Microplastics, Marine Copepods & Freshwater Cladocerans: Investigations for College Biology Laboratory Classes

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ABSTRACT
Microplastic particles (MPs) less than 5 mm in size swirl and bob in freshwaters and seas around the world. To familiarize college biology students with the pressing issue of microplastic pollution and designing their own experiments, I assigned investigation into whether marine copepods (Tigriopus californicus) or freshwater cladocerans (Daphnia magna) ingest MPs in the laboratory.

Groups of students produced a title, hypothesis, and annotated bibliography. They developed their experiments in a project planning table. They carried out three weeks of experiments. Students wrote papers or gave poster presentations. They wrote reflections that revealed expected gains, such as recognition of the importance of sample size, and more nuanced gains, such as developing personal views on working with live organisms.

The students found that 20 μm of blue MPs could be seen within the digestive tract and released fecal pellets of Tigriopus californicus within 24 hours. And, 20 μm of red MPs accumulated in the digestive tract of Daphnia magna within two days. The ingestion did not increase death rates over controls (in keeping with much published research on this topic). Students had the opportunity to see and reflect on the direct interaction of organisms with plastic pollution.

Key Words: Microplastics; zooplankton; marine; freshwater; plastic pollution.

Introduction
Upper-level biology laboratory classes provide an opportunity to indulge in inquiry-based projects designed to hone students’ experimentation skills while they learn about current issues at the intersection of science and society. The two experiments for upper-level biology students described here are designed to help students investigate the potential effects of microplastic pollution in aquatic ecosystems and provide students with the opportunity to design their own experiments from start to finish, an opportunity that they may not have even as undergraduate researchers in faculty laboratories.

Microplastics
Microplastics (MPs) are plastic particles less than 5 mm in size. First reported in the Sargasso Sea by Carpenter and Smith (1972), MPs swirl and bob in untold numbers in both marine environments (Andrady, 2011) and freshwater environments (Li et al., 2020). MP particle counts are estimated at 12,000/m³ in freshwater environments and approximately 10,000/m³ in marine environments (Wu et al., 2019). Quantity by weight has been measured as 1 × 10⁻³ to 1 × 10⁴ mg/L (Lenz et al., 2016; cf. Huvet et al., 2016). Primary MPs include microbeads manufactured for inclusion in personal care products and for sandblasting (Andrady, 2011). The Netherlands banned microplastic bead manufacture, import, and sales in 2014. Other countries have followed suit, including the US where the ban on MPs in personal care products took effect in 2017. However, MPs, like plastics in general, do not break down easily, and we will be finding them in soil and water for many centuries.

While a number of countries have banned primary MPs, secondary MPs formed by the degradation of plastic bags and anything else made of plastic will continue to be generated (Cole et al., 2011; Andrady, 2011; Rochman, 2018). Although wastewater treatment plants remove MPs with high efficiency, MPs in wastewater effluent nonetheless enter waterways (Mason et al., 2016). In addition, MPs in sewage sludge spread on farm fields or landfills can also run off into waterways (Zubris & Richards, 2005).

The stories of albatrosses feeding plastic toys and bottle caps to their chicks (Kenyon & Kridler, 1969; Pettit et al., 1981; Auman et al., 1997) and sea turtles inextricably wound in plastic debris (Carr, 1987) are all too familiar. Research tells us that even as plastics break down to tiny particles they remain potentially dangerous. Microplastics are just the right size to be mistaken for food by zooplankton—a group that is vital at the base of aquatic food chains (Setälä et al., 2014; Lusher et al., 2017; Butterell et al., 2019). Adding to this danger is the fact that MPs take up chemicals including carcinogens from the surrounding water (Rochman et al., 2013). The chemicals become part of the mistaken meal.

