IDENTIFYING CULTURAL AND NON-CULTURAL FACTORS AFFECTING LITTER PATTERNS IN HICKORY CREEK, TEXAS

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Plastic deposition in hydrological systems is a pervasive problem at all geographic scales from loci of pollution to global ocean circulation. Much attention has been devoted to plastic deposition in marine contexts, but little is known about inputs of plastics into local hydrological systems, such as streams. Any attempt to prevent plastic litter must confront people’s behaviors, so archaeological concepts are used to distinguish between various cultural inputs (e.g., littering) and non-cultural forces (e.g., stream transport) that affect litter patterns on the landscape. Litter surveys along Hickory Creek in Denton, TX, are used to assess these factors.

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CHAPTER 1

INTRODUCTION AND BACKGROUND

Litter has been a common problem in communities for centuries, creating an aesthetic disturbance that is difficult to remediate. *Plastic* is a relative newcomer to the pollution scene and is becoming increasingly prevalent in society, especially in the form of packaging and single-use, “disposable” goods (Barnes et al., 2009; Thompson et al., 2009a; Stevens, 2002). Plastic’s success as a material arises from its variety of benefits over competing materials, including extreme versatility, a high strength-to-weight ratio, and low production costs (Andrady and Neal, 2009; Thompson et al., 2009b). Plastic is inexpensive to produce and is often treated as disposable, which is related to the fact that short use-life packaging makes up the largest share of plastic uses (Stevens, 2002). An increasing ubiquity of plastic use coupled with its low perceived value results in more plastic ending up as litter. Although the amount of paper, metal, and glass litter has decreased over the past 45 years, the number of plastic items found as litter has increased by over 165%, according to a nationwide survey (MSW Consultants, 2009).

While several comprehensive studies have addressed litter near roadways (MSW Consultants, 2009; R.W. Beck, Inc., 2007), relatively little is known about litter accumulation in streams. Litter in or near streams can become highly mobile once it enters the channel’s current (William and Simmons, 1999), thus it should not be assumed that the patterns exhibited by fluvial litter are the same as other littering contexts, such as roads. This potential mobility of litter in fluvial contexts makes cleanup of stream litter challenging. Information about behaviors that lead to littering near streams can aid in understanding and curtailing littering pollution at its source, prior to its entry into the fluvial system.

The fluvial context of littering is complicated by three characteristics of plastic itself, which represents an especially pernicious type of litter in this context. First, almost half of all plastic items are buoyant (Barnes et al., 2009; Hammer, Kraak, and Parsons, 2012), which increases the potential for mobility in streams by leading to dispersion from the input point and makes it harder to target cleanup efforts. Second, plastic is built to last (Barnes et al., 2009; Stevens, 2002); it does not break down on the landscape, which leads to long-term accumulation if it is not removed. Third, as stated above, plastic is common, and is becoming increasingly more ubiquitous as litter.

If nothing is done or if cleanup efforts are ineffective, this accumulation of plastic will essentially turn streams into moving landfills that collect litter from the surrounding watershed, in a similar way to oceanic gyres acting as collection points for plastic debris in the oceans. The fluvial and marine contexts are even more intimately connected than this, though, as rivers directly contribute a considerable amount of litter and debris to the oceans (Barnes et al., 2009; Hammer, Kraak, and Parsons, 2012; Williams and Simmons, 1997b). But few streams lead directly to the ocean, as there are often lakes, reservoirs, and higher order rivers lying between them and this destination; these intermediary bodies of water can become local endpoints for litter movement. In the North Texas region, human-constructed reservoirs represent the likely endpoint for litter rather than an ocean. The stream selected for this study, Hickory Creek, flows into Lewisville Lake, along with the other major streams flowing through Denton, Texas (Pecan Creek, Clear Creek, and Cooper Creek). Although the specific effects of litter accumulation are unknown, reservoirs are an important source of water in this region, especially since most of the streams are intermittent and have variable streamflow (Texas Water Development Board, 2014). However, one environmental concern related to plastic is the chemical leaching of additives (chemicals that make plastic stronger, more durable, and more lightweight) that are potentially toxic (see sources in Guart et al., 2011; Hammer, Kraak and Parsons, 2012; Teuten et al., 2009).

In an effort to assist in targeting cleanup efforts and litter education campaigns, the goal of this study was to determine whether the spatial distribution of stream litter, in particular plastic, is related to certain cultural and noncultural factors. The cultural, or behavioral, factors relate to the act of littering itself, and were represented by an area's exposure to people. Exposure takes the form of accessibility of a site to vehicular and foot traffic, so proximity to roads, bridges, and recreational areas with footpaths were taken into consideration during analysis. The noncultural factors relate to other forces affecting litter patterns, such as wind (aeolian) and water (hydrological) forces, and were measured as differential accumulation of items with different physical properties (such as glass being more dense and less mobile than plastic), and using partial burial as one proxy for exposure to natural forces. In order to better comprehend the spatial distribution of litter along a stream gradient, an eight-month longitudinal study of litter accumulation was carried out at several areas along Hickory Creek in Denton, Texas (Fig. 1.1 and Fig. 1.2). Hickory Creek is considered to be a sub-watershed within the Lewisville Lake watershed, which is itself nested within the Elm Fork of the Trinity River of the Upper Trinity River basin (NCTCOG, 2010). The Elm Fork extends south into the northern edge of Dallas County. Hickory Creek is an intermittent stream with a watershed covering almost 125,000 acres; the watershed comprises various land uses including agriculture, rangeland, as well as suburban and urban development (Table 1.1).

Each area considered in this study was selected based on specific characteristics related to exposure, primarily proximity to roads, bridges, and recreational areas (Table 1.2). It was expected that the amount and type of litter found at each area would vary based on these factors, with roads, bridges, and recreational areas acting as input points for litter (cultural deposition zones). To test these expectations, the areas were compared using several measures and indices, including litter density, diversity measures (index of qualitative variation), a beverage-bag index (BBI), an aluminum-bag index (ABI), and burial percentages for different use types.

The effects of exposure and hydrologic/aeolian factors on litter patterns were analyzed at two scales: between areas and within areas (i.e., between sites). Each scale is covered in a separate chapter, with the between-area analyses in Chapter 2 and the within-area analyses in Chapter 3. The between-area analyses are an attempt to identify and understand the larger-scale processes that work across the entire study area, and the within-area analyses are focused primarily on examining how those large-scale processes work at a smaller scale. Based on these two scales of analysis, the research questions for this study are:

1. Are there different litter patterns *between* different areas related to cultural (exposure to people) and noncultural (hydrologic deposition) factors?
2. Do litter patterns vary *within* areas related to the above factors?

Although the study of litter can be approached from various theoretical and methodological frameworks, the analysis of litter patterns using expectations derived from exposure to people lends itself well to an archaeological approach. All items found as litter originate in a cultural context, and at some point a decision is made to discard these items on the landscape; this behavioral component is especially salient since it appears that around 80% of littering is intentional (Action Research, Inc., 2009; Schultz et al., 2013). The behavioral archaeological approach advocated by Schiffer (1987) uses a variety of cultural and noncultural factors (termed *formation processes*) to interpret the patterns of artifacts on the landscape. In the present study, cultural factors (also called c-transforms) are related to exposure to roads, bridges, and recreational areas and whether people are in vehicles or on foot, and noncultural factors (termed n-transforms) are related to the effects of hydrologic and (to a lesser extent) aeolian forces. The ultimate goal of this study was to be able to make inferences about human behaviors based on litter patterns that are mediated by c- and n-transforms so that targeted recommendations about litter prevention and cleanup could be made. In order to understand how this approach can be used, the literature in litter studies, both traditional and stream-oriented, must be investigated.

Litter Studies

Although people tend to have a common sense or intuitive definition of what constitutes litter, it can be defined as “a form of pollution caused by the willful or careless mishandling or improper disposal of waste materials” (MSW Consultants, 2009, 1-1), or more simply as “any item that is in an unacceptable location, regardless of origin” (Schultz et al., 2013). Both of these definitions embody a strong normative component through the use of “improper” and “unacceptable,” and this is reflected in the goal of many litter studies to focus on littering behavior and not necessarily litter materials (Action Research, Inc., 2009). The main thrust for research on littering has come from Keep America Beautiful (KAB), which was created in 1953 to address litter as an important issue and has commissioned some of the most comprehensive surveys on littering behaviors in the U. S. (Action Research, Inc., 2009; MSW Consultants, 2009; R. W. Beck, Inc., 2007). Besides examining the types of items that make up litter and determining littering rates for these various categories, litter studies generally address issues related to who tends to litter, where greater amounts of litter occur, and how to prevent future littering (Action Research, Inc., 2009).

Based on a nationwide sample across urban, rural and suburban sites from ten states, littering was observed in 17% of all disposal actions by individuals, and 81% of these littering actions appeared to be intentional (Action Research, Inc., 2009; Schultz et al., 2013). Common litter items include cigarette butts, paper items, food wrappers, and plastic items, with cigarette butts constituting a higher proportion of the litter than other categories (Action Research, Inc., 2009; MSW Consultants, 2009; Sibley and Liu, 2003). In terms of overall littering trends, there seems to have been a decrease in the amount of litter since the last national litter survey conducted in 1969 (MSW Consultants, 2009; R.W. Beck, Inc., 2007). However, this trend needs to be examined more closely, because the decline is driven primarily by a reduction in paper, metal and glass items; plastic litter has increased by over 165% since 1969 (MSW Consultants, 2009).

Littering rates and trends by themselves are not very useful if the sources of littering cannot be identified. To that end, in the 1970s KAB highlighted seven primary sources of litter, which for the purposes of this study include littering from pedestrians and cyclists, motorists, and trucks with uncovered loads (Action Research, Inc., 2009). These categories are broad, and it seems that the general situation has not changed much since 1970 in terms of important litter sources (MSW Consultants, 2009). In fact, it appears, based on a nationwide survey of U.S. roadways, that around 70% of litter comes from motorists and pedestrians (Schultz et al., 2013; MSW Consultants, 2009), which justifies emphasizing these categories for further study and targeted litter reductions. While the sources of litter are useful for targeting purposes, this information alone is inadequate for a complete picture. Understanding the factors that cause people to litter is also needed.

The comprehensive surveys prepared for KAB led to agreement that there are two primary scales at which littering occurs: the individual and the contextual (Schultz et al., 2013; Action Research, Inc., 2009). Both of these scales relate to the psychology of littering, so the real difference between them comes down to whether the characteristics of the individual are being examined (such as age, gender, or social position) or whether the individuals' external context is being examined (such as proximity of trash receptacles or the amount of litter already present at the site); most litter studies attempt to address both scales. In terms of the individual or demographic characteristics of litterers, the primary variables are age and gender. Age has generally been found to have a negative relationship with littering, with older people less likely to litter than younger people, although this is not always the case (Bator, Bryan, and Schultz, 2011; Durdan, Reeder, and Hecht, 1985; Krauss, Freedman, and Whitcup, 1978). Gender seems to be a less useful variable in terms of predicting littering behaviors, in that there is some evidence that men litter more than women, but the difference is not substantial (Action Research, 2009; Schultz et al., 2013). Overall, these factors summarize who is likely to litter, but there does not seem to be enough consistency in results for them to be used effectively in reducing or preventing litter.

Contextual or environmental predictors of littering also relate to the characteristics of an area that can affect littering behaviors, such as the number and position of trash receptacles, the presence of anti-littering signage, and the amount of litter already present in the area. The incidence of littering is higher if no trash receptacles are present or if the receptacles are spaced too far apart (Bator, Bryan and Schultz, 2011; Cope et al., 1993); in this case, convenience seems to play a large role in whether someone will litter (Schultz et al., 2013). This pattern holds for motorists as well as pedestrians, with a 28% reduction in litter along highway locations after the introduction of roadside trash receptacles (Finnie, 1973). Adding signs that contain a positive message about keeping the area clean or a warning to discourage littering acts (such as a threat about littering fines) both work to reduce the frequency of littering behavior, and there does not seem to be a significant difference between positive and negative messages in terms of reducing litter (Reiter and Samuel, 1980). Finally, areas with litter already present increase the probability of leading more people to litter. This is likely connected to norms regarding the acceptability of littering if other people have already done so (Action Research, Inc., 2009; Finnie, 1973; Schultz et al., 2013).

Common methodologies employed in litter studies center on either behavioral observations or litter surveys. This is essentially a divide in methods between observing people littering compared to making observations of what has been littered after the fact and inferring the behavior. The first approach, making behavioral observations, is used when information on the characteristics of individuals is desired because this approach allows the researcher to collect demographic data on litterers (Action Research, Inc., 2009; Bator, Bryan, and Schultz, 2011; Schultz et al., 2013). Although this is an accurate method for determining litter sources, since the researcher can actually watch the act of littering as it occurs, it is also time-intensive (especially if a longitudinal study is desired) and can be unnecessary if the contextual factors under study can be inferred from patterns in the litter itself.

The second approach, litter surveys, is a common tool used to assess the relative amount of litter at sites (usually roadways), although the specific methods employed vary (MSW Consultants, 2009; R. W. Beck, Inc., 2007). The Institute for Applied Research (IAR), an environmental consulting firm, developed a methodology for conducting litter surveys that has become commonly adopted in litter studies; its procedures include a stratified random sampling design of survey sites, visual counting of littered objects (due to the high number of sites surveyed), and exclusive consideration of sites along roadways (R. W. Beck, Inc., 2007). Although another comprehensive national survey by Mid Atlantic Solid Waste (MSW) Consultants (2009) includes non-roadway sites, the primary focus of that study is also on roadways.

The litter survey methodology used in the present study differs greatly from that used by the IAR for three reasons. (1) The sites used in this study were purposively selected to highlight litter differences along the upstream-downstream gradient of Hickory Creek and areas with different levels of exposure to people. (2) Littered objects were tallied after collection for proper disposal or recycling rather than visually counted, which allowed for a longitudinal analysis of the effectiveness of cleanup efforts. (3) Although the sites in the present study are in close proximity to roadways, the actual survey sites (and the implications) target the stream corridor of Hickory Creek and variability in exposure to roads, bridges, and walkways. Litter studies can highlight the social factors affecting why people litter and who tends to litter, but litter patterns cannot be taken at face value when dealing with streams due to the addition of natural factors that have the potential to transport litter away from its litter deposition context.

Litter in Streams

What happens to litter in streams reflects a convergence of cultural and natural factors (c- and n- transforms, respectively), because though people are the ultimate source of litter, hydrologic forces disperse litter from its initial input point. This means that both factors must be included in an analysis of the sources of litter and its distribution. Stream litter has been approached differently in the academic and applied spheres, with the difference largely based on where the information originated (either in an academic journal or from a governmental agency or department report). While applied research on stream litter is still occurring in cities across the nation, academic research on this specific subject is limited and fairly outdated (at least 15 years old). No sources from the United States could be located.

Unlike research on marine systems, litter in freshwater streams has received little consideration in the academic literature. However, there has been a call for more attention in this area from those studying marine litter, with the primary reason being to identify sources of litter inputs to the rivers that lead to the oceans (Ryan et al., 2009; Thompson et al., 2009b). Only two articles could be located that actually assess litter sources, movement, and sinks in freshwater streams (Williams and Simmons, 1997a and 1999). They provide a sufficient framework for the problems that arise when studying this issue, but many of the details do not apply to this study because the research has almost exclusively taken place in the United Kingdom. In addition, these studies are at least 15 years old, and while the general context has stayed the same, the details may vary considerably by stream system and even within stream gradients.

Two primary sources have been identified for litter entering streams, based on a case study of the River Taff, South Wales, UK. These are sewage inputs from combined sewer overflows (CSO) as the minor source and “fly tipping,” or illegal dumping, as the major source (Williams and Simmons, 1999). Combined systems are sewer pipes that also act as conveyance for storm water. Normally both the sewage and storm water are carried to a sewage treatment plant (USEPA, 2012a); however, during heavy rainfall, the system will overflow and discharge untreated wastewater directly into streams. Since there are no combined sewer systems in Texas (they are generally found in older cities), this finding does not apply to this context and we are left with illegal dumping as the primary source of stream litter. Williams and Simmons (1999) found that the existence of a road in close proximity to the stream was the biggest factor affecting illegal dumping, and much of the debris was composed of household items. A large quantity of plastic containers were recorded at these dumping sites, but they failed to appear further downstream during baseline surveys, which seems to indicate that once plastic containers are entrained by stream flow, they travel large distances—perhaps even out of the stream system—due to their buoyancy (Williams and Simmons, 1997b).

In terms of stream transportation and deposition of litter, plastic litter seems to move most during flood events, at least in the case of Low Density Polyethylene (LDPE) sheeting, and resulting deposition events occur mainly in the mid-bank zone (Williams and Simmons, 1997a).

