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Review

A meta-analysis of the effects of exposure to microplastics on fish and aquatic invertebrates

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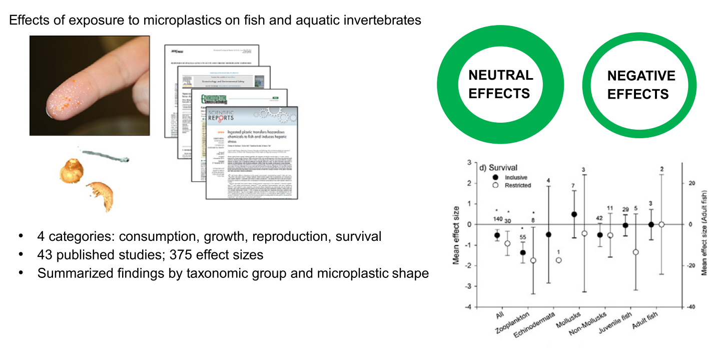
HIGHLIGHTS

- Microplastics may pose directly deleterious threat to aquatic organisms worldwide.
- Studied impacts of microplastic exposure on aquatic animals for 4 response categories
- Meta-analysis of published studies on consumption, growth, reproduction, survival
- Overall there were few negative impacts, many neutral impacts for these categories.
- Impacts related to microplastic exposure may be more subtle than these categories.

GRAPHICAL ABSTRACT



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ABSTRACT

Microplastics are present in aquatic ecosystems the world over and may influence the feeding, growth, reproduction, and survival of freshwater and marine biota; however, the extent and magnitude of potential effects of microplastics on aquatic organisms is poorly understood. In the current study, we conducted a meta-analysis of published literature to examine impacts of exposure to microplastics on consumption (and feeding), growth, reproduction, and survival of fish and aquatic invertebrates. While we did observe within-taxa negative effects for all four categories of responses, many of the effects summarized in our study were neutral, indicating that the effects of exposure to microplastics are highly variable across taxa. The most consistent effect was a reduction in consumption of natural prey when microplastics were present. For some taxa, negative effects on growth, reproduction and even survival were also evident. Organisms that serve as prey to larger predators, e.g., zooplankton, may be particularly susceptible to negative impacts of exposure to microplastic pollution, with potential for ramifications throughout the food web. Future work should focus on whether microplastics may be affecting aquatic organisms more subtly, e.g., by influencing exposure to contaminants and pathogens, or by acting at a molecular level.

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Contents

1. Introduction

Plastic pollution is a significant concern for aquatic systems around the world. Microplastics, typically defined as plastic pieces that are <5 mm in size, have been documented in aquatic systems on all seven continents, in both freshwater and marine environments (Barnes et al., 2009), along beaches (Browne et al., 2011), in sediment (Claessens et al., 2011), and in the water column itself (Eriksen et al., 2013). The sources of microplastics available in the wild vary, but include the breakdown of larger plastic items such as food or drink containers, fibers from synthetic clothing, industrial waste, and components of some beauty products (Biginagwa et al., 2016; Kershaw and Rochman, 2015). Though concerns about the effects of plastic pollution on aquatic systems were voiced as early as 1978 (Gregory, 1978; Laist, 1997), the topic has been brought to the forefront in recent years in both the scientific literature and popular media, including such public responses as regulations against the use of microbeads in hygiene products (Pallone, 2015). Researchers and concerned citizens have advocated for information on how microplastics might impact aquatic ecosystems and biota, including fish and aquatic invertebrates (Browne et al., 2007; Seltenrich, 2015). Consequently, the number of studies examining potential impacts of microplastics on aquatic foods webs has increased exponentially (Lusher et al., 2017).