The concept of “no free lunch” in the food chain—the idea that each trophic level eats and is eaten in turn, is familiar to the public and biology students (Figure 1). Indeed, several studies...
have documented trophic transfer of MPs (reviewed in Lusher et al., 2017). Primary consumers, such as copepods and cladocerans (water fleas), appear to be particularly susceptible to the effects of microplastic ingestion (Cole et al., 2015; Yu et al., 2020). Copepods, cladocerans, and other zooplankton are eaten by larger organisms that are eaten in turn by even larger organisms. Although the effects of MPs are not fully understood, humans may also be affected by MPs as they continue to be more common in the environment and return to us via the food chain (Setälä et al., 2014). Microplastics have been detected in human tissues (reviewed in Miller et al., 2020), and some immunological effects on human cells have been documented (Hwang et al., 2020).

In recent years some foreign countries, US states and cities have banned single use plastic bags in response to our greater understanding of the environmental hazards of plastics in general (Povich, 2021). However, the COVID-19 pandemic necessitated greater use of plastics in health care and carryout food. As the world continues to grapple with the pandemic, the pedagogy on plastic pollution described in this article and in Brander and colleagues (2011) is likely to be even more attractive to educators and students in both secondary and post-secondary educational settings. The scientific community and the public have learned in recent years that we are paying a high price for the convenience of plastics.

**Introduction to the Two Investigations**

The foundational question in the marine copepod experiment is: Do copepods (*Tigriopus californicus*) eat MPs in the laboratory, and do they suffer ill effects? Likewise, the question in the freshwater experiment is whether cladocerans (*Daphnia magna*) make this mistake as well. In carrying out these projects each student group may decide on their own research question, their procedures, and statistics. The written assignments associated with these investigations ask students to practice their skills in presenting their data in a poster or paper, researching the literature, and reflecting on the scientific process (see Supplement 1 and 2 available with the online version of this article).

**The Value of Independent Investigation in Laboratory Courses**

The several benefits for students of research-based laboratory courses include honing lab techniques, growing confidence in oneself as a scientist, and understanding the way that scientific information is amassed. Active learning in general is recommended widely (Brewer & Smith, 2011; Olson & Riordan, 2012) to increase students’ retention of concepts (Weaver et al., 2008; Brownell et al., 2012; Freeman et al., 2014).

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**Investigation Design & Weekly Schedule**

The two courses in which these experiments are conducted at Ursinus College enroll 16–22 students and meet for three hours of lecture and three hours of laboratory per week. The experiments fill over half of the semester of weekly laboratory periods. All enrolled students have taken the introductory cell biology, genetics, and statistics courses. Some students have also taken the introductory cell biology, genetics, and statistics courses.

**Week 1**

In Week 1 the students become familiar with the organisms and film them under the dissecting or compound microscope (40–100×). The instructor can expect a lot of excitement when the students see the copepods (*T. californicus*), particularly the females carrying eggs, darting around. The cladocerans (*D. magna*) generate even more wonder—students can see the anatomy of not only the adult but also the eyes and heartbeat of offspring that are moving within the brood pouch of the parent.

**Week 2**

The groups of three or four students per group turn in a title and hypothesis and revise them if necessary while doing an unrelated laboratory exercise in Week 2. At Ursinus, most groups hypothesized that the copepods and cladocerans would mistake the MPs for food, feeding on appropriate food would decrease due to MPs in the gut, and that the copepods would die as a result.

**Week 3**

Each group turns in an annotated bibliography in Week 3 and a “project planning table.” The table challenges the students to
think through and report the hypothesis, the number of individuals in each experimental group, the number of groups, the controls, the length of the experiments, how frequently the animals will be fed, how frequently data will be collected, what will be measured (e.g., death rate, number of plastic MPs ingested), and the statistical analysis. The project planning table provides the instructor with the opportunity to provide abundant feedback. Students learn by rethinking their own experiments. This process greatly increases the rigor of their experimental designs (see Supplement 1).

**Weeks 4–6**

Experimentation occurs during the laboratory periods during Weeks 4, 5, and 6. The instructor can circulate the room to brainstorm about problems that arise.

