



# Boring crustaceans damage polystyrene floats under docks polluting marine waters with microplastic

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## ABSTRACT

Boring isopods damage expanded polystyrene floats under docks and, in the process, expel copious numbers of microplastic particles. This paper describes the impacts of boring isopods in aquaculture facilities and docks, quantifies and discusses the implications of these microplastics, and tests if an alternate foam type prevents boring. Floats from aquaculture facilities and docks were heavily damaged by thousands of isopods and their burrows. Multiple sites in Asia, Australia, Panama, and the USA exhibited evidence of isopod damage. One isopod creates thousands of microplastic particles when excavating a burrow; colonies can expel millions of particles. Microplastics similar in size to these particles may facilitate the spread of non-native species or be ingested by organisms causing physical or toxicological harm. Extruded polystyrene inhibited boring, suggesting this foam may prevent damage in the field. These results reveal boring isopods cause widespread damage to docks and are a novel source of microplastic pollution.

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## 1. Introduction

Marine borers can cause substantial damage to marine structures. The most extensive and costly damage occurs in wooden structures by teredinid bivalves (shipworms) and isopod crustaceans (Cragg et al., 1999; Neily, 1927). For example, the non-native shipworm *Teredo navalis* destroyed the timber pilings and supports of docks in San Francisco Bay causing nearly 50 structures to collapse and causing \$615 million in damages (Cohen and Carlton, 1995; Miller, 1926; Neily, 1927). Crustacean borers are also very destructive (Cookson et al., 1986; Cragg et al., 1999; Kofoed and Miller, 1927), especially in Australia where timber replacement costs from marine borers are around \$20 million per year (in 1986 AUD dollars; Cookson et al., 1986). Moreover, borers can attack non-wooden structures as well, such as rock sea walls (Chilton, 1919), concrete structures (Kofoed and Miller, 1927), and even steel support beams (Irwin, 1953).

Burrowing sphaeromatid isopods bore into numerous substrata used in marine structures and facilities in brackish temperate and tropical regions (Carlton, 1979; Chilton, 1919; Cragg et al., 1999; Kofoed and Miller, 1927). Boring isopods are native to the Indo and West Pacific but are non-native in North America and perhaps in the Caribbean (Carlton and Iverson, 1981; Carlton and

Ruckelshaus, 1997; Harrison and Holdich, 1984). These estuarine isopods tolerate a wide range of salinities (0–43 PSU, Estevez, 1994; Riegel, 1959) and temperatures (5–42 °C; Jansen, 1971). However, they suffer mortality after several days at the lowest salinity (0 PSU) or temperature (5 °C; Jansen, 1971; Riegel, 1959). In the field, the boring isopods *Sphaeroma quoianum*, *Sphaeroma terebrans*, and *Sphaeroma peruvianum* are most often found between 5 and 31 PSU salinity (Davidson, 2008; Davidson et al., 2008, unpublished data). The burrowing isopods *S. quoianum* and *S. terebrans* live for 12–18 months and 10 months, respectively, and can produce up to two cohorts before dying (Schneider 1976, Thiel, 1999).

These borers are especially destructive to expanded polystyrene floats (commonly known as Styrofoam) used in many docks. Densely clustered colonies of these direct-developing isopods perforate the submerged surface of the float and appear to reduce its functionality. While burrows are initially shallow (less than 30 mm deep, and rarely exceeding 60 mm; Davidson and de Rivera, 2012; Perry and Brusca, 1989; Talley et al., 2001), subsequent generations and colonizers extend and build from old burrows, creating an interconnected burrow network (as described by Talley et al., 2001; Thiel, 1999). This extensive network substantially reduces the density of the outer 60 mm of the float, making the foam noticeably weaker and more susceptible to breakage. As the outer surface is removed, additional area of the float becomes vulnerable to attack. Boring sphaeromatid isopods are filter feeders that excavate burrows for habitat (Rotramel, 1975; Si et al., 2002); therefore, any consumption of excavated material is likely

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incidental (Messana et al., 1994; Rotramel, 1975; Si et al., 2002). While some floats are encapsulated with hard plastic shells or sheets, many docks or facilities either do not use these materials, or the encapsulation materials are damaged and vulnerable to isopod burrowing (per. obs.).

Minute plastic particles are created through the boring process of polystyrene floats by *S. quoianum* (Carlton, Chang, and Wells, unpublished, as cited in Carlton and Ruiz, 2005), *S. terebrans*, and *S. peruvianum* (per. obs.). Like other microplastics (defined as <5 mm in diameter, Arthur and Bamford, 2009) in the marine environment, these particles may have detrimental effects to marine organisms (Carpenter et al., 1972; Cole et al., 2011; Gregory, 1996; Thompson et al., 2004). Plastics persist for hundreds to thousands of years in normal oceanic conditions (Barnes et al., 2009). Also, polystyrene fragments and other minute plastics in the marine environment are readily colonized by biofilm and other organisms causing them to sink (Barnes, 2002; Gregory, 2009; Ye and Andrady, 1991). Thus, these particles may interact with benthic (Graham and Thompson, 2009; Thompson et al., 2004) and pelagic organisms (Boerger et al., 2010; Carpenter et al., 1972; Davison and Asch, 2011). Ingested microplastics may cause both toxicological effects by transmitting bioaccumulating toxins (Mato et al., 2001; Teuten et al., 2009) and possibly physical effects by occluding feeding structures or inducing a false indication of satiation.