The mid-bank zone likely received more litter due to its position, since the lower bank was almost constantly in contact with water movement and the upper zone was out of reach for most flood events. In addition to the effects of flood events, LDPE plastic sheeting is more likely to become stranded during low flow conditions in the stream, with a majority becoming entangled at the first obstacle in one experiment (Williams and Simmons, 1997a). However, even in high flow periods there were still a high number of stranded items, which points to the influence of riverbank vegetation and watercourse obstacles in trapping litter. In conclusion, the authors note that litter movement seems to be mainly a function of "flow regimes" and "site physical characteristics" (Williams and Simmons, 1997a, 138), which are similar factors to the ones in this study (exposure and stream gradient rank).

These studies highlight a core difficulty encountered when analyzing and managing stream litter, that of potentially highly mobile litter. This makes determining the source of litter complicated, since where debris is found is not necessarily where it was deposited, and it makes controlling for this type of litter even more complicated, especially when trying to target behaviors that led to littering in the first place (William and Simmons, 1999). Dispersal of litter from its input point also has the effect of increasing the scope of the problem, from a single dumping site to an unknown distance downstream of the site (William and Simmons, 1999). While these general findings apply to all contexts of stream litter, they do not necessarily help structure solutions to the problem because they are largely descriptive. What is needed is a stronger, more comprehensive methodological framework that can quantify these relationships in order to connect the litter found at certain areas to the human behaviors or hydrological processes that likely led to its deposition.

The other context for litter in streams and river systems comes from a more applied perspective, generally from initiatives or policies originating in local, state, or federal agencies or departments. Municipal governments often approach stream litter from a storm water perspective, but actual tactics usually extend beyond storm water itself to community outreach and education to stop litter at its source (USEPA, 2012b). Much of this municipal focus on floatables (i.e., litter that floats) in storm water is derived from federal regulations (such as the Clean Water Act), which set the overall objectives to be accomplished and leave implementation approaches to regional and local levels of government.

As noted above, many of the cleanup efforts directed toward floatables at the municipal level are related to storm water management, which is regulated by the National Pollutant Discharge Elimination System (NPDES) and authorized under the Clean Water Act. Under this framework, permits are issued to control polluted storm water discharges from municipal separate storm sewer systems (MS4s), and six key categories for improvement are identified: 1) public education and outreach; 2) public involvement; 3) illicit discharge detection and elimination; 4) construction site runoff control; 5) post-construction runoff control; and 6) pollution prevention/good housekeeping (USEPA, 2005). The EPA has generally placed floating trash under the first and third categories above, with a special emphasis on source and structural controls to reduce trash entering water bodies (USEPA, 2012b). Oklahoma City's Storm Water Quality (SWQ) Division is a good example of a successful floatable debris monitoring program, with 32 collection and monitoring sites and almost 7,000 pounds of debris collected in 2012 (SWQ, 2012). Although this is a highly beneficial program, storm water is not the only source for debris in streams and rivers.

Local strategies to reduce floatables target two elements that are usually complementary components of a single plan: areas and behaviors. These are also known as structural and institutional controls, respectively (Gordon and Zamist, 2007). Structural controls are the technical means used to physically prevent litter from entering storm drains, the channel itself, or other input points, and they include screens at the opening of storm water drains at the street, nets at the output point where storm water drains into a stream, and litter booms placed across an entire channel to prevent litter already in the stream from moving further (Gordon and Zamist, 2007; USEPA, 2012b). Structural controls are reactive strategies that are not based on preventing littering acts but on controlling the outcome of long-term littering. In contrast, targeting behaviors (institutional controls) through various educational and community outreach plans to increase public awareness is a form of preventive management that attempts to stop litter from occurring in the first place; many institutional controls are designed to be adaptive to address both adults and children (Fairfax County Stormwater Management, 2010).

Most programs are directed at both structural and institutional controls as a comprehensive strategy to reduce litter in streams. For instance, under NPDES MS4 regulations, the first two key categories are related to institutional controls that target behaviors, while the other four categories are implemented using structural controls to target littered areas (USEPA, 2005). Additionally, community involvement in cleanup events (like KAB's Great American Cleanup) is a mix of both approaches, because direct interaction with litter in polluted waterways raises awareness in communities in addition to keeping the area clean.

Although structural controls seem to be effective in preventing debris from entering streams or stopping the debris from moving further once it enters a stream, they do not completely address litter that is directly deposited near streams, which bypasses most of the controls implemented from a storm water approach. In addition, institutional controls could potentially be made more effective if the characteristics of litter found in local streams are identified. People might be more inclined to get involved if a direct connection can be made between them and their local watershed's pollution. An archaeological perspective can help frame information on these characteristics of litter.

Archaeological Framework

Many perspectives, such as those from stream ecology, hydrology, and geography, can be used to understand plastic inputs into streams and are included in this study to some degree. An ecological perspective would stress the nature of litter as a pollutant and its effects on wildlife and the functioning of stream ecosystems. A hydrological approach would assess litter from the standpoint of debris transport within the stream and how this is affected by fluvial geomorphological processes. Both ecology and hydrology would analyze litter as a type of sediment that follows the same cycle other sediments follow of entrainment, transport, and deposition. In addition, a geographic perspective allows for the mapping and modeling of spatial patterns in plastic debris. Despite the value of each of these perspectives, only an archaeological perspective seeks to provide a direct linkage between patterns in material culture on the landscape and the behaviors that lead to such patterns. An archaeological perspective, thus, is ideal for studying spatial patterning in litter for the purpose of making inferences about littering behaviors.

Archaeology is the study of the relationship between material culture and human behavior (Rathje, 1979; Rathje, 1981; Schiffer, 1987). It is archaeology's domain to provide a link between patterns of human-made objects on the landscape and the human behaviors (and natural forces) that created these patterns. One way this has been done is through Schiffer's formation process framework, which is a component of behavioral archaeology. The framework is ideal for linking patterns in deposition of cultural materials (e.g., litter) to human behaviors and natural processes that influence those patterns prior to and during deposition.

Schiffer (1987) advocated a conceptual approach for analyzing and interpreting patterns in archaeological data that incorporates a variety of cultural and noncultural factors (termed *formation processes*) to help determine the relationship between deposited artifacts and human behaviors. Within this framework, a formation process is anything that influences an artifact or depositional context (i.e., a site or region) after material culture has entered the archaeological context (described below). His basic premise underlying this formation-process approach is that various actions have affected artifacts on the landscape since their deposition (e.g., hydrological or aeolian transport, fragmentation and weathering, burial, etc.), and so distributions of artifacts often do not fully represent the cultural system from which the artifacts derived. Fortunately, formation processes tend to have regular causes and consequences, which means they can be identified, predicted, and accounted for when examining artifact patterns on the landscape (Schiffer, 1987).

The formation process approach relies on understanding the concepts of systemic context and archaeological context. The systemic context is the period of an artifact's life history in which it is used to fulfill a function within a cultural system (its "use life"), and the archaeological context is the period in which an artifact interacts only with the physical/non-cultural environment (often referred to as the "natural environment") after it is intentionally or unintentionally discarded. Much research in archaeology is aimed at making inferences about human behaviors in the systemic context from studying artifacts recovered from (often buried within) the archaeological context. This form of inference requires identifying and accounting for the various formation processes (e.g., weathering, fragmentation, burial, dispersal) that acted on artifacts after they entered the archaeological context (i.e., after they were discarded or abandoned). The moment of discard of material culture items (artifacts) marks this transition from the systemic to the archaeological context (Schiffer, 1972); in the context of this study that moment of discard is littering, which means this framework is directly applicable to plastic litter.

Schiffer (1972) developed an artifact life-history model with three distinct stages to diagram the relationship between the systemic and archaeological contexts as they affect different types of artifacts; this model has been adopted and revised for this study (Fig. 1.3). The first stage considers the raw material that is used to make the artifact, before it has entered a cultural system (in the case of plastics this is most often petroleum). The second stage is the systemic context, where the raw material is modified into a functional artifact, and the artifact is used, maintained, and possibly given, traded, or sold to another group (lateral cycling) or recycled to be made into something else. As noted above, the final step of the systemic context and the beginning of the archaeological context is discard, which can be intentional (when the item is no longer useful) or unintentional (e.g., losing an artifact).

Application of Schiffer's conceptual model to a common single-use plastic item, such as a water bottle, yields interesting results. The raw material used to make plastics, petroleum, took millions of years to form. After extraction, various manufacturing stages occur (it is not important which ones for our purposes) and eventually someone purchases the water bottle. These types of "disposable" containers (along with most types of packaging and other bottles) are typically only designed for a single use, after which the material is discarded to a trash receptacle, in a recycling bin, or on the landscape as litter. Once on the landscape (or even in a landfill), plastic resists degradation and takes much longer to break down than other materials, such as paper (Andrady and Neal, 2009; Stevens, 2002). Thus, the typical use life history of a plastic bottle can be summarized as manufacture from a material made from something millions of years old, use for less than a day, followed by deposition in a landfill or on the landscape where it takes an unknown amount of time to break down.

By examining the spatial patterns of plastic debris found near Hickory Creek, inferences can be made about the behaviors that led to plastic discard and entry into this contemporary and local archaeological context. Past societies offer limited sources of information, thus archaeologists must often infer the systemic context from the archaeological with varying degrees of uncertainty. However, since plastic debris originates within a contemporary culture, the implications of its spatial patterning in this modern archaeological context can offer direct information on human behavior, because inferences and expectations can be supported with detailed prior knowledge. This means that the distinction between the two contexts is especially important in contemporary material culture studies because the transition from the systemic to the archaeological context is an *ongoing* process and behaviors can be inferred from different types of plastics (e.g., water bottles versus plastic bags). Instead of using the archaeological context to understand how past peoples lived, this context is used to understand the current behaviors of people. This enables the development of area-level profiles of various types of litter and plastic that largely correspond to people's actions, which is especially important since the areas in this study represent potential high input points for plastic pollution.

The influences of various processes on spatial distributions in litter must be accounted for to use this model. Formation processes come in two forms: cultural and noncultural. The cultural factors (also known as c-transforms) are events initiated by human actions that transfer materials from the systemic to the archaeological context (e.g., manufacture, use, and discarding of artifacts), or human-caused events exerting an influence on materials after they are in the archaeological context, such as plowing a field that disturbs artifacts (Schiffer, 1987; Schiffer, 1975). Non-cultural factors (also known as n-transforms) are any effects of the natural environment on artifacts themselves and on their distribution on the landscape (Schiffer, 1987). N-transforms generally incorporate the principles and laws developed in other disciplines, such as geology, hydrology, and physics.

For practical purposes, it is important to differentiate between plastic objects that have not been greatly affected since their discard onto the landscape and plastic objects that have been dispersed and deposited by hydrologic and other processes (e.g., wind). For instance, if a plastic water bottle has not been greatly affected by n-transform processes, then it is more or less in the same location as when it was littered and thus where people littered can be located. However, if it has been moved by aeolian or fluvial processes, then it is possibly removed from its original depositional context, which means that the location in which it is found is not necessarily where it was littered; this confounds an ability to make inferences about littering behaviors. The c-transforms incorporate the act of littering itself (from vehicles and on foot), cleanup efforts, and human interference. The n-transforms are hydrologic and aeolian forces.

For example, the act of littering from a vehicle is a form of cultural deposition that determines the initial resting place of a discarded item. Littering from a vehicle can be either intentional (throwing trash out of windows) or unintentional (carelessness, trash blowing out of vehicle windows or truck beds). If an item littered from a vehicle has not yet been affected by other forces, such as wind or water, then it is expected to be found near the roadway. Based on this, areas that are more exposed to roads should have higher abundance of litter directly discarded from vehicles. Littering on foot can come from people visiting the site area for recreational activities or people traveling (in transit) through the area. However, at the areas in this study, it is more likely that people on foot are taking part in recreational activities (such as hiking) or traveling to engage in recreational activities (such as fishing spots), rather than traveling *through* the area, especially since these sites are not connected to other areas through sidewalks or footpaths.

Cleanup efforts and human interference are the c-transforms that affect litter *after* initial deposition. Although cleanup is the ultimate goal of this study, it can also bias data in unforeseeable ways. This might include people cleaning certain areas but not others (which would affect comparisons between sites) or conducting certain activities that indirectly affects debris (such as mowing by the road, which fragments and disperses debris).

The primary n-transforms under consideration are hydrologic and aeolian forces. Under the influence of either of these forces, plastic items (or litter in general) act as sedimentary particles and can be incorporated into the sediment transport model. Sediment transport is a fundamental principle of geomorphology, and it describes how the forces of wind, water, and ice move sediment particles in a repeating cycle. It has been compared to a conveyor belt that transports material from one place to another (Pielou, 1998), and the conveyor belt components are entrainment, transport, and deposition. Entrainment refers to a particle being picked up by an erosional agent (in this case water), and this is governed primarily by the velocity of the stream current and the size of the particle (Pielou, 1998). Transportation is the movement of a particle or object, and deposition is the process of a particle ceasing to be transported and its subsequent accumulation in a location. Williams and Simmons (1997a) have carried out experiments to test the depositional patterns in stream litter, and their results as described in the previous section can be used as descriptive guidelines for hydrologic n-transforms. Hydrologic factors will be studied using the proxy measures of differential transport of items with different physical properties and burial percentage of items (with burial representing a natural force that has affected an item).

Summary

Analysis of how formation processes are related to an area’s exposure to people (c-transforms) and hydrologic/aeolian forces (n-transforms) provides a framework for making inferences about littering behaviors. Characteristics of the areas chosen for this study can be used to generate general expectations about what types of litter will be found (Table 1.2), and will help in interpreting the patterns of litter on the landscape.

The rest of this study is organized as follows. Chapter 2 covers the between-area analyses, which includes the methods (site selection, litter expectations for each area, data collection procedures, and data analysis), results, and discussion for that question. Chapter 3 covers the within-area analyses, and the focus is more on the results and discussion since the methods are very similar to Chapter 2. Lastly, Chapter 4 is a conclusion that includes a discussion of the implications of this research related to each research question under a unified formation process approach for understanding stream litter.

CHAPTER 2

BETWEEN-AREA LITTER COMPARISONS

The purpose of this study was to assess spatial patterns of litter at four study areas to determine to what extent these patterns were related to cultural factors (e.g., exposure to people) and noncultural factors (e.g., hydrological forces). The effects of these cultural and noncultural factors can be analyzed at two scales: *between* areas and *within* areas. This chapter focuses on the former, using the broad characteristics of each area to establish expectations that aid in the interpretation of results (Table 2.1). The following chapter deals with similar expectations, but at a finer spatial scale.

In order to identify the various factors affecting litter patterns, a combination of analyses was used to approach the problem from multiple angles. Density was calculated as the number of items/meter/month at each area, and this was used to compare overall abundance of litter. In addition, use type (U. type) profiles were constructed for each area, depicting the proportion of each type of litter making up the total. Several indices were constructed to further highlight differences between areas based on the relative abundance of certain U. types and material types (M. types). These indices are: beverage-bag index (BBI), aluminum-bag index (ABI), and plastic-glass index (PGI). Each of these indices is comparing two item categories that vary in terms of physical properties and/or use-life characteristics (how the item is assumed to be used). These indices were compared across areas using nonparametric Kruskal-Wallis H tests. This chapter includes the following sections on study area locations, sampling and survey procedures, analytical methods, results, discussion, and a chapter conclusion.

Study Area Locations

This study centers on the Hickory Creek watershed, located in the southern portion of the City of Denton, Texas, and extending northwest of the city (Fig. 2.1). This watershed covers almost 125,000 acres of primarily agriculture, rangeland, and urban land uses (Table 2.2), with urban development mostly occurring near Interstate Highway 35 (Banks et al., 2008; Banks et al., 2005). Although a higher population density in the developing urban areas will likely lead to an increase in litter in the watershed just from the increased population density (Inyang et al., 2003), roads themselves play a role in litter deposition on the landscape. This is especially the case for roads that run near or over Hickory Creek because litter has a shorter distance to travel before it ends up in the stream. The upper reaches of the creek are intermittent, only flowing when there is a precipitation event, but the stream exhibits steadier flow in its lower reaches. This has implications for litter transport, in that intermittent sections of the stream will likely only experience entrainment and transport of litter during high precipitation events, and the perennial sections will likely have a background of constant transport with peaks during precipitation events.

Hickory Creek flows in a southeastern direction, and, along with the other streams flowing through Denton (Pecan, Cooper, and Clear), empties into Lewisville Lake. This reservoir serves as a source of drinking water for Denton and Dallas, in addition to various recreational uses. Once litter ends up in the reservoir, cleanup efforts become complicated due to the large surface area of the lake and potential dispersion of litter.