**Weeks 7 & 9**

The instructor can use these experiments to build scientific writing and speaking skills. In BIO310 biological oceanography, each student writes an individual paper in two drafts in scientific style (See Supplement 1). The first draft is due in Week 7, and the final draft is due in Week 9. In BIO336 freshwater biology, each pair of students produces and presents a poster rather than writing a paper. The pairs of students present their posters in Week 6 (See Supplement 2). Each student completes an evaluation of the other posters. Students in both classes write an individual reflection in Week 9 in which they are invited to reflect on what they wish they had known when they started the experiment, what they wish they had done differently, and what ethical dilemmas they encountered in the experiment or data reporting.

**Methods**

The marine copepod *T. californicus* and the freshwater cladoceran *D. magna* can be purchased from Carolina Biological Supply, Burlington, North Carolina. Three jars of mixed adult and juveniles containing 30–40 individuals of *T. californicus* or *D. magna* purchased weekly for six weeks are enough for 3–4 lab groups of 3–4 students each. Purchasing mixed adult and juvenile cultures allows the students to view the two life stages and provides more adults as the juveniles develop.

The *T. californicus* can be maintained for a few days prior to experimentation in the jars in which they were shipped. Lids must be loose to allow air to enter the jar. Many websites provide instructions on how to maintain them in long-term culture. We cultured them in 10 gallon aquariums with live plants in natural light and fed them Roti-Rich food from Florida Aqua Farms. A pump attached to a 3/16-inch diameter tube that was weighted down with a rock in the aquarium provided aeration. Air stones should not be used because small bubbles can become trapped under *Daphnia* spp. exoskeletons. During the experiments at Ursinus College, the students fed *D. magna* the Roti-Rich food and exposed them to concentrations of MPs up to 4 mg/L on Day 1. Food and MPs were added every other day for a final maximum concentration of 20 mg/L at the end of 7–10 days.

Clear, blue, and red polystyrene 5 µm and 20 µm 10mg/mL MPs can be purchased from Degradex by Phosphorex Hopkinson, Massachusetts. Overall, the blue MPs seem most visible in the experiments. The clear MPs are difficult to see through the microscope. The red MPs are difficult to see in stressed *Daphnia* that become redder through increasing their hemoglobin concentration (Fox, 1948). Students can observe the red lipid droplets in *T. californicus* with red MPs in the gastrointestinal tract until they are familiar with the anatomy of the organism.

The *T. californicus* and *D. magna* can be viewed in depression slides in seawater under a dissecting microscope at up to 40× or a compound microscope at 40× or 100×. Shredded gauze creates a “fishing net” in the slide that immobilizes the organisms. Students can take photos holding their phones up to the eyepiece or may use a camera attached to the microscope. We used an AmScope MU300 camera attached to the microscope. The experiments can be carried out in 30 mL plastic conical tubes or glass dishes on a bench or rotating platform (to provide aeration). Lids or coverings should be loose to allow airflow yet slow evaporation. Pasteur pipette with the tips cut off can be used to transfer the organisms into other containers without harm. At Ursinus College all unused *T. californicus* and *D. magna* were fed and maintained until they reached the end of their natural lives. The small number of organisms that ingested MPs went into the regular waste.

The students can propose statistical analyses if they have already taken statistics, or statistical methods can be suggested by the instructor. Ursinus College students used t-tests, linear regression analyses, Fisher's exact tests, or chi-square contingency tables appropriate for their experimental design using R (The R Project for Statistical Computing), JMP Statistical Software, Excel, or IBM SPSS software.

**Results**

In this investigation, students had the opportunity to design their own experiment from start to finish. Their experiments focused on whether zooplankton actually ingest the MPs known to be contaminating both freshwater and marine ecosystems.

