera CE, in preparation. Accelerated erosion of saltmarshes infested by an invasive burrowing crustacean.

Website

Non-native Aquatic Species of Oregon website. The website is currently being edited and reformatted be hosted under the Portland State University domain.

Presentations

Timothy M Davidson. Feb 28-Mar 1, 2008. *The density and associated fauna of a non-native habitat-altering isopod* (Sphaeroma quoianum) *in a temperate estuary* 31st Annual Pacific Estuarine Research Society meeting in Newport, Oregon

Timothy M Davidson. October 2008. Poster: *Accelerated erosion of saltmarshes infested by an invasive burrowing crustacean*. Environmental Science and Management Colloquium, Portland, OR

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