The four “areas” sampled in this study were situated adjacent to Hickory Creek at intervals along its lower length, in order to assess localized stream gradient (upstream/downstream) differences in litter assemblages and potential patterns that could arise from exposure characteristics of the areas (Fig. 2.2). All of the areas were located near roadways (with three of them centering on vehicular bridges), since roads have long been recognized in litter studies as places with high littering potential due to the amount of traffic (Action Research, 2009; R.W. Beck, Inc., 2007). As a result, these areas likely represent high input points for litter entering the stream. Due to this requirement of finding places adjacent to both the creek and roadways, and for physical and legal ease of access reasons, the decision on where to place the areas was non-random, and so there may be limited applicability of the specifics of this study to other settings, although the methods and interpretive framework could easily be replicated.

Each of the three bridge areas was divided for purposes of sampling into three sites with the bridge as a reference point. One site was located upstream of the bridge, one downstream, and a final one was placed further downstream after a 100-meter gap (see Fig. 2.3a for an example). This was done in order to assess litter profile differences within areas, targeting the effects of bridges and other features within areas. In addition, each site consisted of two 50-meter-by-2-meter transects that parallel the stream (so areas were made up of a total of six transects, two per site). Depending on the area, the distance of the first transect to the stream ranged from less than one meter (McNair and Old Alton) to around 1.5 meters (Country Club Road and Hickory Creek Dump) from the edge of the stream; the second transect ranged from approximately two to four meters from the initial transect. The area that did not contain a bridge, Hickory Creek Dump, had only two transects instead of six, since there was no focal point (i.e., bridge) around which to situate the sites. While this difference would affect the between-area comparison of litter *counts*, this had no effect on the calculations of density and the indices, because density is measured as items *per meter* per month rather than an areas total length, and the indices are proportions.

The furthest upstream area, Country Club Road (CCR), is a bridge area with a road running parallel to the downstream and further downstream sites, but not upstream (Fig. 2.3a). This area was chosen due to its location near a bridge and its high exposure to vehicular traffic. This area is also occasionally used for fishing activities; during multiple sampling events I noticed people fishing, with their vehicles parked just off the road. After preliminary surveys in which in situ litter was collected and tallied, it was expected that this area would largely contain litter originating from moving vehicles, due to the proximity of roads to the stream.

The next area, Hickory Creek Dump (HCD), is located approximately 800 meters downstream of the CCR (Fig. 2.3b). This area does not include a bridge, and so it is the only area with two instead of six transects; it was included in the study after preliminary surveys revealed that this particular location was subject to littering activities as an informal dumping ground. In addition to the more commonly littered items found across all areas, I discovered several large dumped items over the course of sampling, including a T.V., a washing machine, many bags of organic waste (yard trimmings), and parts of a wooden fence. It is also likely that this area was used for fishing, as stripped fish remains were found during several sampling events and there is an unpaved area between the road and stream that was observed to be used for parking. However, as with CCR, it was expected that HCD would also contain a high proportion of litter from moving vehicles due to the proximity of the road and the secluded nature of the area from regular foot traffic.

Further downstream, the McNair area (McN) is positioned around a bridge on a tributary of Hickory Creek (Fletcher Branch) that joins the main channel between HCD and the furthest downstream area, Old Alton (Fig. 2.2 and 2.3c). This area was partially within the southern end of the Lake Forest Park in Denton, TX, and was bounded on either side by housing developments. The upstream site was located within the park and was host to hiking and other recreational activities, but the downstream section was not directly exposed to human activities. Because of this, it was expected that much of the litter found in downstream sites would be hydrologically deposited and not directly littered. In addition, the channel of Fletcher branch tributary is smaller than the main branch of Hickory Creek (where the other areas are located), so there were potentially more opportunities for entrapment of litter in vegetation due to stream channel’s smaller surface area.

The furthest downstream area, Old Alton (OA), is approximately five km upstream from where the mouth of Hickory Creek empties into Lewisville Lake. While the upstream and downstream sites were situated around a currently in-use concrete vehicle bridge, the nearby historical Old Alton Bridge (now a footbridge) runs across the creek and draws visitors. In addition, unpaved trails connected to the bridge run parallel to the stream, which people use for fishing and hiking, based on personal observations during data collection (Fig. 2.3d). Due to its exposure to these activities and its position as the furthest downstream area, litter expectations for this area were direct cultural deposition from recreational activities near the bank and noncultural deposition from hydrological forces transporting litter from upstream.

Sampling and Survey Procedures

Eight separate sampling events took place at roughly monthly intervals between April and December 2013 at the four areas. Monthly sampling provided an ability to gauge the temporal dimension of litter accumulation, to estimate the monthly deposition rate per area, and to aggregate the monthly data to perform statistical analyses. The sampling procedures in the field involved collecting all litter found within transects at the areas, as opposed to just a visual survey, and recording characteristics for each item on a field sheet (see appendix for sample field sheet).

The variables used to record the characteristics of each item at the time of collection were material type, use type (plastic only), resin code (plastic only), degree of cover, and fragmentation status. Material type (M. type) refers to an object's composition in terms of the primary material used in its construction. The four broad categories are plastic, aluminum, glass, and paper. While the main thrust of this study was on plastic debris, all M. types were collected in order to ascertain what proportion of the litter at these sites was plastic, which could help assess the degree to which plastic is a problem in the system. Moreover, these materials exhibit different physical properties, which can be used in analyses to determine transport potential. Heavier, denser materials (glass and aluminum) are generally expected to have a lower transport potential than less dense materials (plastic). Paper and "other" items (i.e., items not made of plastic, aluminum, or glass) were not collected during the first three months of sampling because it was expected that paper would be more likely to fragment, which could falsely inflate the paper count and be more time and energy intensive to survey in the field since these methods revolve around collecting litter and not just visual surveys.

However, these two categories were collected for the final five months of data collection, and were included in analyses involving total litter densities.

Plastic is extremely versatile as a material, and this has led to a great diversity in products that contain plastic as their primary material. This diversity was encapsulated in the variable use type (U. type), which represented the functional purpose of a plastic item. This variable was divided into five categories: beverage containers (BEV), packaging (PACK), food/drink accessories (F/D ACC), bags (BAG), and other (OTH). Beverage containers range from water and soda bottles to fast food and convenience store cups. Packaging was comprised of pre-sealed wrappers and bags, such as candy wrappers, chip bags, and the plastic wrapping around cigarette packs. The food/drink accessories category was created after preliminary surveys were completed and primarily contained straws and fountain drink lids (found separate from their cup), and take-out containers and plastic cutlery, which were encountered less often. The bag category contained any type of open plastic bag (i.e., not pre-sealed), such as grocery bags, garbage bags, and ice bags. Essentially, what separates a bag from packaging is the fact that packaging is pre-sealed with its contents predetermined, while bags serve a more general function of holding any number of different items. The most common items collected for each U. type category are summarized in Table 2.3.

The resin code of a plastic product is the official designation used by the Society of the Plastics Industry (SPI) to quickly identify the type of plastic resin used in the production of that object. This number is primarily used by recycling entities to ensure that only plastic materials containing the same type of resin are recycled together (SPI, 2014). With the exceptions of polyethylene variations (#1, 2, and 3) and polystyrene (#6), the resin code was often not identified on plastic litter items, and so was of limited value for comparison purposes.

Two variables were used to record the condition of an item at the time of recovery: degree of cover and fragmentation status. The degree of cover variable showed whether an object was exposed or partially buried in dirt or organic matter (e.g., leaves) when collected, which can be used to help identify potential formation processes. This variable only contained the two categories of exposed or partially buried. An object was considered to be partially buried if at least a quarter of it was covered by material at the time of discovery, such as dirt, organic matter, or dense vegetation. Degree of cover is an important variable in inferring formation processes related to hydrologic transportation and deposition, because it can generally be assumed that an item buried in sediment or covered by vegetation was either carried in through fluvial transportation (i.e., is not locally deposited litter) or was deposited locally some time ago. Degree of cover was used analytically as a burial percentage.

Fragmentation status was used to assess whether an object found was relatively complete or fragmented, and was divided into the two categories of whole or fragmented. An object was considered to be fragmented when over half the original material was missing, with “original material” being determined based on knowledge of common objects found as litter (especially Styrofoam cups and clearly labeled food packages). For certain other items, such as small plastic fragments with no clear label, the original material was almost impossible to ascertain, and so these items were simply marked as unknown fragments and excluded from analyses involving U. type. Fragmentation varies based on the type of material (e.g., polystyrene breaks down more easily than PET bottles or aluminum) and environmental conditions (e.g., direct sunlight versus shade) (Stevens, 2002), and it is included because, like degree of cover, it can serve as a clue for certain formation processes.

For each month of data collection, the litter samples taken from the areas were reexamined in the lab, to ensure that the field data sheet matched what was actually collected as a control on data quality. In addition, photographs were taken of each transect at the time of reexamination, in case further contextual information was needed after the debris was either recycled or disposed of properly.

Analytical Methods

Determining litter pollution differences between areas required first establishing area expectations for litter based on exposure (vehicular and pedestrian) and stream gradient characteristics, as described in the previous section (Table 2.1). Once the expectations were in place, indices were developed to measure relationships between certain material types (M. types) and use types (U. types), such as a beverage-bag index (BBI), an aluminum-bag index (ABI), and a plastic-glass index (PGI). Density was also calculated to determine where the most litter occurs, with density measured as items/meter/month. The areas were chosen non-randomly due to the necessity of locating places where roads and the stream are in close proximity, and for legal and physical access reasons; thus, nonparametric statistical analyses were used. Samples were collected over eight months to increase the temporal resolution of the data. Monthly index and density values between areas were compared using nonparametric statistics, specifically a series of Kruskal-Wallis H tests, a Spearman’s rho correlation test, and the index of qualitative variation (IQV).

In its most basic form, an index is a single number used to summarize information or data for comparison purposes (Canter, 1996). All of the indices used in this study have a similar formulation and interpretive framework. Whether it's the beverage-bag index (BBI), the aluminum-bag index (ABI), or the plastic-glass index (PGI), each index compares two U. types or a U. type and an M. type as a measure of relative abundance.

The beverage-bag index (BBI) was designed to capture area-level differences in two U. types that represent contrasting use-life characteristics and physical properties. Plastic beverage containers represent a more immediately "consumable" U. type that is designed to be used and disposed of within a relatively short timeframe (Table 2.3), at least compared to other more durable goods made from plastic. Bags, on the other hand, while still disposable, are more likely to be used in transit; that is, they carry other items. This means that beverages are more likely to be directly littered than bags, which highlights a difference in the use-life characteristics. In addition, bags are more readily transported by aeolian processes, and bottles are more readily transported by hydrological processes; thus the BBI also provided a means to analyze c- and n-transforms. The BBI was used to capture the monthly variation in the ratio of beverages to bags between study areas, and was calculated by the formula:

$$\Sigma \text{ Beverage} / \Sigma \text{ (Beverage + Bag)}$$

The BBI varies from 0.00 to 1.00; a score of 1.00 indicates that plastic beverages dominate and a score of 0.00 means plastic bags dominate (no beverages are present). A high BBI supports the inference that litter from cars and pedestrians occurred in the area, and a relatively intermediate or low BBI supports the inference that non-point pollution from upstream or terrestrial sources are creating a general litter trap. These contrasting interpretations are due to the different expected uses of beverages versus bags, and can be further supported using monthly burial percentages for both U. types in each area.

The aluminum-bag index (ABI) was used to measure the ratio of aluminum items to plastic bags, primarily as an extension of the BBI. Nearly 92% of the identifiable aluminum litter recovered was beverages, primarily beer (58%), soda cans (17%), and energy drinks (9%). Therefore, aluminum could be used as a second proxy for beverages (as a functional use type), and the monthly ABI scores could be compared to the BBI to determine if they follow a similar pattern. However, the strength of the ABI is that aluminum has different physical properties than plastic, which means comparing the relative distribution of aluminum to plastic beverages will give insight into the relationship between behavioral factors (people littering beverages in certain locations) and hydrological factors (aluminum and plastic experiencing differential transport by the stream that affects their distribution). The ABI works in the same manner as the BBI, using the formula:

$$\Sigma \text{ Aluminum} / \Sigma \text{ (Aluminum + Bag)}.$$

A value of 1.00 indicates dominance of aluminum items, and a value of 0.00 means no cans (and dominance by plastic bags).

The plastic-glass index (PGI) compared the monthly abundance of plastic to glass as a ratio. Plastic and glass have very different physical properties, which are relevant for analyzing transportation into and within streams. While plastic is relatively light and durable due to its high strength-to-weight ratio (Andrady and Neal, 2009), glass is relatively heavy and breakable; this means that plastic has a higher potential for mobility into and within the stream context. Like the other indices, the PGI varies from 0.00 to 1.00, with a score of 1.00 meaning plastic dominates over glass and a score of 0.00 meaning there is no plastic relative to glass (glass dominates). If the PGI differs between areas, a low value indicates that littering occurred but plastic was transported out of the area by the stream. A high value indicates litter is not being transported substantially or that inputs are balanced by transport from the area.

For the statistical analysis, areas were compared using nonparametric Kruskal-Wallis H tests and Spearman's rho correlation tests, and the index of qualitative variation (IQV) was used to measure evenness among categories (both M. types and U. types). The Kruskal-Wallis H test was used for the majority of the statistical analyses in this study. This test was appropriate for these analyses because more than two samples (areas) were being compared and no assumptions were made about the distributions of the data. The Kruskal-Wallis test compared the median monthly proportions of a variable across areas. The H_0 for this test is that the medians are equal (the distribution of proportions is the same across areas), and the H_a for this test is that at least one pair of medians is not equal (the distribution of litter is not the same across areas).

A Spearman's rho correlation test was used to determine if there was a relationship between the monthly BBI at an area and its corresponding ABI for that month. As a nonparametric test of correlation, Spearman's rho is based on ordinal-scale data, and it operates by converting scores to ranks and then performing a correlation test on those ranks. The H_0 for Spearman's rho is that there is no relationship between the variables (rho = 0). All of the statistical tests were run using IBM's SPSS Statistics software (v20).

To complement the categorical distributions of litter in pollution profiles, the index of qualitative variation (IQV), a nominal measure of variability, was used to describe the "evenness" of categories within pollution profiles. An IQV score of 0.00 represents no diversity (i.e., all cases in one category) and a score of 1.00 represents maximum diversity (i.e., all categories with an equal number of cases). The IQV was included in the M. type and U. type profiles for both research questions.

Results

The analytical results are divided into three broad components: litter density and diversity, use types and littering behaviors, and stream transport and deposition. Litter density and diversity encompass where the most and least litter was found and how this relates to the diversity in use types recovered at each area. Use types and littering behaviors deal with the relationship between an item's functional purpose (U. type) and the littering behavior associated with it. Finally, stream transport and deposition incorporate finding ways to measure the effects of stream forces (transport and deposition) on litter assemblages.

Although monthly scores of density and index values are used in the statistical tests and for discussion purposes, the overall temporally aggregated profiles are included to provide an overview of the dataset. In terms of material types (M. types), plastic is a major component of the litter at each site, ranging from 74% at Old Alton (OA) to 87% at McNair (McN) (Table 2.4). Aluminum reaches 17% of the litter at OA and is less at the other areas, and glass never makes up more than ten percent of the litter found at an area. The index of qualitative variation (IQV) for M. types reveals that McN has the lowest diversity and OA has the highest, which corresponds with the percentages of plastic found at these sites.

For the first section on litter density and diversity, looking at the medians and dispersion in density scores of total litter, Hickory Creek Dump (HCD) has the highest median monthly density and the highest variability in density over time (shown as interquartile range, or IQR, which describes the range of the middle 50% of the distribution) (Table 2.5). Additionally, McN has both the lowest median density and the lowest variability in density over time. In fact, the ordinal rank for medians in density matches the rank of IQR values for areas, which means the areas with high density also have high variability of density across months, and the sites with low density have low variability (Table 2.5).

A Kruskal-Wallis test was run to compare the median monthly density of litter (items/meter/month) across areas. A significant result was observed (H = 24.82, df = 3, $p < .001$), therefore the H_0 that the medians are equal is rejected. A significant difference exists in median monthly densities of litter across areas. Follow-up pairwise comparisons revealed that the differences lie between HCD and McN ($p < .001$), HCD and OA ($p = .019$), and between Country Club Road (CCR) and McN ($p = .003$). Thus, those areas with high exposure to roads (CCR and HCD) have significantly higher densities of litter accumulation.

Similar differences between areas are observed for Kruskal-Wallis analyses of the BBI and ABI data (Table 2.6). The most important differences in median BBI and ABI values occur between OA and McN, as HCD and CCR tend to be similar to one another in these analyses (Fig. 2.4 and 2.5). Importantly, the ABI and BBI values correlate across sampling units (monthly sampling events at each site) (Fig. 2.6); values of zero were omitted from the analysis for the few months in which no beverage plastic or aluminum litter was collected. The correlation indicates that beverage plastic and aluminum cans tend to co-occur. Unlike for median monthly

BBI and ABI values there was no significant difference among areas for the PGI (Table 2.6), which suggests that n-transforms that influence heavy and light litter do not vary between areas.