**Tigriopus californicus Investigation**

Data from a few semesters of running these experiments are presented here so that instructors who adopt these experiments for their own classes have an idea what to expect. In the fall of 2020, six groups of three or four students each designed a unique experiment based on the experimental design of studies in the literature. All student groups did six- to seven-day experiments in which there were eight to ten *T. californicus* in each control group (given food only).
and experimental group (given algal food and MPs). The starting MP concentrations on Day 1 selected by the various groups were from 0 to 20 mg/L (final concentration). Feeding and adding MPs every other day resulted a total maximum final concentration of 60 mg/L.

The 20 µm blue or red MPs were evident in the gastrointestinal tract of some individuals (Figure 2A) and in fecal pellets (Figure 2B) in the culture vessels within 24 hours. Although deaths in experimental conditions were higher than in the controls, linear regression and Fisher’s exact tests did not show a significant difference in death rate over the controls even at the end of the experiment at the highest concentration of MPs exposure (p < 0.05).

Daphnia magna Investigation

In the spring of 2020, two research groups in the freshwater biology class carried out this investigation. The D. magna accumulated the 20 µm MPs in their gastrointestinal tract (Figure 3). Although more individuals died in the experimental conditions than the controls, there was no statistically significant increase in death rate due to MP ingestion, as determined by a chi-square or Fisher’s exact test (p > 0.05).

Figure 2. (A) Tigriopus californicus with a 20 µm blue bead in gastrointestinal tract. (B) T. californicus feces containing eight 20 µm blue polystyrene microspheres. Photos provided by D. Briggs, M. Fuchs, A. Pham, and J. Siberski.

Figure 3. (A) Daphnia magna with food in gastrointestinal tract. (B) D. magna with 5 µm red polystyrene microplastic spheres in gastrointestinal tract after two days. (C) D. magna with MPs in gastrointestinal tract after seven days. Photos provided by V. Bearden and A. Schwerdt.

Discussion

Tigriopus californicus Investigation

In the classes for which these experiments were developed, students tested whether T. californicus and D. magna would ingest MPs and thus incur a higher death rate than control individuals and related hypotheses. Although the highest MP concentrations that some students tested in this study were several orders of magnitude higher than the commonly reported concentrations at sea (Lenz et al., 2016), the death rate was not statistically significantly higher due to MP ingestion in either T. californicus or D. magna. While our
sample sizes were small, this finding is in accordance with some of the research published on this question (Lee et al., 2013, Cole et al., 2015; Yu et al., 2020). The microspheres seemed to pass through the digestive system without gut impaction or other acute harm in the test organisms. However, longer term effects are known: a semester-long study could test for the higher death rates and longer development time in F1 offspring as well as decreased numbers of F1 (Lee et al., 2013) and lower F1 hatching success (Cole et al., 2015), which have been reported. The concept of MP ingestion could even be done as a single-lesson demonstration rather than a long-term project for students.

An instructor adapting these investigations may also choose to ask students to explore potential effects of zooplankton ingestion of MPs on other ocean communities. In addition to directly observing that organisms can mistake plastic for food, students can observe the MPs in fecal pellets. MPs in fecal pellets have been reported in the ocean (Katiia et al., 2017). Students can discuss the implications of sinking fecal pellets on organisms in the deep sea that depend on food raining down on them from surface communities. Some deep-water fish are important fishery species. This brings the lesson back to the idea of no free lunch in aquatic food chains—pollution we deliver to the lower trophic levels may come right back to us.

**Daphnia magna Investigation**

The two student groups that investigated *D. magna* did not find a significant increase in the death rate of *D. magna* exposed to MPs and simultaneously fed Roti-Rich food at even the highest MP concentration, which was several orders of magnitude higher than found in freshwaters. This is in keeping with some published results (Ma et al., 2016; Horton et al., 2018; cf. Zhang et al., 2019; reviewed in Yu et al., 2020). However, as with copepods, the story does not end here: a semester-long study could mimic published studies that show that MP exposure decreases feeding rate, F1 number, and F1 survival (Martins & Guilhermino, 2018), number of broods and other effects (Pacheco et al., 2018, cf. Ogonowski et al., 2016; Rist et al., 2017). We used spherical MPs; irregularly shaped particles appear more harmful than microspheres, perhaps due to gut injury (Yu et al., 2020).