The damage caused by boring isopods to polystyrene floats under floating docks can result in economic costs and contribute to microplastic pollution. This paper reports observations of the destructive effects of boring isopods on foam floats, quantifies the density of burrows and individuals in floats, quantifies the abundance of plastic particles created from the boring process, and discusses the morphology and ecological implications of the plastic particles created through the boring process. Furthermore, results of an experiment examining how different polystyrene float types may prevent damage by borers are presented. Together these observations, surveys, and experimental results reveal (a) the damaging effects of non-native and native borers on the floatation in docks, (b) how a non-native species contributes to microplastic pollution, and (c) approaches to reduce these effects in the many bays that harbor populations of boring isopods.

## 2. Methods

### 2.1. Observations of isopods attacking floats

Shoreline surveys were conducted in Yaquina Bay, Oregon, USA, and in Budai Township and Tainan, Taiwan. Both the high tide lines and docks and marinas in intertidal and shallow subtidal areas were examined for damaged polystyrene flotsam or floats; populations of *Sphaeroma* sp. occurring in adjacent substrata were also noted. Search effort was focused on areas between 5 and 31 PSU, where boring isopod populations are most often found (Davidson, 2008; Davidson et al., 2008). Polystyrene floats and flotsam were considered burrowed by sphaeromatids if they harbored living or dead individuals in their burrows or if vacant burrows were consistent with the morphology of burrows created by sphaeromatid isopods: (i) vermiform burrows with smooth walls, (ii) circular diameters between 2 and 10 mm, and (iii) up to 77 mm deep, and (iv) mostly straight without abrupt changes in direction (Barrows, 1919; Davidson and de Rivera, 2012; Talley et al., 2001). To my knowledge, no other boring organism creates burrows consistent with this morphology and the burrows of other organisms (e.g. small grapsid crabs) are rare (per. obs.). Furthermore, these surveys are supplemented with additional reports of isopod burrowing from both published sources and unpublished observations.

### 2.2. Mean density of individuals and burrows of *S. quoianum* in expanded polystyrene flotsam

Between February 2005 and May 2006, samples of burrowed expanded polystyrene floating dock flotsam encountered during surveys of Coos Bay ( $n = 18$  pieces) were collected. Each piece was photographed with a haphazardly placed  $10 \times 10$  cm quadrat in the burrowed area of the float. The number of quadrats photographed varied concomitantly with the size of the expanded polystyrene flotsam found. One quadrat was used to estimate the burrow density of small pieces (30–60 cm long) and between 6 and 50 quadrats for larger pieces (entire floats >60–100 cm long). Digital analysis software, ImageJ 3.0 version 1.49u, was then used to count the total numbers of burrows per quadrat.

Burrowed expanded polystyrene float mimics were deployed in Coos Bay, Oregon for 1 year (2005–2006) to provide an estimate for how many isopods inhabit expanded polystyrene floats. The float mimics were constructed of a burrowed expanded polystyrene float found in the field (devoid of isopods). Blocks were cut to  $10 \times 10 \times 8$  cm (length, width, depth). Each block was surrounded in polyethylene tape exposing only the burrowed  $100 \text{ cm}^2$  face. Burrow densities in these mimics were  $64.2 \pm 2.3$  burrows per  $100 \text{ cm}^2$  (mean  $\pm$  95% CI). The blocks were affixed facing downwards to weighted PVC tubing and placed around a length of rebar planted into the ground. The weighted PVC tube kept the orientation of the blocks pointing downward while allowing the floats to move up and down with the tide along the rebar pole. These expanded polystyrene dock mimics were deployed in six different locations with salinity between 10 and 31 PSU in Coos Bay, Oregon.

### 2.3. Quantity and morphology of the plastic particles created during boring by *S. quoianum*

A lab experiment was conducted to quantify the numbers of particles created by *S. quoianum* during the boring process (methodology described in detail in Davidson et al., in preparation). Small colonies of 20 adult isopods (7–12 mm in length) from Coos Bay, Oregon were placed inside cages with an expanded polystyrene foam block ( $800 \text{ cm}^3$ ) with one exposed surface ( $100 \text{ cm}^2$ ). Fifteen small holes (4 mm deep) were created in each block to prompt isopods to begin burrowing; these values were not included in the measurements of burrow length. Each cage was then submerged in a closed aerated aquarium at one of 13 water temperatures (7.5–25.2 °C) to vary burrowing intensity (Davidson et al., in preparation). Isopods were allowed to burrow for 2 months. At the end of the experiment, the number of burrows created and mean lengths were measured in each foam block and the plastic particles were collected by discharging the aquarium water through a  $63 \mu\text{m}$  sieve. The particles were placed on a gridded paper filter ( $1 \text{ cm}^2$  grid) and agitated to help homogenize the distribution of particles on the grid. The total number of grid squares occupied by plastic particles was counted and then five subsamples ( $1 \text{ cm}^2$  squares) were randomly selected to be photographed using a digital microscope camera. The numbers of particles in each square subsample were counted using digital analysis software. The total number of particles created during the boring process in the different blocks was calculated by multiplying the mean number of particles per subsample ( $1 \text{ cm}^2$ ) by the total number of squares occupied by plastic particles. The relationship between the number of particles created per burrow and mean burrow length (total burrow length in a block/number of burrows created) was examined using ordinary least squares regression. The data were square-root transformed to meet assumptions of linearity, homogenous variance, normality, and reduce the influence of outliers. The lowest value appeared to be influential (Cook's Distance = 0.81), however, its removal did not substantially change the shape of the relationship (but reduced

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