In terms of diversity in plastic use types (U. types), McN has the highest index of qualitative variation (IQV) score at .98, which means the categories are fairly even (Table 2.7). OA has the lowest IQV at .85, which indicates some categories make up a larger portion of the profile than others. However, the IQV as a measure of evenness is not very sensitive, because fully half of the plastic items recovered from OA are beverages, yet the IQV still seems fairly high at .85. Thus, even small differences in the IQV can actually mean quite large differences in terms of the relative frequency in categories. Still, it can be seen that beverages are usually the most abundant U. type, and bags tend to be the least abundant in each area. However, this does not hold at McN, where beverages are a much lower percentage and bags are much higher than other areas. The differences between areas in the diversity of U. types measured by the IQV are also visible in radar diagrams that present proportional abundances of types in Fig. 2.7.

Discussion

Litter density is a measure of how much litter was recovered in each area, and its analysis lays the foundation for the rest of this research by providing a reference point for comparison of diversity profiles and indices. In terms of litter density, the areas can be broken down into two general groups, based on the Kruskal-Wallis results (Table 2.6). The first group contains the high litter density areas, Country Club Road (CCR) and Hickory Creek Dump (HCD), which are statistically distinct from the lower density areas, McNair (McN) and Old Alton (OA) (Fig. 2.8). This difference in densities can be generally related back to the types of exposure for each area.

In addition to the high litter density at both CCR and HCD, these areas are also parallel to the road, which leads to greater exposure to vehicles than areas where the stream is perpendicular to the road. High traffic of vehicles passing these areas presents a greater opportunity to litter than pedestrian-frequented areas (such as OA). *Both* of these areas are parallel and they have a statistically higher density of litter than the perpendicular areas (McN and OA).

The two low-density areas, McN and OA, in addition to being different from CCR and HCD, have different exposure expectations from each other. McN is somewhat exposed to pedestrian traffic in the upstream site, but is fairly secluded from human access in the downstream and separate downstream sites (Fig. 2.3c). On the other hand, OA is generally exposed to pedestrian traffic in all sites, but based on area observations, the separate downstream site does seem to have a lower frequency of visitors. Despite these differences between OA and McN, in general pedestrian traffic presents a different pattern than vehicular traffic.

If stream transport was a significant factor in litter patterns, we might expect to see higher litter densities in downstream areas, not upstream, but the results show the reverse (Fig. 2.8). However, since CCR and HCD are parallel to a road, they likely represent a high intensity litter input zone, which could overshadow any stream transport appearing in the litter distributions. In other words, while stream transport and deposition contribute to these litter patterns (based on personal observations), localized inputs may be more important.

These density results are also tied to the use type (U. type) pollution profiles for each area, which depict the relative proportion of each U. type at each area (Fig. 2.7). CCR and HCD are both high-density areas, and also share similar U. type profiles; in fact, at ordinal scale they are identical. CCR and HCD both have fairly high proportions of beverages (BEV), packaging (PACK), and food/drink accessories (F/D ACC), and low proportions of bags (BAG) and other items (OTH). BEV, PACK, and F/D ACC tend to be associated with more immediately consumable goods (Table 2.3), since these items are usually designed to be short-term containers for a product and then discarded once the product is consumed. If the similarity in litter density between CCR and HCD is due to the influence of the road, it is possible that these U. type profiles indicate the types of litter that can be expected near roadways (at least in rural and suburban roads). In this study, exposure to roadways leads to high density and relatively high diversity of litter in nearby streams.

McN has the highest diversity of plastic U. types (compare IQV scores in Table 2.7). Specifically, this seems to be primarily due to the higher proportions of BAG and OTH in this area (Fig. 2.7). Combining this increased diversity with low litter density shows that McN did not receive much litter, and what it did receive was diverse. This supports an interpretation that McN acts as a depositional zone for litter, a type of “polymer trap.”

Finally, OA exhibits moderate litter density and the lowest diversity in U. types, with fully 50% of the plastic recovered being from beverages (Table 2.7). The OA sampling area is situated in a park with hiking trails, thus littering behaviors there likely relate to recreation. For example, 13 of the 16 fishing-related items that were recovered during the surveys are from OA. Further, fishing items tended to be found in those OA sites that had the highest densities of beverage litter; 85% of the fishing gear was found in the upstream and downstream sites, and 92% of the beverages were found in the same sites. Fishing in combination with hiking likely accounts for the high density of beverage plastic and aluminum litter at OA.

Analysis of the BBI explores differences in two U. types with different physical properties and use-life characteristics across areas. Of particular interest is the difference in BBI values between OA and McN. As indicated by the boxplots, the monthly BBI shows that OA tends to be consistently beverage-dominated, with little variation from month to month (Fig. 2.4). This high amount of beverage litter with little dispersion means that beverage plastic consistently outnumbered bag plastic each month. In contrast, McN has a lower average BBI score than OA and its range spans the entire possible spectrum of scores. At McN, at least one month was dominated by beverage plastic litter but a different was dominated by bag litter. In sum, McN displays extreme temporal variability in U. types deposited. The BBI by itself does not reveal whether these patterns at McN and OA are caused by behavioral factors (c-transforms) or noncultural factors (n-transforms), so another measure is needed to further refine this relationship.

The ABI is used to further explore the distribution of beverages and bags across areas. Since almost 92% of aluminum recovered that could be identified was from beverage cans, aluminum can be compared to plastic beverages in a similar index. This helps to further identify the cultural and noncultural factors because the different physical properties of aluminum and plastic are expected to result in different transportation patterns when subjected to hydrological forces (with aluminum being more dense, and thus less buoyant and mobile, than plastic). The Kruskal-Wallis results for the ABI are similar to those of the BBI (Table 2.6), in that McN has a significantly lower median monthly ABI score than OA. In terms of median comparisons, the ranking for the BBI and ABI are the same (Fig. 2.4 and 2.5). This similarity is also revealed in the Spearman's rho analysis (Fig. 2.6). At OA, where the BBI is high, so is the ABI, but at McN where the BBI is low, so is the ABI. This indicates that people deposited both types of beverage litter at OA during recreation. However, at McN, bag plastic litter is about as likely to be deposited as beverage litter, which suggests that a different mechanism influences litter deposition in this low-exposure context.

The high diversity but low density of litter at McN indicates that it is subjected to chronic, sustained low-level pollution from non-point sources. That beverage litter or other types of litter do not dominate at McN indicates that plastic bag litter is moderately more important there, which supports an interpretation that multiple, dispersed c- and n-transform cause litter deposition there. For example, it is likely that low-level chronic aeolian deposition of bag litter has a higher relative impact because of the lack of high-density dumping such as that occurring at HCD and CCR and the lack of specialized use such as that occurring at OA. To summarize, McN seems to be a low density polymer trap.

The differences between areas appear to relate primarily to level of exposure to littering behaviors (c-transforms), and analysis of the PGI supports this interpretation. Although Kruskal Wallis analysis of the PGI returned marginally significant results, no differences in follow-up pairwise comparisons were found (Table 2.6). This means that there are no major differences between areas in terms of monthly PGI (Fig. 2.9). The PGI highlights differential hydrological transport of plastic and glass, since these two materials have very different physical properties (plastic is lighter and more buoyant than glass). Since the PGI scores for each area are relatively high, plastic dominates in each of these areas compared to glass. One possible reason for this is that litter is not being transported out of the areas by the stream, which would mean that plastic is being littered and the stream lacks sufficient discharge to carry these items or lacks the height to reach these items (at least during the period of sampling). Another reason is that high plastic litter rates (inputs) offset the transport from the area (outputs), so that at the time of sampling plastic is still the dominant material.

These results can be used to develop strategies to reduce litter in streams; these strategies revolve around targeting either behaviors or areas for cleanup efforts. The high litter densities at both CCR and HCD can be generally traced to vehicular traffic traveling parallel to the areas. Since the source of litter can be identified, and there is little evidence of the actions of n-transforms, these areas should be targeted for behavioral reductions in littering actions, with potential strategies focusing on the road itself. This can take the form of positively or negatively phrased signs (Reiter and Samuel, 1980) or the addition of trash receptacles in the area (Finnie, 1973). These behavioral strategies can also be implemented at OA, although the focus should be on the trails rather than the roads, since the largest source of the litter is likely pedestrians in this area. Additionally, these three areas should be subjected to regular cleanup actions because of their high litter densities. McN presents a different case than the other three areas, because the sources of litter cannot be identified and the area is more heavily influenced by n-transforms. McN therefore indicates a landscape-scale litter problem; litter there is less abundant, but it is more diverse and draws from a wider variety of sources. Because of this, behavioral strategies may have little to no effect, and instead direct cleanup actions should be employed.

Conclusion

Between-area litter comparisons were approached through several analyses, including consideration of litter density, litter diversity, and multiple indices. The indices were constructed to gauge differences between areas based on the relative abundance of certain U. types and M. types. Significant differences were found in litter density between areas, with the higher density areas of CCR and HCD being statistically separate from the lower density areas of McN and OA. Additionally, CCR and HCD had similar proportions of U. types (Fig. 2.7), which is likely the result of vehicular litter from the road running parallel to the areas. McN had higher diversity overall, and higher proportions of bags and "other," while OA specialized in beverage litter. The similarity in results across areas from both the beverage-bag index (BBI) and the aluminum-bag index (ABI), and the significant correlation between the two, demonstrate that the high amount of beverages at OA are the result of cultural factors (the category of "beverage," regardless of material type), and not differential transport of plastic and aluminum by the stream. The following chapter expands on these results at a finer spatial scale, and by examining litter expectations for c- and n-transforms using the site as the unit of analysis.

CHAPTER 3

WITHIN-AREA LITTER COMPARISONS

The previous chapter explored variability among the four study areas in terms of the cultural and noncultural factors affecting litter accumulation patterns. In this chapter, the distribution of litter accumulation was considered at a finer spatial scale through examination of sites and transects within three of the study areas, CCR, McN, and OA (HCD was excluded here because only one section of transects was done in that area). Each of the three areas was situated near a vehicular bridge that crosses Hickory Creek, and within each area transects were sampled upstream, immediately downstream, and far downstream from the bridge (Fig. 3.1). Thus, this chapter assesses not only exposure to roads, pedestrian traffic, and recreation, but also exposure to inputs from bridge traffic. As with the between-area analyses presented in Chapter 2, expectations of c- and n-transforms acting on litter patterns can be developed at this finer spatial scale; c-transforms should be more important closer to bridges and roads, and n-transforms, if important at all, should increasingly impact litter patterns progressively downstream from bridges with decreasing exposure to roads or in places with less traffic. Analyses presented in this chapter assess the distributions of litter density, plastic-litter diversity, and litter burial using sites and transects as the spatial units of analysis.

Materials and Methods

Data from transects within sites in three of the areas studied in Chapter 2 are analyzed to assess within-area litter accumulation patterns related to bridge exposure. Bridges were used as reference points for the placement of sites, with one site upstream of the bridge, one downstream, and one further downstream after a 100 m gap (Fig. 3.1). Each of these sites was further divided into two 50-meter-by-two-meter transects that run parallel to the stream. The one area lacking a bridge, HCD, was added to the study after preliminary surveys revealed this location was used as a dumping ground. However, HCD is not located near a bridge and comprises only one site instead of three, and so is not included in this chapter. The specific characteristics of each area and the sites within the areas are described in Chapter 2.

The analytical approach taken in this chapter is a simplified version of that reported in Chapter 2, centering on two sets of analyses. The focus of the first set of analyses is on density and plastic use type (U. type) diversity. Samples sizes were insufficient for allowing comparative analyses using the BBI, the ABI, and the PGI; instead, monthly litter densities and plastic-litter diversity are compared across sites. The second set of analyses examines the relationships among burial, litter density, and plastic beverages and bag deposition.

Litter density within areas is compared using the Kruskal-Wallis H test, which is a non-parametric test that requires relatively few assumptions about the distributions of data compared to similar parametric approaches. Three separate tests are done to make comparisons of median monthly density between sites to determine if there are differences in density within areas related to proximity to bridges. Plastic litter diversity for each of the three transect locations (upstream, immediate downstream, and far downstream) is profiled using radar diagrams and summarized using the index of qualitative variation (see Chapter 2 for details).

For the second set of analyses at the within-area spatial scale, Spearman’s rho correlation is used to determine if there is a relationship between the aggregated density score (time-averaged litter density combining all months) at a site and the corresponding burial percentage (recorded as percent of total items buried). Similar analyses are done to compare abundance of plastic bags and plastic beverages at sites and corresponding burial percentages. The Spearman's rho and Kruskal-Wallis tests were run using IBM's SPSS Statistics software (v20).

Results

Litter Density and Plastic Litter Diversity

CCR Density—Nonparametric descriptive statistics were calculated for within-area (site-level) litter density. The median litter densities within CCR show that the downstream and separate downstream sites are similar, while the upstream site shows a dramatically lower median (Table 3.1); the Kruskal Wallis H test indicates that there is a significant difference in the medians (Table 3.2). The interquartile range (IQR) follows a similar pattern as medians for CCR, as the site with the highest median also has the greatest variability between months, and the site with the lowest median has the least dispersion. This distribution of density at CCR makes sense given that there is no road exposure upstream from the bridge there, but the two downstream sites parallel the road. It appears that litter density at CCR relates most closely to vehicular traffic exposure.

McN Density—For the McNair Area (McN), the upstream site has the highest median litter density, but low variability across months (Table 3.1). Although there is no significant difference in median density among the three sites at McN (Table 3.2), the separate downstream site has the lowest monthly densities of litter (Fig. 3.2), which is contrary to what might be expected if n-transforms drive litter density differences within the area. This suggests that what input that does occur in the area is at the McN bridge, and that the “polymer trap” there first accumulates a high variety but low density of material that is *not* moved downstream by n-transforms.

OA Density—At Old Alton (OA), there is a clear distinction between the separate downstream site and the other two sites; not only does it have the lowest median density, but there is low monthly variability indicating that density there is usually low (Table 3.1 and Fig. 3.3). The Kruskal Wallis H test indicates that there is no significant difference in median litter density among the three sites ($\alpha = 0.05$); however, the p value for the test is 0.067 and sample size is small, thus test power may not be high enough to identify a non-random difference (Table 3.2). These results suggest that within the OA area, litter density tends to be highest near the bridge, which also is the part of the area with the highest vehicular and pedestrian traffic, indicating that c-transforms play an important role there.

CCR Diversity—Analysis of plastic litter diversity clarifies those factors (n- or c-transforms) that appear to be driving patterns in litter density. U. type diversity varies within areas, especially at McN and OA (Fig. 3.4), which could indicate that different factors affect litter distributions at sites within areas. Patterns are summarized statistically as IQV scores for sites, which show at least one site within McN and OA has lower “evenness” than others (Table 3.3). In general, there are minor differences in U. type composition between sites at CCR, and diversity of types is moderate at each site there (Fig. 3.4). An interesting contrast emerges between the within-area patterns at McN and OA, however; the inter-site patterns are inversed between the two areas.

McN Diversity—At McN diversity is relatively high in the sites near the bridge, but quite low far downstream (where density is also very low). Debris collected far downstream at McN tends to be in the “other” U. type and was dominated by survey flagging tape, which is likely from a one-time discard event (see Summary section below). In Chapter 2, it was suggested that McN is a low-density “polymer trap” perhaps influenced by nonpoint source pollution and aeolian deposition. The canopy downstream from the bridge is tightly closed, thus, the far downstream site would not be as exposed to these n-transforms. The upstream and immediate downstream sites are more open, and thus are vulnerable to trapping a wide variety or debris deposited into the system by non-point pollution related to n-transforms and low exposure to discard from vehicular and pedestrian traffic (c-transforms).

OA Diversity—At Old Alton, the pattern observed in plastic litter diversity is reversed with the upstream and immediate downstream sites exhibiting low diversity centering on the beverage U. type. In Chapter 2 it was suggested that littering at OA appears to relate most closely to littering by hikers and sport fishers who use the area; those activities are concentrated near the bridge. Thus, the low density, but higher diversity far downstream site at OA may relate to a downstream hydrological “polymer trap” accumulating low densities of debris from upstream stretches of Hickory Creek.

Analysis of Litter Burial

The litter density and plastic diversity analyses indicate that n-transforms and c-transforms play important roles in terms of factors that influence the distribution of litter within each area. In Chapter 2, it was shown that these transforms can also be used at a more general scale to explain differences between areas. At the area scale, it was clear that McN stood apart because though litter density tends to be low there, diversity is relatively high. In addition, the BBI and ABI analyses in Chapter 2 showed that plastic bags were more important at McN that at other sites. Although analysis of the PGI in Chapter 2 indicates that debris that floats (plastic) tends to be important in all study areas compared to debris that is heavy (glass), there is much to be gained by considering n-transforms in more detail at the finer within-area scale. At the site-level spatial scale, it is possible to assess differences in burial percentage as it relates to litter density, plastic beverage abundance (which appears to indicate direct littering behavior), and plastic bag abundance (which appears to be indicative of exposure to aeolian litter deposition).