Indeed, we conducted some preliminary experiments with irregularly shaped microplastic shards. They were lethal within minutes to *D. magna* that ingested them.

**A Rapidly Evolving Field of Research**

While it is commonly believed by the public that plastics do not break down, the billions of particles collectable from aquatic environments contradicts that notion. Research on the effects of MPs has burgeoned since 2015. Students can become aware of MPs and discuss the complex body of research on them as part of these experiments. As described, copepods and cladocerans, among all invertebrates studied, are considered very sensitive to MPs, but results vary with species, size and shape of MP particles, length of study, and whether the exposed organisms or subsequent generations are studied as described in this article (Yu et al., 2020). Further, use of higher concentrations of MPs than found in aquatic systems by both the students and researchers can lead to a conversation about the principles behind ecological risk assessment. A call for standard operating procedures in measuring MP concentrations in aquatic systems (Lenz et al., 2016) and for testing the effects of MPs in the laboratory (Botterell et al., 2019; O’Connor et al., 2020; Yu et al., 2020) also make this an excellent body of literature for students to examine to contemplate best practices in environmental research.

**Pedagogical Gains**

Discussions of environmental issues can make students feel like throwing up their hands in despair; there are so many environmental issues of concern. To help them maintain perspective, instructors can ask students to generate in class discussion a list of ideas to prevent MP pollution.

Another lesson to be learned from this investigation is about using animals in experiments. At Ursinus College, some students worked for the first time with living organisms in these investigations. No student declined to participate, but some students expressed concern about disposing of the organisms at the end of the experiment. This is a weighty consideration. They were told that if they did not wish to experiment using living organisms that their view was respected and they would be given data to analyze with no effect on their grade. Other students remarked in their written reflections that they valued the opportunity to gain experience with husbandry of organisms.

Certain pedagogical gains really stood out in conducting these experiments. Students reported that it was valuable to examine posters that addressed the same research question and note the differences in data expression (e.g., bar graph versus table) and choice of statistical analysis. In their written reflections the students reported learning about the importance of sample size and mentioned nuanced aspects of experimental design, such as the time interval between multiple data point collections and the number of data points. Their comments reinforced the value of multiweek independent projects in laboratory courses. Students remarked:

“I loved the Daphnia lab as it was student-ran and we could pick our own research topics and investigate water quality issues.”

“The project was difficult to come up with our own idea and conduct the experiment on our own, but it was realistic for when we go to grad school or out into the real world.”

The most poignant remark was from a senior undergraduate who said that in her honors research she had picked up an oar and rowed on the research question that was the focus of the faculty member’s laboratory, and that she was happy for the opportunity to design an experiment completely from scratch, including the methodology. Sometimes a simple remark lets the instructor know: Mission Accomplished.

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**References**

Andrady, A.L. (2011). Microplastics in the marine environment. *Marine Pollution Bulletin, 62*(8), 1596–1605.

Auman, H.J., Ludwig, J.P., Giexy, J.P. & Colborn, T.H.E.O. (1997). Plastic ingestion by Laysan albatross chicks on Sand Island, Midway Atoll, in 1994 and 1995. *Albatross Biology and Conservation*, 239–44.
Bottrell, Z.L., Beaumont, N., Dorrington, T., Steinke, M., Thompson, R.C. & Lindeque, P.K. (2019). Bioavailability and effects of microplastics on marine zooplankton: A review. Environmenal Pollution, 245, 98–110.

Brandt, S.M., Fontana, R.E., Mata, T.M., Gravem, S.A., Hettinger, A., et al. (2011). The ecotoxicology of plastic marine debris. The American Biology Teacher, 73(8), 474–78.

