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Viewpoint

Buzzing Beyond Annoyance: Flies as Nature's Composite Samplers of Terrestrial Fecal Contamination

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While eating a meal outside or in your kitchen, the presence of flies incessantly buzzing around is common. Not only annoying, flies pose a public health hazard.[1,2] Some flies—including house flies and blow flies—consume feces as part of their diet. This fecal material contains trillions of microbes, which may include pathogens and antibiotic-resistant organisms. Flies carry pathogens two ways: physically attached to their body as they land on the feces, and inside their alimentary canal. When a fly lands on any surface following a meal (which could include the chicken and rice you are planning to eat for dinner), it may vomit. This fly "speck" may be composed of fecal remnants that contain pathogenic organisms. Flies also defecate, and many pathogens can survive passage through the fly alimentary canal.[1] The consumption of these pathogens by humans can lead to an infection, which is a prerequisite for illnesses such as diarrheal disease. The same behavior that causes flies to pose a public health risk also creates a unique opportunity for environmental monitoring. Certain species of flies—including blow flies and house flies—can be viewed as nature's composite samplers of fecal material in the terrestrial environment.

Environmental samples are typically collected via grab, passive, or composite sampling.[3] Grab samples are discrete samples collected from a single location and time-point. Passive samples require a material that spontaneously absorbs or adsorbs the contaminant of interest from the surrounding environment. Composite samples are mixtures of multiple individual samples which may be pooled geographically or temporally. Combining samples to form a composite sample may provide a more representative understanding of the target of interest in a population but loses information about individual samples. Composite sampling is also used because it can dramatically reduce analytical costs via a reduction in the number of analyses required. Methods for composite sampling are well developed for air, water, and soil monitoring, as well as for clinical testing.[3]

Natural fly behavior mimics that of a composite sampler (Figure 1). Flies continuously move from attractant to attractant during daytime hours, feeding on a variety of organic material that includes feces for some species.[1,2] Through ingestion, or attachment to the body surface, flies gather microbes and chemicals present in the terrestrial locations they visit, effectively creating a composite sample. While flies are capable of up to 20 km of flight in a single day, long-distance travel is rare when nearby food is plentiful.[1,2] Instead, flies will often travel less than a few hundred meters in a single day, indicating that they may be used as composite samplers of the localized terrestrial environment.

Fecal material contains a wealth of information about the individuals and populations that generate it. Testing pooled feces via wastewater-based monitoring for analytes of interest has been used since the early 1900s and became widespread during the COVID-19 pandemic.[4] While effective for public health surveillance, many communities lack these aquatic matrices (e.g., a piped wastewater system or drainage canals that receive fecal wastes). Some examples include rural communities in the United States who use septic tanks or communities in low- and middle-income countries reliant on onsite sanitation such as pit latrines. Flies could also be used to monitor analytes of interest in low-income communities or animal populations that openly defecate in the environment. Monitoring this terrestrial fecal contamination could provide actionable information to public health officials or other stakeholders in these communities of interest. Potential use cases include advanced warning about emerging and re-emerging infectious diseases, monitoring antimicrobial resistance, or for fecal source tracking to identify the primary contributors to terrestrial fecal contamination. Flies also collect chemicals from the environment and can be used to sample contaminants from areas that are inaccessible or unsafe for humans to visit.[5]

Similar to other environmental matrices, the potential for microbes to remain viable while being carried by flies is influenced by environmental conditions. Desiccation, espe-