To assess these relationships, data from each site are time averaged (transects and month data are combined). Spearman's rho correlation is used to determine if the aggregated litter densities at sites are related to the site's total burial percentage. Similarly, Spearman's rho analysis is used to determine if the aggregated percentage of plastic bags and percentage of beverage-plastic found at each site (Fig. 3.4) relate to a site's total burial percentage. A significant strong negative correlation is observed between burial percentage and litter density, a strong negative correlation is observed between plastic beverage abundance and burial percentage, and a strong positive correlation is observed between plastic bag abundance and burial rate (Table 3.2). The percentage of buried items is high when litter density is low in areas that have little to no beverage plastic, and the percentage of buried items is high when plastic bag abundance is high. Burial of litter occurs more frequently in sites within the stream system that have low discard rates (litter density) and that are low in terms of exposure to pedestrian and vehicular traffic. Such sites occur at McN, upstream at CCR, and separate downstream at

OA. Litter deposition at those sites tends to be influenced by n-transforms rather than c-transforms.

Summary

While Chapter 2 demonstrated that Country Club Road (CCR) overall had a fairly high density of litter (Fig. 3.5), it is now apparent that this pattern is primarily driven by the downstream and separate downstream areas (Fig. 3.6). There are two possible reasons for this distinction between the upstream and downstream sites. One is the influence of the bridge. People may be littering from their vehicles at the bridge and litter is then transported to the downstream and separate downstream sites, with greater accumulation closer to the bridge than further downstream (Fig. 3.6). The other is the road running parallel to both of the downstream sites.

In Chapter 2, McNair (McN) had the overall lowest average density out of the areas (Fig. 3.5). With no significant Kruskal-Wallis result for McN, these sites have statistically similar litter densities, and so the area-level density distribution is fairly representative of the sites. However, while the medians are similar, the interquartile range and range varies greatly between sites at McN (Table 3.1). The downstream site shows more dispersion than the upstream and separate downstream sites (Fig. 3.2). While on average these three sites have similar densities, the upstream site showed the highest monthly densities of litter.

Old Alton (OA) displayed moderately low litter density in Chapter 2 (Fig. 3.5). Like McN, the lack of a significant Kruskal-Wallis difference means these sites within OA are statistically similar. However, while the overall result is non-significant (although it is close to significant), there is an obvious difference in the litter densities at the downstream and separate downstream sites (Fig. 3.3). This is possibly related to the amount of recreational use each site receives, with people tending to hike and fish closer to the footbridge and just upstream of the vehicular bridge more frequently than farther downstream.

As noted in the above section, U. type diversity varies within areas, especially McN and OA (Fig. 3.4). The diversity of U. types changes least across sites at CCR compared to the other two areas, having a remarkable similarity in IQV between sites (Table 3.3). The most abundant U. types shift between beverages, packaging, and food/drink accessories between sites, all of which were described in Chapter 2 as more immediately “consumable” items. The only category that does not fit this pattern is “other” items at the upstream site, which was around 25% of the plastic recovered at that site (Fig. 3.4). The percentage of bags is consistently the lowest at these sites and never rises above 15%.

At McN, the upstream and downstream sites have fairly even proportions of U. types, with high IQV values (Table 3.3). Notice the higher percentage of bags than CCR, especially at the immediate downstream site (Fig. 3.4). Assuming that bags are less likely to be directly (intentionally) littered than items from beverages and packaging, and that bags are the most mobile and most easily ensnared of plastic U. types, the upstream and downstream sites at McN likely have a larger indirect (nonpoint) littering component than CCR. In this case, indirect litter accumulation is the result of aeolian and hydrologic processes depositing litter. The separate downstream site at McN is somewhat of an anomaly, with 45% of the plastic belonging to the “other” U. type category. Most of these “other” items were loose pieces of surveyor's tape, which could mean this litter came from only a few individuals; additionally, the sample size at this particular site was small (n = s20).

U. type diversity at OA shows a dramatic change downstream. The upstream site has the lowest diversity out of all the sites, according to the IQV, and the separate downstream site is tied for the highest diversity amongst sites from all areas (Table 3.3). At the upstream site, 60% of the plastic is from beverages, and at the immediate downstream site beverages are 50% (Fig. 3.4). These two sites are clearly driving the high frequency of beverages discussed in Chapter 2, because the separate downstream site does not show a tendency towards beverage plastic and appears to be a hydrological polymer trap.

The second set of analyses involves validating the expectations of c- and n-transforms at both the site and area level using burial as a proxy for n-transforms, since the dirt and vegetation covering the object were deposited by wind and water. The burial percentage of litter is compared to three separate variables through correlation: litter density, percentage of bags in a site, and the percentage of beverages in a site.

The Spearman's rho correlation results indicate that there is a relationship between a site's litter density and its corresponding burial percentage, at least for the sites in this study; sites with a higher litter density tend to have a lower burial percentage of litter, and vice versa (Fig. 3.7). McN is more secluded than both CCR and OA, and so it is less likely to receive culturally deposited (i.e., directly littered) objects; this means that the items that *do* end up at McN tend to be hydrologically deposited or carried in through aeolian processes. In addition to the seclusion of the area, the surface area of the tributary on which McN is located is lower than the other three areas, which means items in hydrological transport have a higher chance of being near the bank (where there is thick vegetation to ensnare items). In contrast, CCR (similarly to HCD, which was covered in Chapter 2) is very exposed to human activities and is thus more likely to receive culturally deposited objects. Objects littered there tend to more-or-less remain where they were discarded, and so there is a lower percentage of buried items.

The second and third Spearman's rho correlations measure whether sites with higher percentages of plastic bags or beverages also tend to see a high percentage of total litter partially buried. The significant result for burial correlation with bags indicates that sites with a higher percentage of bags also have a higher overall percentage of buried litter, and vice versa (Fig. 3.8). McN again tends to be the high burial area, and bags make up a fairly high percentage of the plastic (as described in Chapter 2). This relationship could mean that bags are rarely found where they were initially discarded due to their high mobility, and not only are bags easily moved by wind and water, but they are also easily ensnared in vegetation. Since more bags are ending up at McN and objects in general are being transported in and buried, then this is further evidence that McN is a polymer trap produced primarily by n-transforms.

The final correlation is similar to the one above except beverages are substituted for bags, and the distribution shows an inverse pattern (Fig. 3.9). Sites with a higher percentage of beverage plastic tend to have a *lower* overall percentage of buried litter, though there is much more variability here than in the other correlation analyses. This supports the BBI-ABI correlation finding that beverage litter tends to be in greater abundance in areas that are directly influenced by discard behaviors. The burial correlation shows that beverage plastic litter is ending up at sites with low overall hydrological/aeolian influence (CCR and HCD), and few beverages are showing up at the opposite type of site (mainly McN).

CHAPTER 4

SYNTHESIS AND CONCLUSIONS

The purpose of this study has been to determine whether the spatial distribution of stream litter is related to exposure to people and/or aeolian and hydrologic forces. This purpose was refined into two separate scales of analysis that framed the research questions, which were:

1. Are there different litter patterns *between* different areas related to cultural (exposure to people) and noncultural (hydrologic deposition) factors?
2. Do litter patterns vary *within* areas related to the above factors?

Although these two questions are covered in separate chapters, they both cover the same general question: Can geographers identify the cultural and noncultural factors that shape patterns in litter encountered near streams? To be able to identify these factors is to have a better understanding of the behavioral component of this problem, which is what ultimately must be addressed if litter in our waterways is to be reduced.

The fundamental goal of the formation process approach (and archaeology in general) is to be able to make inferences about people's behaviors through analysis of characteristics of the items they leave behind. Making these inferences requires being able to identify the factors that have potentially affected litter items since their discard, such as stream or aeolian transport. In other words, this means making the distinction between cultural and noncultural deposition. One way to address this is to compare the distributions of items with different physical properties (i.e., comparing highly mobile with less mobile item categories), such as the beverage-bag index (BBI), the aluminum-bag index (ABI), and the plastic-glass index (PGI) from Chapter 2. Another way to address this distinction is to use degree of cover (burial) as a proxy for n-transforms, such as the three burial percentage correlation tests from Chapter 3. Although it is difficult to say with certainty whether a specific item was directly littered or deposited by the stream, these analyses can give area- and site-level indicators for the presence or absence of n-transforms and c-transforms.

Using the BBI and ABI in conjunction allowed for a statistical comparison of item categories with different use-life and physical characteristics. Although both plastic beverages and aluminum are denser and less mobile than plastic bags, plastic beverages and aluminum are also different in terms of buoyancy and therefore mobility. However, plastic beverages and aluminum should have similar use-life characteristics, since almost 92% of the identifiable aluminum was from beverages. Therefore, the similar Kruskal-Wallis results for both the BBI and the ABI across areas and the correlation result (Fig. 4.1 and 4.2) indicate that either the physical characteristics of plastic and aluminum play no role in their transport (unlikely) or the category of “beverage” is driving this pattern.

Using burial as a proxy for n-transforms, several patterns emerge from site-level data. The high burial at McN is associated with low litter density, a high percentage of bags, and a low percentage of beverages. This not only reinforces the assumptions of the beverage-bag index (BBI), but also suggests that McN functions as a polymer trap. Not much litter was found in the area, but what *was* found was probably carried in by hydrological or aeolian forces. On the other hand, the low burial at a more exposed area like CCR is associated with high litter density, a relatively low percentage of bags, and a relatively higher percentage of beverages. This is likely due to littering from vehicles.

Implications for Litter Policies

These relationships between the influence of cultural and noncultural process on litter accumulation can also be formulated in reference to point source versus nonpoint source pollution. Point source pollution generally has an easily identifiable source, while nonpoint source pollution can originate from multiple sources and generally indicates a larger scale of a problem. Litter recovered from CCR and HCD can be considered point source pollution because the evidence points to a low effect of stream transport and high effect of direct inputs. In other words, the source of the problem can be clearly identified. Litter at OA falls between the two categories, because although it is most likely originating with pedestrians in the area, pedestrians have a wider range of movement than vehicles on a linear road and therefore it is somewhat more difficult to predict where litter will be found. Lastly, litter at McN seems to be strongly influenced by hydrological or aeolian factors, which makes it nonpoint source pollution. The items found at McN likely originated from multiple unknown sources, both upstream and from terrestrial sources. Due to the potential long distance transport of litter and the inability to identify sources, McN indicates a landscape-scale litter problem. Litter there is less abundant, but it is more diverse and draws from a wider variety of sources.

Different sources of litter call for different strategies for prevention and cleanup. Since the point source litter areas (CCR, HCD, and OA) have identifiable sources, the sources (vehicles and pedestrians) themselves can be targeted for litter prevention. This can take the form of signage, the presence of trash receptacles, and other preventive means. However, at OA, the trails and bridge areas should be targeted, while at CCR and HCD the roads themselves should be targeted. The high density of litter at CCR and HCD indicate that regularly scheduled cleanups are necessary unless littering behaviors change. At OA littering cleanup can target those areas frequented by sport fisher and hikers, and strategic placement of receptacles may have a large influence.

McN presents a different case in terms of cleanup and prevention. Installing signage or trash receptacles at McN may have little to no effect if much of the litter is not being directly littered at that location; behaviorally speaking, there is nothing to target. Instead, direct cleanup of McN would be effective because of the low litter density over time. The complication with nonpoint source pollution is that although cleaning up the one area in this study with hydrological/aeolian deposition would be relatively easy, predicting and locating other areas that also have this type of deposition would be more difficult. However, at McN, litter density is very low, thus cleanup efforts should have a longer lasting impact and would not be necessary at the same intensity and frequency of HCD and CCR.

Limitations

The limitations of this study revolve around the amount and type of data collected. The nonrandom selection and use of only four study areas may limit the generalizability of the results to other settings. These areas were chosen specifically for their characteristics (bridge present, parallel to road, etc.), and so caution is warranted when generalizing to other areas that are either missing these characteristics, or have these characteristics in a different combination. In other words, with only one site dominated by pedestrians (OA), one by n-transforms (McN), and two by vehicular litter (CCR and HCD), a full spectrum of the influences of n-transforms and c-transforms on littering in streams should not be generalized from this study.

What would be especially interesting is sampling more areas like McN, areas that are fairly secluded with high n-transform expectations. McN being placed around a bridge increases chances of direct littering rather than purely hydrologically-deposited litter, so sampling areas that are further away from human activities than even McN, as in areas with no bridge or association with human activities, would provide additional information on the types of litter that are likely to be present as nonpoint source pollution.

In addition to more study areas to further support the results, including more types of litter would broaden the potential scope of this research. As noted in Chapter 2, paper and “other” material types (i.e., items not made of plastic, aluminum, or glass) were not collected during the first three months of sampling, which means the dominance of plastic is inflated somewhat when comparing material types (Table 4.1); though this inflation is minimal because of the small amounts of paper and other materials, particularly at ordinal scale. However, this had no effect on the analyses involving plastic use types. Additionally, cigarette butts were collected for two months, but the great amount of time and energy expended in their collection led to their exclusion from this study, although it should be mentioned that cigarette butts often make up a high proportion of litter (Action Research, Inc., 2009; MSW Consultants, 2009; Sibley and Liu, 2003).

Further Research

Two basic ways to further extend this research are to increase the number of areas and increase the number of sampling events. Increasing the number of areas would allow for the duplication of litter expectations among areas, which would serve to further support the inferences made about factors affecting litter distributions. Increasing the number of sampling events (i.e., months or even years of data collection) would also increase the temporal depth of data and provide a more representative sample of the variability in littering and stream hydrological processes (e.g., flow regimes) over time.

In order to test the litter policy implications of this framework, additional research should focus on testing the effectiveness of preventive and cleanup strategies. This would require collecting data on litter both before and after the implementation of strategies. Although the areas sampled in this study do receive periodic attention for cleanup, a longer-term study could provide data on weekly, monthly, and annual litter deposition rates. If those rates decrease with implementation and revision of policy, this type of data could provide a measure for determining the success of policies and practices. An additional analysis that could accompany this is a general stream survey along much of the length of Hickory Creek to track where litter is being deposited to provide a more representative spatial sample; this survey could be carried out every three months to see the temporal change over larger sections of the stream than just the areas covered in this study. These data on litter density could be easily mapped and used in policy decisions on litter cleanup strategies. Indeed the temporal and spatial scales can be modified extensively to provide new data that complement those presented in this thesis.

Conclusion

This study represents a fusion of archaeology and litter studies; though, technically speaking, litter studies are often archaeological in nature, even if the researchers are unaware. Archaeology provides the conceptual framework while litter studies provide the subject matter. However, archaeology also provides a temporal perspective that is often missing in litter studies, a perspective that is connected to how we conceive of plastic as a material. Plastic items are designed to be durable, to persist (Stevens, 2002); this is true even for items meant for the trash, like many of the containers and much of the packaging in existence (Barnes et al., 2009). These characteristics of plastic (durability and disposability) create a problem, but most people who use disposable plastics do not seem to recognize the paradox of plastic (it's convenience related to its durability). A general disconnect between the short use-life of plastic (disposability) and its long-term preservation in the environment (durability) exists, which leads many people to adopt an attitude of disposability toward the material. This helps explain the trend of increasing plastic litter over the past 45 years, even though abundance of the other types of litter has decreased (MSW Consultants, 2009).

With this increase in plastic litter comes a potential threat to ecosystems, especially in a marine context. It is generally accepted that between 60 and 80% of the debris in the oceans is plastic (Barnes et al., 2009; Gregory and Ryan, 1997), which means that plastic is *the* primary problem in terms of marine litter. This plastic debris threatens many groups of marine organisms, including many species of seabirds, whales, seals, fish, and sea turtles (Derraik, 2002). Larger items can lead to entanglement and strangulation, while smaller items can become ingested and lead to starvation (Derraik, 2002; Laist, 1997). The oceans represent the ultimate endpoint for plastic litter, but solving the problem from that endpoint is difficult because plastic is highly mobile once entrained in ocean currents, which leads to a high diffusion from the input source (Hammer, Kraak, and Parsons, 2012; Sheavly and Register, 2007). Any relatively large body of water, such as Lake Lewisville into which Hickory Creek flows (Fig. 4.3), could present similar problems of diffusion, albeit at a smaller scale. In this situation, preventive measures that focus on the sources of litter are the only way to reduce the overall flow of new debris into these systems. One way this can be done is to target the rivers and streams that lead to these large-scale endpoints, rather than just targeting the endpoint itself.