Brewer, C.A. & Smith, D. (2011). Vision and Change in Undergraduate Biology Education: A Call to Action. American Association for the Advancement of Science. https://visionandchange.org/finalreport/.

Brownell, S.E., Kloser, M.J., Fukami, T. & Shavelson, R. (2012). Undergraduate biology lab courses: Comparing the impact of traditionally based “cookbook” and authentic research-based courses on student lab experiences. Journal of College Science Teaching, 41(4), 36–45.

Carpenter, E.J. & Smith, K.L. (1972). Plastics on the Sargasso Sea surface. Science, 175(4027), 1200–41.

Carr, A. (1987). Impact of nondegradable marine debris on the ecology and survival outlook of sea turtles. Marine Pollution Bulletin, 18(6), 352–56.

Cole, M., Lindeque, P., Fileman, E., Halsband, C. & Galloway, T.S. (2015). The impact of polystyrene microplastics on feeding, function and fecundity in the marine copepod Calanus helgolandicus. Environmental Science & Technology, 49(2), 1130–37.

Cole, M., Lindeque, P., Halsband, C. & Galloway, T.S. (2011). Microplastics as contaminants in the marine environment: A review. Marine Pollution Bulletin, 62(12), 2588–97.

Freeman, S., Eddy, S.L., McDonough, M., Smith, M.K., Okoroafor, N., et al. (2019). Active learning increases student performance in science, engineering, and mathematics. Proceedings of the National Academy of Sciences, 116(23), 8140–15.

Fox, H.M. (1948). The haemoglobin of Daphnia. Proceedings of the Royal Society of London. Series B-Biological Sciences, 135(879), 193–212.

Horton, A.A., Vrijver, M.G., Lahive, E., Spurgeon, D.J., Svendsen, C., Heutink, R., van Bodegom, P.M. & Baas, J. (2018). Acute toxicity of organic pesticides to Daphnia magna is unchanged by co-exposure to polystyrene microplastics. Ecotoxicology and Environmental Safety, 166, 26–34.

Huvet, A., Paul-Pont, I., Fabioux, C., Lambert, C., Suquet, M., et al. (2016). Reply to Lenz et al.: Quantifying the smallest microplastics is the challenge for a comprehensive view of their environmental impacts. Proceedings of the National Academy of Sciences, 113(29), e1123–24.

Hwang, J., Choi, D., Han, S., Jung, S.Y., Choi, J. & Hong, J. (2020). Potential toxicity of polystyrene microplastic particles. Scientific Reports, 10(1), 1–12.

Katić, K., Choy, C.A., Sherlock, R.E., Sherman, A.D. & Robison, B.H. (2017). From the surface to the seafloor: How giant larvaceans transport microplastics into the deep sea. Science Advances, 3(6), e1700715.

Kenyon, K.W. & Kridler, E. (1969). Laysan albatrosses swallow indigestible matter. The Auk, 86(2), 339–43.

Lee, K.W., Shim, W.J., Kwon, O.Y. & Kang, J.H. (2013). Size-dependent effects of micro polystyrene particles in the marine copepod Tigriopus japonicus. Environmental Science & Technology, 47, 11278–83.

Lenz, R., Enders, K. & Nielsen, T.G. (2016). Microplastic exposure studies should be environmentally realistic. Proceedings of the National Academy of Sciences, 113(29), e1121–22.

Li, C., Busquets, R. & Campos, L.C. (2020). Assessment of microplastics in freshwater systems: A review. Science of the Total Environment, 707.

Lusher A., Hollman P. & Mendoza-Hill, J. (2017). Microplastics in fisheries and aquaculture: Status of knowledge on their occurrence and implications for aquatic organisms and food safety. Food and Agriculture Organization of the United Nations.

Ma, Y., Huang, A., Cao, S., Sun, F., Wang, L., et al. (2016). Effects of nonplastics and microplastics on toxicity, bioaccumulation, and environmental fate of phenanthrene in fresh water. Environmental Pollution, 219, 166–73.