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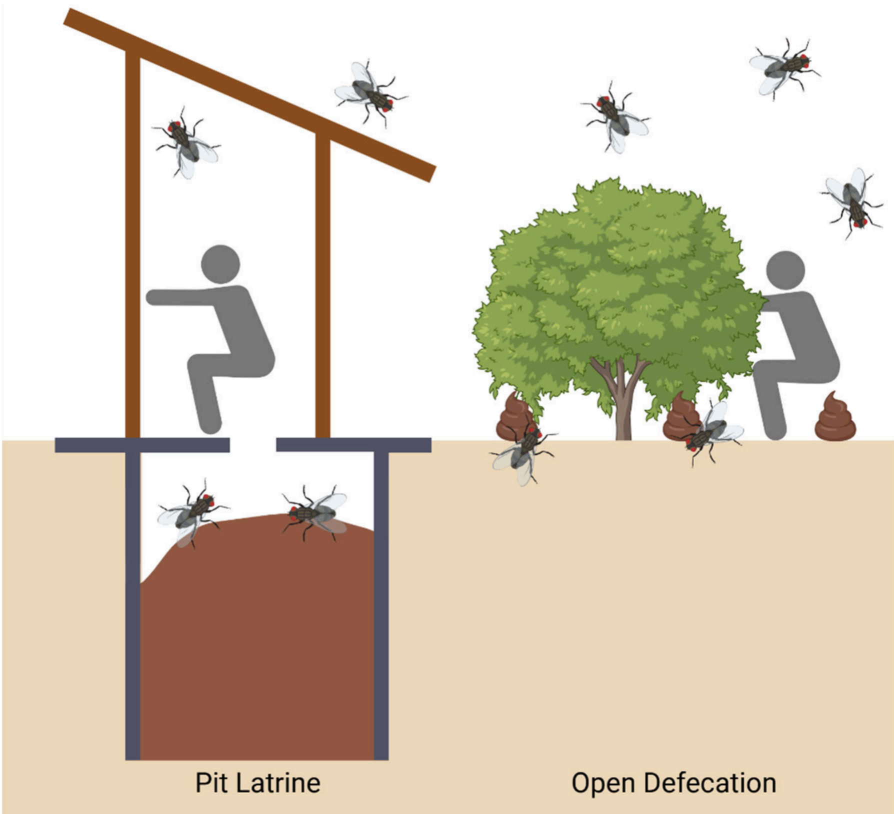

Figure 1. Flies move from attractant to attractant, collecting fecal microbes on their outer body and in their alimentary canal.

cially on the external fly body, can inactivate microbes. After ingestion, microbial survival is affected by varying pH levels along the alimentary canal, though the effects of temperature and humidity on microbial persistence within the fly gut is unclear. Warmer temperatures and higher humidity likely result in greater food intake by flies, yet warmer temperatures may also accelerate microbial decay compared to cooler temperatures.

Species of flies vary across regions and ecosystems, yet they share common behaviors: they seek out water, carbohydrates, protein sources, and sites suitable for egg-laying. Species have distinct ecological niches, feeding habits, and preferences,[1] which can be leveraged for targeted sampling. Blow flies, for example, can be easily and almost instantaneously attracted to a baited trap containing strong-smelling materials.[6] Many other fly species, such house flies, are readily collected with baited or sticky traps that are left in the environment over a period of time. The combination of this ease of capture and fly behaviors results in rapid and scalable methods that allow flies to serve as nature's composite samplers of feces in the terrestrial environment.

Other insects share similar behaviors and may also act as natural samplers. Bees collect pollen while foraging and bring this mixture back to their hive. Some species of beetles and cockroaches consume fecal material and may form a composite sample of their feeding sites. Alternatively, earthworms may act as passive samplers through bioaccumulation of soil-based contaminants from their burrowing and feeding habits.

Despite the many benefits of using flies as natural composite samplers, there are also limitations to this approach. One limitation is that flies are opportunistic feeders, and their movements are influenced by the availability of food and breeding sites. As a result, the analytes they carry may represent the specific microenvironments they frequent and not the broader environment. In addition, flies are poikilotherms, meaning that they cannot regulate their body temperature except by behavioral means.[1,2] This means that flies are only present in the warmer spring, summer, and fall months in the higher latitudes and do not survive in extreme environments (e.g., the poles and at high elevations). However, flies can often be found year-round in warm tropical environments.

Flies, despite their reputation as pests, serve a unique role as nature's composite samplers of fecal material. We can leverage this behavior to advance our understanding of the pathogens and other analytes present in fecal material in the terrestrial environment. Improved monitoring could help inform investment and decision making to achieve Sustainable Development Goal 6, which aims for universal coverage of adequate and equitable water and sanitation infrastructure by 2030.

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Biography

Drew Capone is an Assistant Professor in the Department of Environmental and Occupational Health in the School of Public Health at Indiana University-Bloomington. He developed an interest in water, sanitation, and hygiene (WASH) while serving in rural Mozambique as an Education Volunteer with the United States Peace Corps (2014-2016). Since 2017 Drew has partnered with researchers at the Mozambique National Institute of Health on WASH research and he has built additional collaborations to investigate WASH challenges in the United States and in low-income countries. Drew's research uses tools from engineering, epidemiology, and environmental microbiology to investigate the problems affecting low-income individuals and aims to improve public health in the communities where these people live. He loves training his students to catch and analyze flies and he is excited to use flies as composite samplers in future projects.

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