Table 1.1
Land use distribution in the Hickory Creek watershed[a]

Land Use	**Drainage Area (acres)**
Urban	29,447
Agriculture	38,998
Rangeland	45,734
Forest	9,182
Water	1,109
Total	124,470

[a] Reprinted from Banks et al. (2008)

Table 1.2

Site exposure and stream gradient characteristics

Site Name (abbr)	Rank Along Stream Gradient[a]	Bridge Site?	Recreational Uses	Site Parallel or Perpendicular to Road	Exposure Expectations[b]	Relative Amount of Litter[c]
Country Club Road (CCR)	1	Yes	Some fishing	Parallel	Vh; Pd	High
Hickory Creek Dump (HCD)	2	No	Some fishing	Parallel	Vh; Pd	High
McNair (McN	3	Yes	Hiking	Perpendicular	Hd; Pd	Low
Old Alton (OA)	4	Yes	Fishing; Hiking	Perpendicular	Pd; Hd	Med

[a] Traveling from upstream to downstream

[b] Ranked from highest to lowest expectation. Pd = pedestrian littering; Hd = hydrological deposition; Vh = vehicle littering

[c] Based on a general ranking of total litter found at each site

Table 2.1

Site exposure and stream gradient characteristics

Site Name (abbr)	Rank Along Stream Gradient[a]	Bridge Site?	Recreational Uses	Site Parallel or Perpendicular to Road	Exposure Expectations[b]	Relative Amount of Litter[c]
Country Club Road (CCR)	1	Yes	Some fishing	Parallel	Vh; Pd	High
Hickory Creek Dump (HCD)	2	No	Some fishing	Parallel	Vh; Pd	Med
McNair (McN	3	Yes	Hiking	Perpendicular	Hd; Pd	Low
Old Alton (OA)	4	Yes	Fishing; Hiking	Perpendicular	Pd; Hd	Med

[a] Traveling from upstream to downstream

[b] Ranked from highest to lowest expectation. Pd = pedestrian littering; Hd = hydrological deposition; Vh = vehicle littering

[c] Based on a general ranking of total litter found at each site

Table 2.2
Land use distribution in the Hickory Creek watershed[a]

Land Use	Drainage Area (acres)
Urban	29,447
Agriculture	38,998
Rangeland	45,734
Forest	9,182
Water	1,109
Total	124,470

[a] Reprinted from Banks et al. (2008)

Table 2.3
Most common items collected for each plastic use type category[a]

BEV[b] (%)[c]	PACK (%)	F/D ACC (%)	BAG (%)	OTH (%)
Styrofoam cup (31%)	Candy wrapper (18%)	Straw (35%)	Grocery bag (33%)	Surveyor's tape (6%)
Water bottle (29%)	Cigarette package wrapper (12%)	Fountain drink lid (29%)	Garbage bag (8%)	Tobacco dip can (5%)
Soda bottle (8%)	Chip bag (7%)	Cutlery (6%)		Fishing float (3%)

[a] Only includes identifiable items

[b] BEV = beverages; PACK = packaging; F/D ACC = food/drink accessories; BAG = bags; OTH = other items

[c] Percentage listed under each item is out of the total for that category

Table 2.4
Material type pollution profile by area[a]

	CCR	HCD	McN	OA	Total
Plastic	429 (84%)[b]	215 (82)	91 (87)	219 (74)	954 (81)
Aluminum	63 (12)	24 (9)	10 (10)	50 (17)	147 (13)
Glass	21 (4)	23 (9)	4 (4)	25 (9)	73 (6)
Total	513 (100%)	262 (100)	105 (100)	294 (100)	1174 (100)
IQV	.43	.47	.36	.61	.48

[a] Excludes mixed M. types, and "paper" and "other" categories.

[b] Percentage of total per site in parentheses, rounded to the nearest whole number

Table 2.5
Descriptive statistics for between-area analyses.

Test Variable	Area	Median	IQR[a]	Months
Litter Density	CCR	.44	.31	8
	HCD	.81	.58	8
	McN	.09	.11	8
	OA	.25	.14	8
BBI[b]	CCR	.73	.13	8
	HCD	.80	.34	8
	McN	.62	.43	8
	OA	.92	.10	8
ABI	CCR	.57	.30	8
	HCD	.63	.47	8
	McN	.30	.50	8
	OA	.78	.32	8
PGI	CCR	.97	.05	8
	HCD	.92	.13	8
	McN	1.00	.11	8
	OA	.89	.14	8

[a] IQR = Interquartile range

[b] BBI = beverage-bag index; ABI = aluminum-bag index; PGI = plastic-glass index

Table 2.6
Test results for between-area analyses.

Test Type	Test Variable[a]	Test Stat	p value[b]	Sig. Difference
Kruskal-Wallis	Litter density	24.82	< .001*	CCR – McN; HCD – McN; HCD – OA
Kruskal-Wallis	BBI	9.905	.019*	McN – OA
Kruskal-Wallis	ABI	11.372	.01*	McN – OA
Kruskal-Wallis	PGI	8.012	.046*[c]	-
Spearman's rho	BBI-ABI	.779	< .001*	-

[a] BBI = beverage-bag index; ABI = aluminum-bag index; PGI = plastic-glass index

[b] * denotes significance to the .05 level

[c] Difference overall is marginally significant, but no significant pairwise comparisons

Table 2.7

Plastic use type pollution profile by area[a]

	CCR	HCD	McN	OA	Total
BEV	133 (32%)[b]	70 (34)	18 (19)	105 (50)	326 (35)
PACK	107 (25)	44 (22)	22 (24)	32 (15)	205 (22)
F&D ACC	86 (20)	40 (20)	9 (10)	23 (11)	158 (17)
BAG	46 (11)	17 (8)	20 (22)	12 (6)	95 (10)
OTHER	48 (11)	32 (16)	24 (26)	40 (19)	144 (16)
Total	420 (100%)	203 (100)	93 (100)	212 (100)	928 (100)
IQV	.96	.95	.98	.85	.96

[a] Excludes unidentifiable plastic items, whether through extensive fragmentation or unknown nature of object; includes mixed M. types that contain plastic

[b] Percentage of total per site in parentheses, rounded to the nearest whole number

Table 3.1

Descriptive statistics for between-site litter density analyses.

Area	Site	Median	IQR[a]	Months
CCR	Upstr	.15	.23	8
	Downstr	.66	.64	8
	Sep. Downstr	.50	.47	8
McN	Upstr	.10	.08	8
	Downstr	.08	.36	8
	Sep. Downstr	.05	.07	8
OA	Upstr	.21	.29	8
	Downstr	.42	.24	8
	Sep. Downstr	.03	.07	8

[a] IQR = Interquartile range

Table 3.2
Test results for between-site analyses.

Test Type	Test Variable	Test Stat	p value[a]	Sig. Difference
Kruskal-Wallis	Litter density CCR	11.964	.003*	U – D; U – SD[b]
Kruskal-Wallis	Litter density McN	2.512	.285	-
Kruskal-Wallis	Litter density OA	5.398	.067	-
Spearman's rho	Density-burial	-.85	.004*	-
Spearman's rho	%bag-burial	.883	.002*	-
Spearman's rho	%beverage-burial	-.75	.02	-

[a] * denotes significance to the .05 level

[b] U = upstream; D = downstream; SD = separate downstream

Table 3.3
Index of qualitative variation (IQV) across sites within areas

	CCR[a]	McN	OA
Upstr	.94	.98	.74
Downstr	.95	.99	.84
Sep. Downstr	.94	.86	.99

[a] CCR = Country Club Road; McN = McNair; OA = Old Alton

Table 4.1
Material type pollution profile by area[a]

	CCR	HCD	McN	OA	Total
Plastic	429 (84%)[b]	215 (82)	91 (87)	219 (74)	954 (81)
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IQV	.43	.47	.36	.61	.48

[a] Excludes mixed M. types, and "paper" and "other" categories.

[b] Percentage of total per site in parentheses, rounded to the nearest whole number

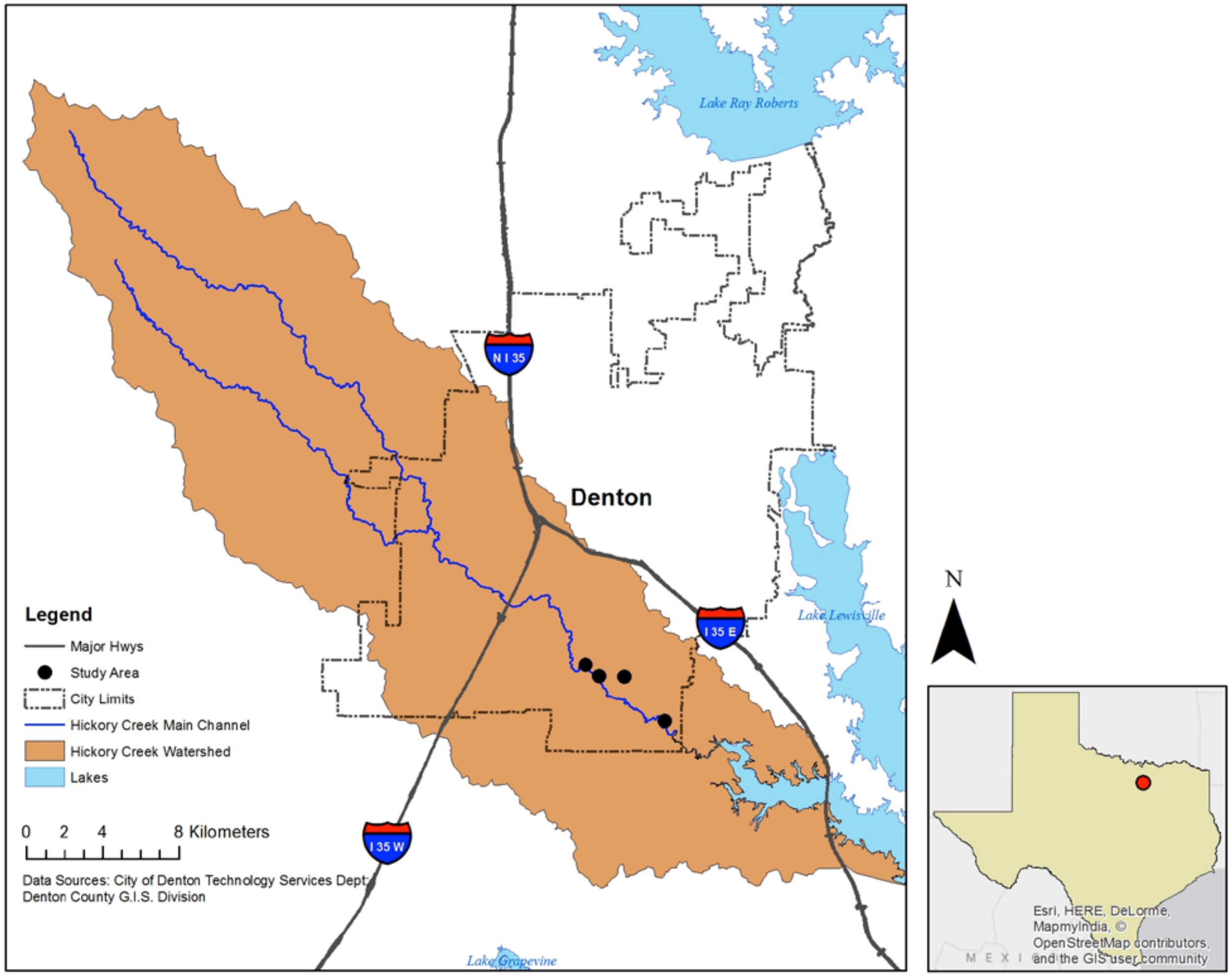


Fig. 1.1. Location of Hickory Creek watershed in northeast Texas. This watershed covers much of the southern end of the City of Denton, which is primarily rural and suburban. Hickory Creek empties into Lake Lewisville near the southeastern edge of the map. The four study areas were placed near the mouth of the creek.

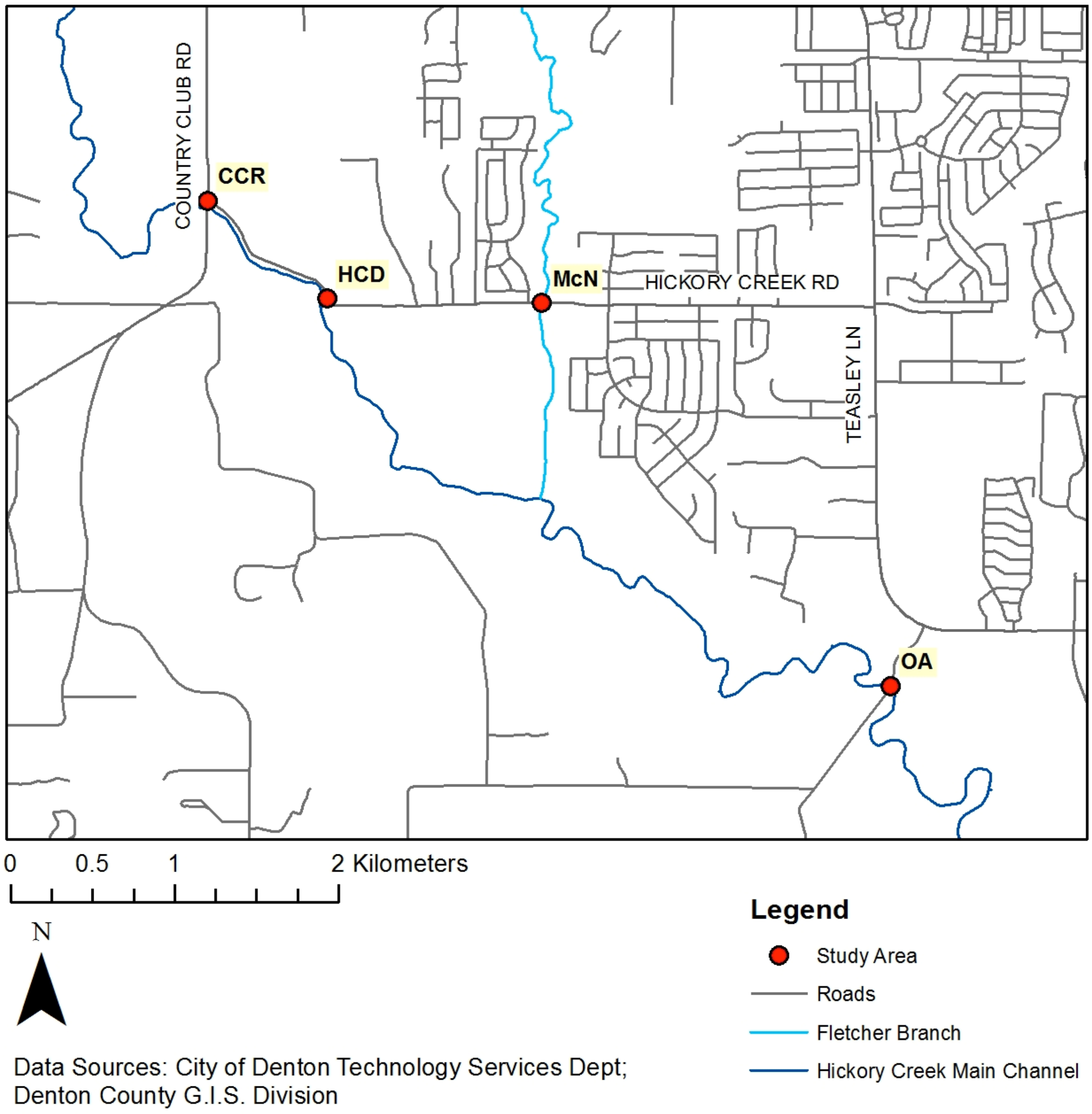


Fig. 1.2. Overview of placement of study areas in relation to one another. Traveling from upstream to downstream, the areas (in order) are: Country Club Road (CCR), Hickory Creek Dump (HCD), McNair (McN), and Old Alton (OA).