Martins, A. & Guilhermino, L. (2018). Transgenerational effects and recovery of microplastics exposure in model populations of the freshwater cladoceran Daphnia magna Straus. Science of the Total Environment, 631, 421–28.

Mason, S.A., Garneau, D., Sutton, R., Chu, Y., Ehmann, K., et al. (2016). Microplastic pollution is widely detected in US municipal wastewater treatment plant effluent. Environmental Pollution, 218, 1045–54.

Miller, M.E., Hamann, M. & Kroon, F.J. (2020). Bioaccumulation and biomagnification of microplastics in marine organisms: A review and meta-analysis of current data. Plos One, 15(10), e0240792.

O’Connor, J.D., Mahon, A.M., Ramsperger, A.F., Trotter, B., Redondo Hasselharm, P.E., Koelmans, A.A., Lally, H.T. & Murphy, S. (2020). Microplastics in freshwater biota: A critical review of isolation, characterization, and assessment methods. Global Challenges, 4(6), 1800118.

Ogionwoski, M., Schür, C., Jarsén, Å. & Gorokhova, E. (2016). The effects of natural and anthropogenic microparticles on individual fitness in Daphnia magna. PLOS ONE, 11, e0155063.

Olson, S. & Riordan, D.G. (2012). Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics. Report to the President. Executive Office of the President. https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/fact_sheet_final.pdf.

Pacheco, A., Martins, A. & Guilhermino, L. (2018). Toxicological interactions induced by chronic exposure to gold nanoparticles and microplastics mixtures in Daphnia magna. Science of the Total Environment, 628(2018), 1741–83.

Pettit, T.N., Grant, G.S. & Whittow, G.C. 1981. Ingestion of plastics by Laysan albatross. The Auk, 98(4), 839–41.

Povich, E. (2021). Pandemic-paused plastic bag bans ripped anew by critics. Stateline. https://www.pewtrusts.org/en/research-and-analysis/blogs/stateline/2021/03/30/.

Rist, S., Baun, A. & Hartmann, N.B. (2017). Ingestion of micro- and nanoparticles in Daphnia magna – quantification of body burdens and assessment of feeding rates and reproduction. Environmental Pollution, 228, 398–407.

Rochman, C.M. (2018). Microplastics research—from sink to source. Science, 360(6384), 28–29.

Rochman, C.M., Manzano, C., Hentschel, B.T., Simovich, S.L. & Hoh, E. (2013). Polystyrene plastic: A source and sink for polycyclic aromatic hydrocarbons in the marine environment. Environmental Science & Technology, 47(24), 13976–84.

Setälä, O., Fleming-Lehtinen, V. & Lehtiniemi, M. (2014). Ingestion and transfer of microplastics in the planktonic food web. Environmental Pollution, 185, 77–83.

Weaver, G.C., Russell, C.B. & Wink, D.J. (2008). Inquiry-based and research-based laboratory pedagogies in undergraduate science. Nature Chemical Biology, 4(10), 577–80.

Wu, P., Huang, J., Zheng, Y., Yang, Y., Zhang, Y., et al. (2019). Environmental occurrences, fate, and impacts of microplastics. Ecotoxicology and Environmental Safety, 184, 109612.

Yu, S.P., Cole, M.C. & Chan, B.K. (2020). Effects of microplastic on zooplankton survival and sublethal responses. Oceanography and Marine Biology: An Annual Review, 58, 351–94.

Zhang, P., Yan, Z., Lu, G. & Ji, Y. (2019). Single and combined effects of microplastics and roxithromycin on Daphnia magna. Environmental Science and Pollution Research, 26, 17010–20.

Zubris, K.A.V. & Richards, B.K. (2005). Synthetic fibers as an indicator of land application of sludge. Environmental Pollution, 138(2), 201–11.

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