Microplastics have been documented in the digestive systems of wild-caught fish (e.g., Foekema et al., 2013; Phillips and Bonner, 2015) and aquatic invertebrates (e.g., Cole et al., 2011); even in mussels and clams that were ready to be sold for human consumption (Van Cauwenberghe and Janssen, 2014; Davidson and Dudas, 2016). Organisms may directly ingest microplastic particles actively, e.g., due to confusion with potential prey, or passively, e.g., during particle filtration (Collignon et al., 2014). There is some evidence that organisms can avoid consuming microplastics through passive and active selection: *Calanus helgolandicus* and *Acartia clausi* copepods selected prey that were smaller than the microplastics present (Cole et al., 2015; Donaghay and Small, 1979), and *Tripneustes gratilla* sea urchin larvae selected microalgae (food) over polyethylene beads as long as food was present (Kaposi et al., 2014). Conversely, *Eurytemora affinis* copepods ingested latex beads at a higher rate than diatom prey (Powell and Berry, 1990), and holothurian sea cucumbers ingested nylon and polyvinyl chloride fragments rather than sand, potentially because ingesting plastic was easier (Graham and Thompson, 2009). Microplastic can also be incidentally ingested by adhering to natural prey items, e.g. seaweed or fish eggs, (e.g., Kashiwada, 2006; Gutow et al., 2016), or via absorption through gills (e.g., Kashiwada, 2006; Watts et al., 2014). Further, plastic particles that have been ingested could be absorbed through gut walls (Browne et al., 2008; Snell and Hicks, 2011).

Once consumed or otherwise ingested, microplastics can remain in the digestive tracts of aquatic organisms for periods of days to weeks before excretion (e.g., dos Santos and Jobling, 1991; Browne et al., 2008; Cedervall et al., 2012; Batel et al., 2016). This retention time likely allows for the transfer of microplastics both up the food web (e.g., Murray and Cowie, 2011; Farrell and Nelson, 2013), and to new geographic locations (Clark et al., 2016). Exposure of individual aquatic organisms to microplastics may negatively impact feeding (e.g., Wegner et al., 2012; Ogonowski et al., 2016), growth (e.g., Au et al., 2015; Jeong et al., 2016), reproductive capabilities (e.g., Della Torre et al., 2014; Ogonowski et al., 2016), or survival (e.g., Booth et al., 2016; Luís et al., 2015), due to, for example, blockage of feeding structures or reduced consumption of prey (e.g., as reviewed by Wright et al., 2013b, Eerkes-Medrano et al., 2015). However, the effects of microplastic exposure do not appear to be consistent across studies. Some organisms may be resilient to stresses induced by microplastic exposure (e.g., Nasser and Lynch, 2016; Watts et al., 2016), and the fact that microplastics can be egested suggests cumulative impacts could potentially be minimized. In addition, the shape of plastic particles (e.g., spheres versus fibers) may influence their ability to be ingested and elicit effects on organism performance. Therefore, the overall potential impact of microplastic pollution in aquatic systems remains difficult to predict.

In the current study, we conduct a meta-analysis to examine impacts of exposure to microplastics on four important responses of fish and aquatic invertebrates: a) consumption and feeding (hereafter called "consumption"), b) growth, c) reproduction, and d) survival. Meta-analyses allow researchers to quantitatively assess the effect of a given treatment (in this case, exposure to microplastics) over multiple studies conducted in different locations, on different taxa, and by different research groups to summarize and understand the broader potential impacts of the treatment in question. For each of the four response categories, we use the results reported in published experimental studies to assess whether effects of exposure of fish and aquatic invertebrates to microplastics are positive, negative, or neutral. We further assess whether the effects are consistent across different taxonomic groups or plastic shapes, respectively. Finally, we examine whether the size of the effect varies with experimental conditions including the size of plastic particles used, the temperature at which the experiment was conducted, and the length of time organisms were exposed to microplastics.

2. Materials and methods

We selected studies to include in our meta-analyses via a search of ISI Web of Science on October 14, 2016, using the term "Microplastic* AND growth OR consumption OR fish OR mussel OR zooplankton OR invertebrate". This initial search yielded 234 papers. Of these, we retained 29 studies for our analyses according to the following criteria: 1) the study examined at least one effect of direct exposure to microplastics on fish or aquatic invertebrate consumption, growth, reproduction, or survival, 2) the study was an experiment (field-based mesocosms were allowed), 3) the study included a "no microplastics" control treatment; and 4) the study reported mean, sample size, and measure of variance for controls and treatments. Forward (i.e., papers that cited each selected paper) and backward (i.e., papers cited by each selected paper) searches performed on this subset of studies in January 2017 yielded an additional 962 papers to examine for additional data. After applying the same criteria for inclusion to these studies, we ultimately included 43 studies in final analyses (Table 1).

We extracted the following information from each study: the species studied; a description of each response included (consumption [e.g., ingestion rate, egestion amount]; growth [e.g., change in weight,