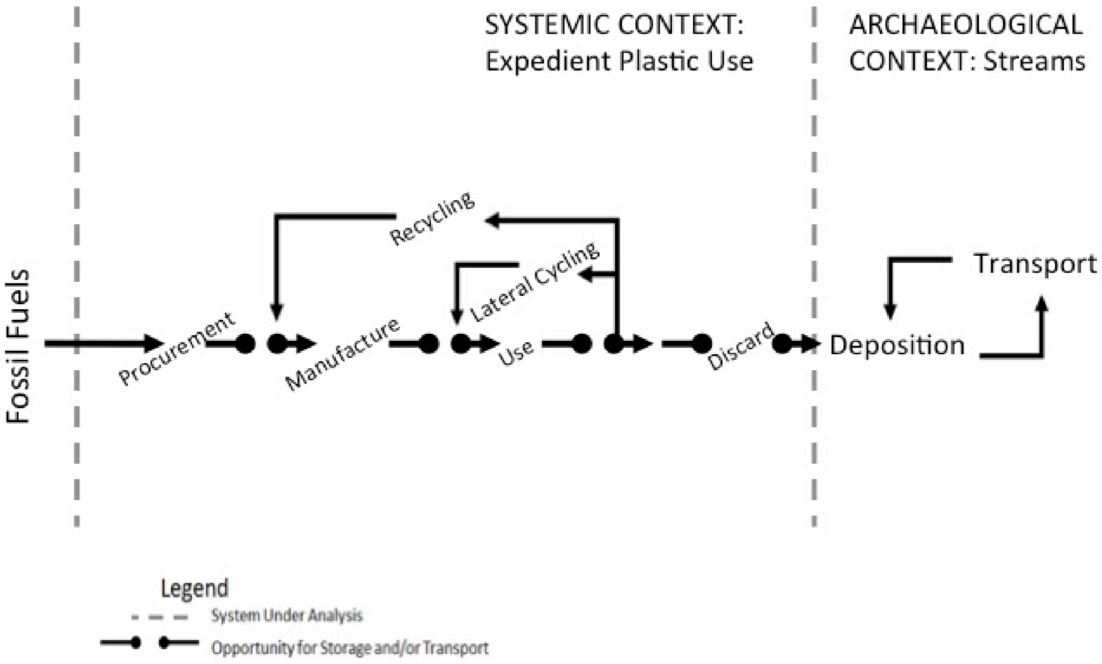


Fig. 1.3. Life cycle model for plastic artifacts, demonstrating the conceptual divide between the systemic and archaeological contexts. In the present study, the act of littering represents this transition from the systemic to the archaeological. Once a piece of litter enters the archaeological context (the stream), it becomes part of the sediment transport cycle, where streamflow will entrain, transport and deposit items based on the stream's discharge and the characteristics of the item (e.g., buoyancy). The ultimate goal of this approach is to make inferences about the systemic context from remains in the archaeological context (reprinted from Schiffer 1972).

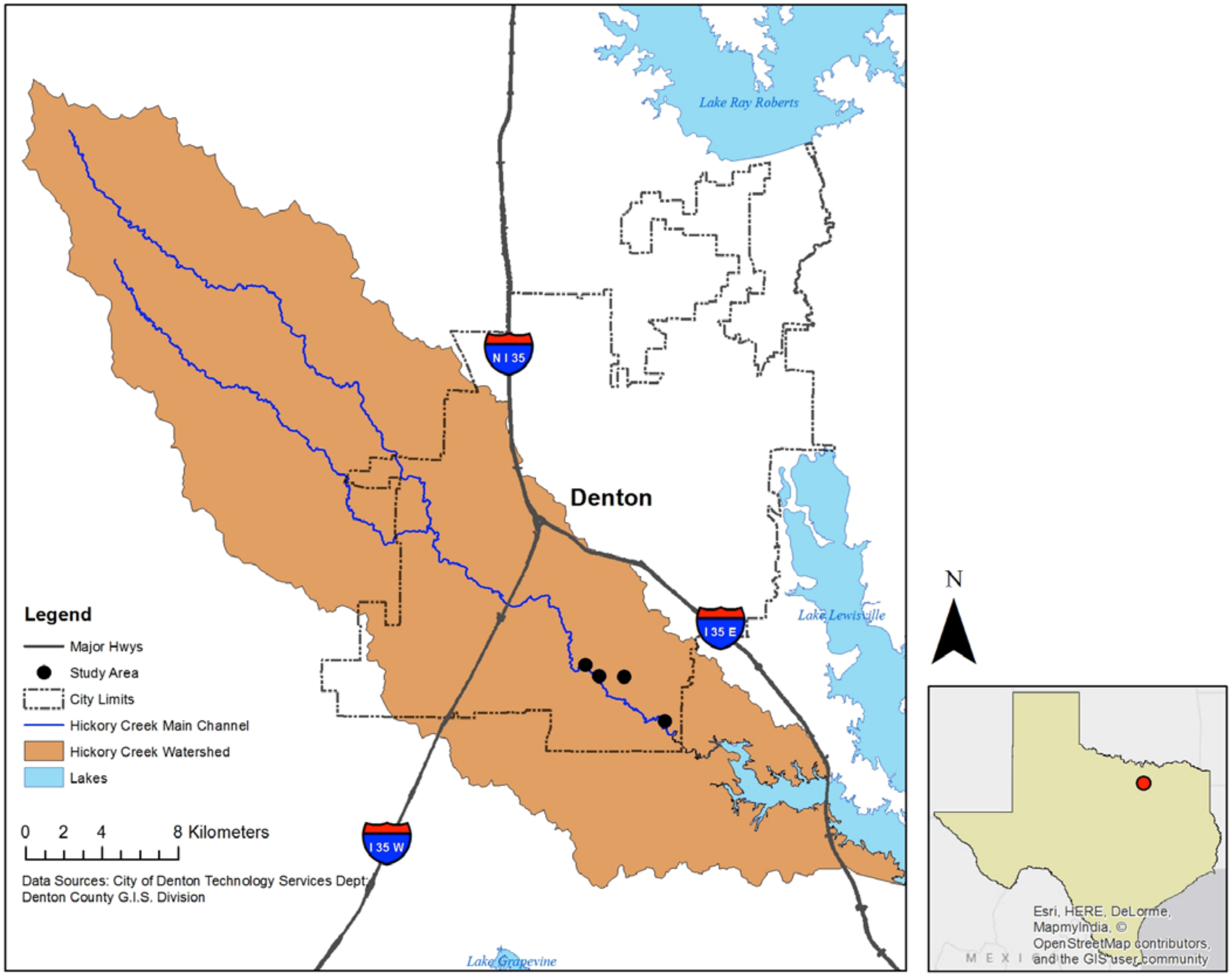
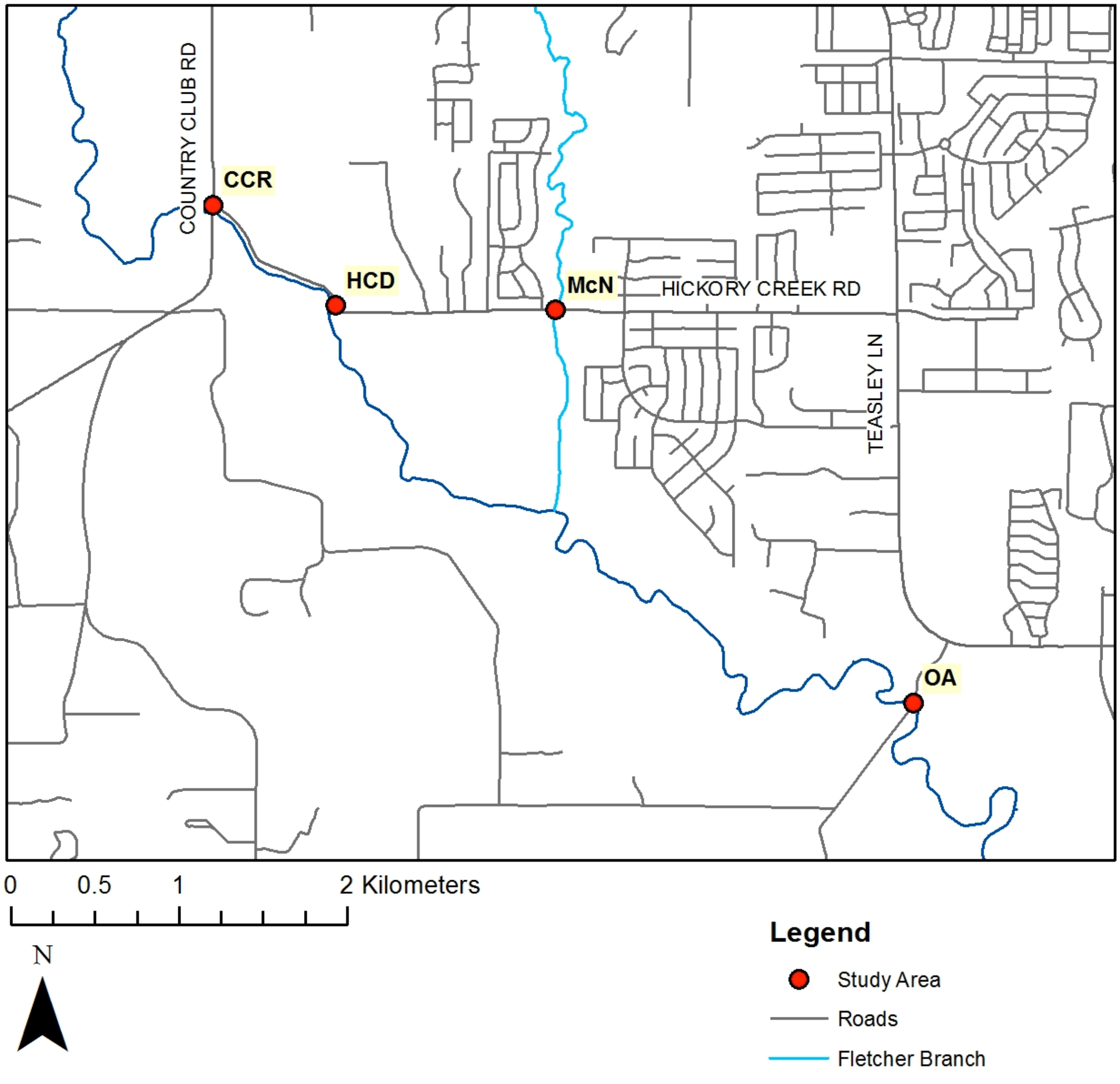


Fig. 2.1. Location of Hickory Creek watershed in northeast Texas. This watershed covers much of the southern end of the City of Denton, which is primarily rural and suburban. Hickory Creek empties into Lake Lewisville near the southeastern edge of the map. The four study areas were placed near the mouth of the creek.



Data Sources: City of Denton Technology Services Dept;
Denton County G.I.S. Division

Fig. 2.2. Overview of placement of study areas in relation to one another. Traveling from upstream to downstream, the areas (in order) are: Country Club Road (CCR), Hickory Creek Dump (HCD), McNair (McN), and Old Alton (OA).

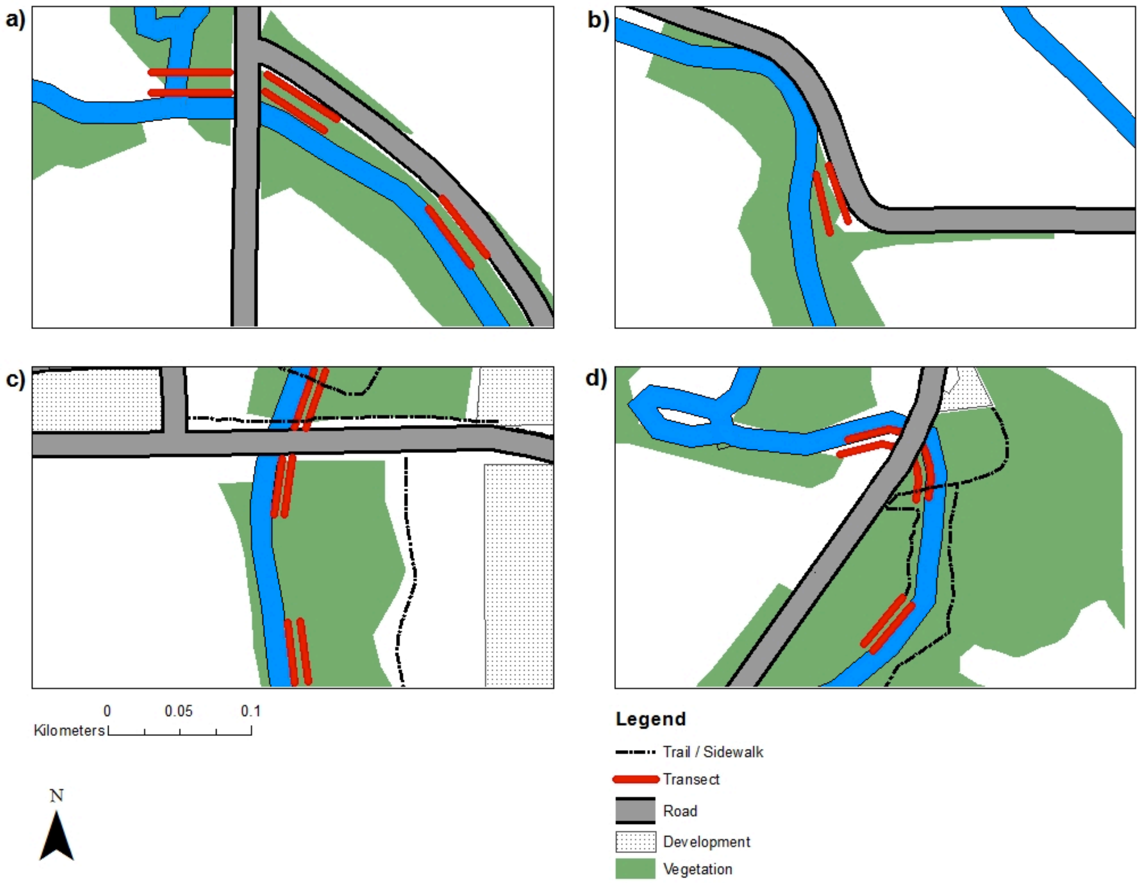


Fig. 2.3. Diagram of transect placement for each area on Hickory Creek. a) Country Club Road is the furthest upstream area, and is heavily exposed to roads. b) Hickory Creek Dump is the next area traveling downstream, and was chosen based on the location of an illegal dumping area nearby. c) McNair is located on a tributary of the main channel (Fletcher Branch), at the southern edge of the Lake Forest Park of the City of Denton; the northern transects are bounded on either side by housing developments. d) Old Alton is the furthest downstream area and is used as a recreational site for fishing and hiking; unpaved trails following parallel to the stream give pedestrians access to downstream areas of the area, although fishing has also been observed around the upstream transects as well.

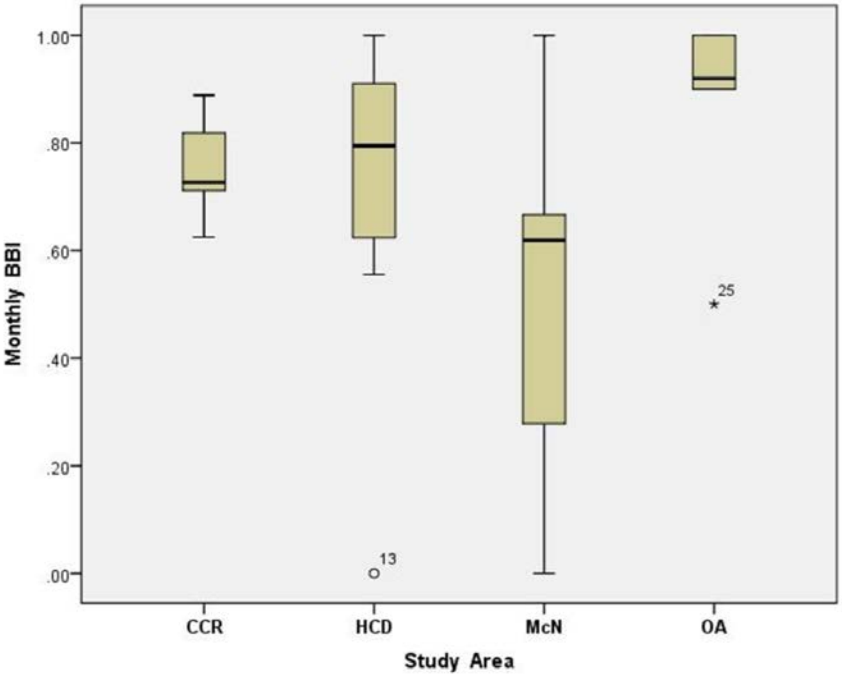


Fig. 2.4. Boxplots of monthly beverage-bag index (BBI) scores across areas. A BBI score of 1.00 indicates only beverages, no bags for that month, and a score of .00 indicates only bags, no beverages.

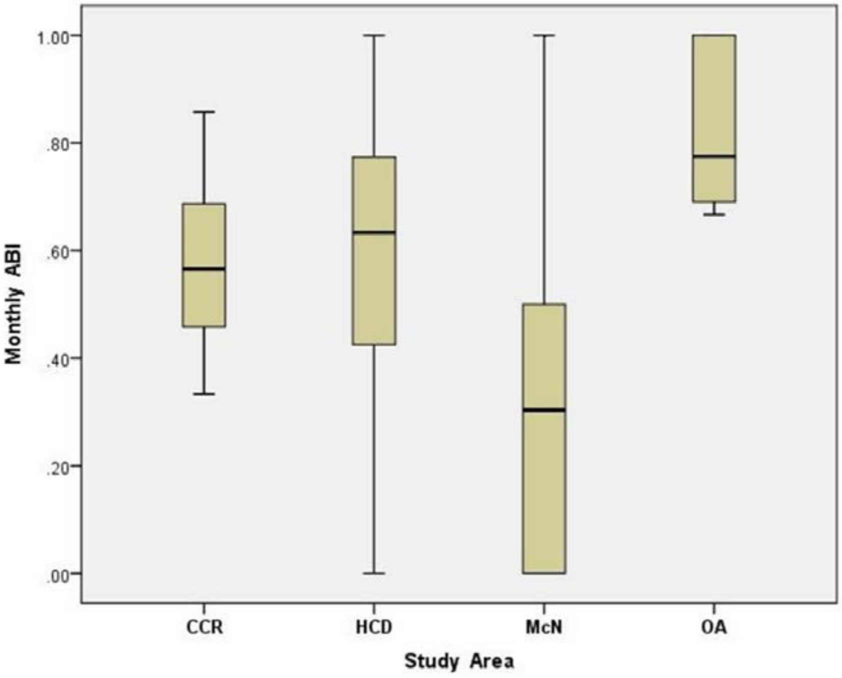


Fig. 2.5. Boxplots of monthly aluminum-bag index (ABI) scores across areas. An ABI score of 1.00 indicates only aluminum, no bags for that month, and a score of .00 indicates only bags, no aluminum.

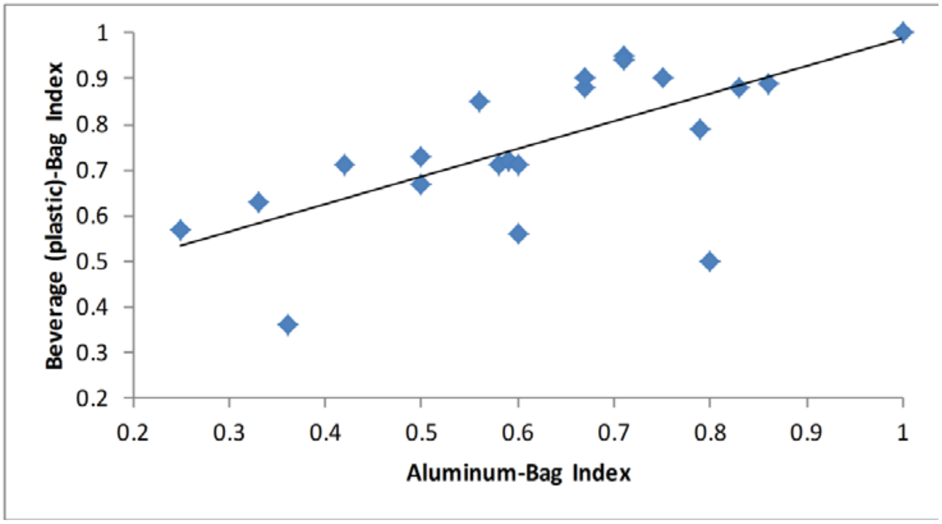


Fig. 2.6. Scatterplot diagram of the beverage-bag index and aluminum bag index. Each data point represents an area's score for a specific month. A significant correlation was found using Spearman's rho.

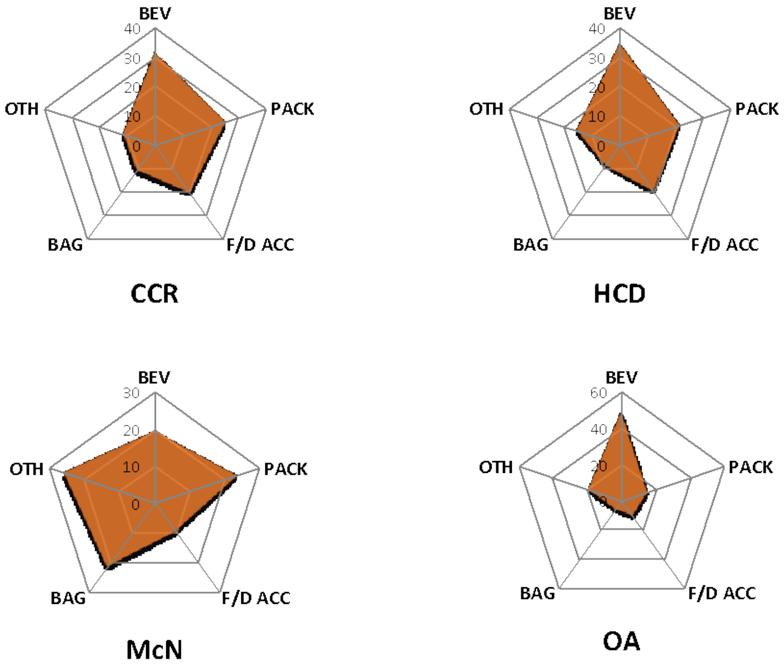


Fig. 2.7. Radar charts of plastic use type proportions among areas. The proportion increases the further the line is from the center of the diagram, and the area for each study area equals 100%. BEV is beverages, PACK is packaging, F/D ACC is food/drink accessories, BAG is bags, and OTH is other items.

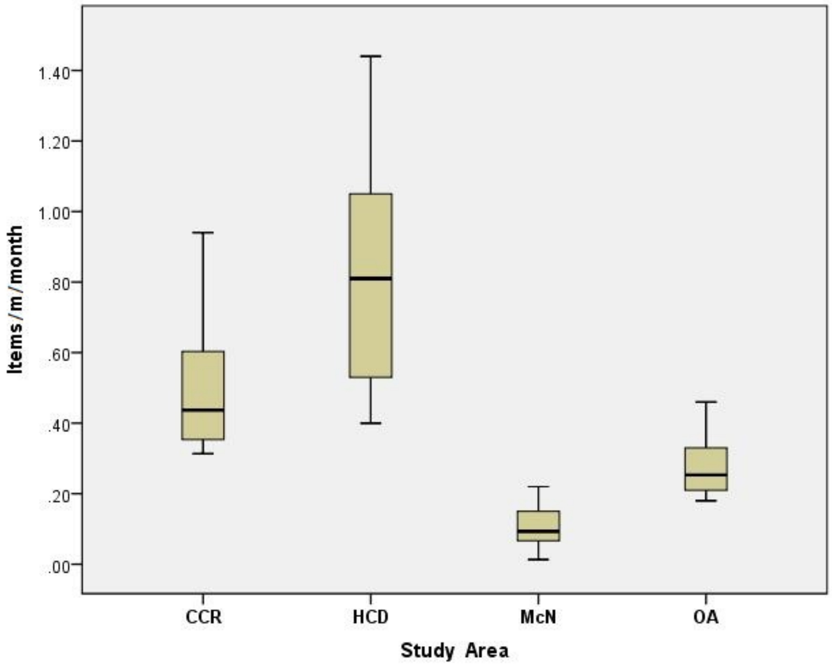


Fig. 2.8. Boxplots of litter density between areas. Litter density is measured as the number of items per meter per month. CCR is Country Club Road, HCD is Hickory Creek Dump, McN is McNair, and OA is Old Alton. The Kruskal-Wallis results indicate that CCR and HCD belong in a different group than McN and OA, which can be traced to the road that runs parallel to both CCR and HCD.

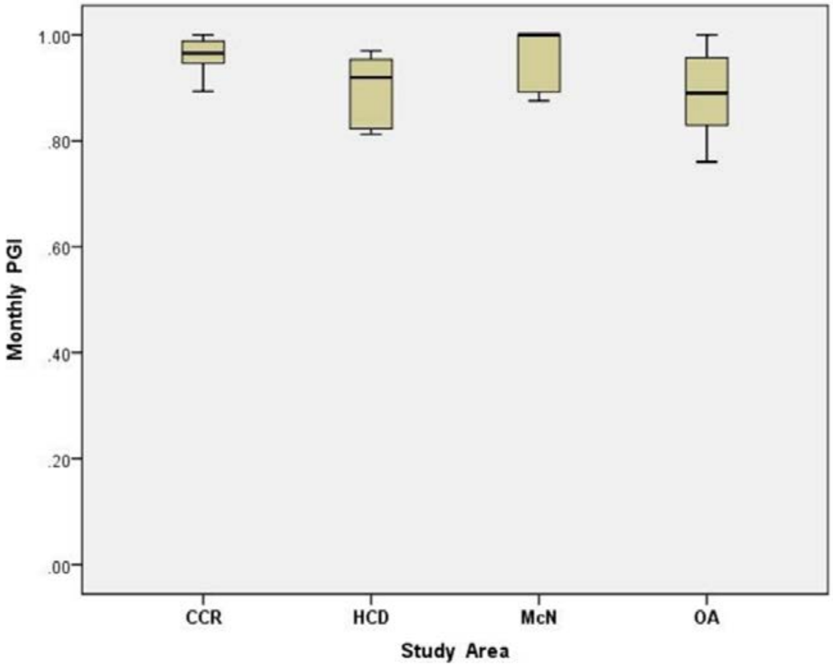
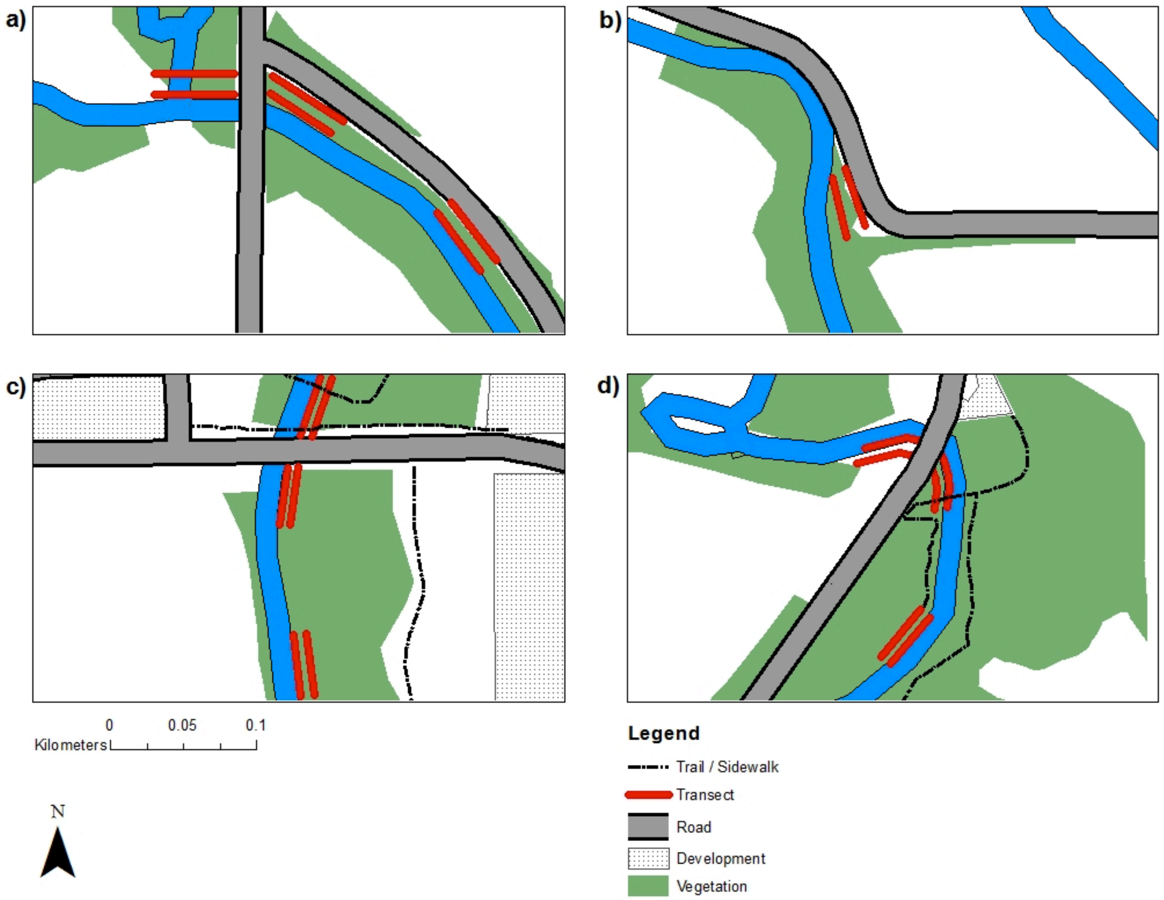


Fig. 2.9. Boxplots of monthly plastic-glass index (PGI) scores across areas. A PGI score of 1.00 indicates only plastic, no glass for that month, and a score of .00 indicates only glass, no plastic.



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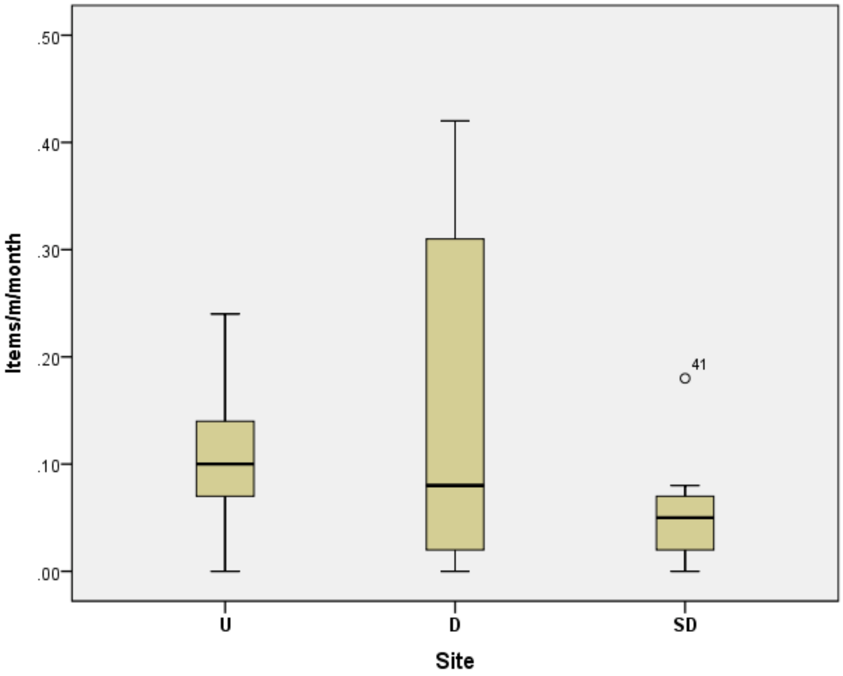


Fig. 3.2. Boxplots of litter density between sites within McNair. Litter density is measured as the number of items per meter per month. U is upstream, D is downstream, and SD is separate downstream. No significant Kruskal-Wallis results were observed.

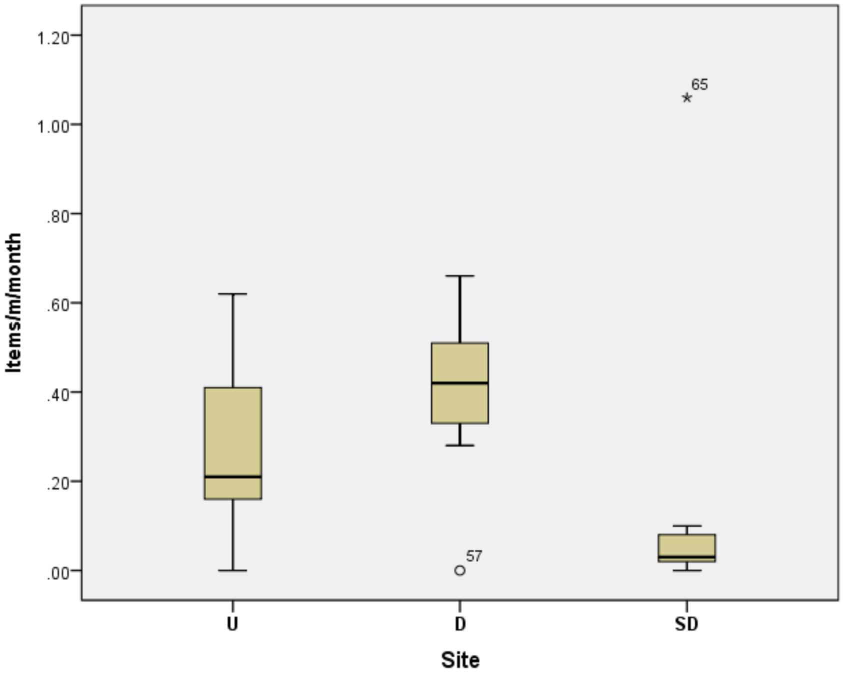


Fig. 3.3. Boxplots of litter density between sites within Old Alton. Litter density is measured as the number of items per meter per month. U is upstream, D is downstream, and SD is separate downstream. No significant Kruskal-Wallis results were observed.

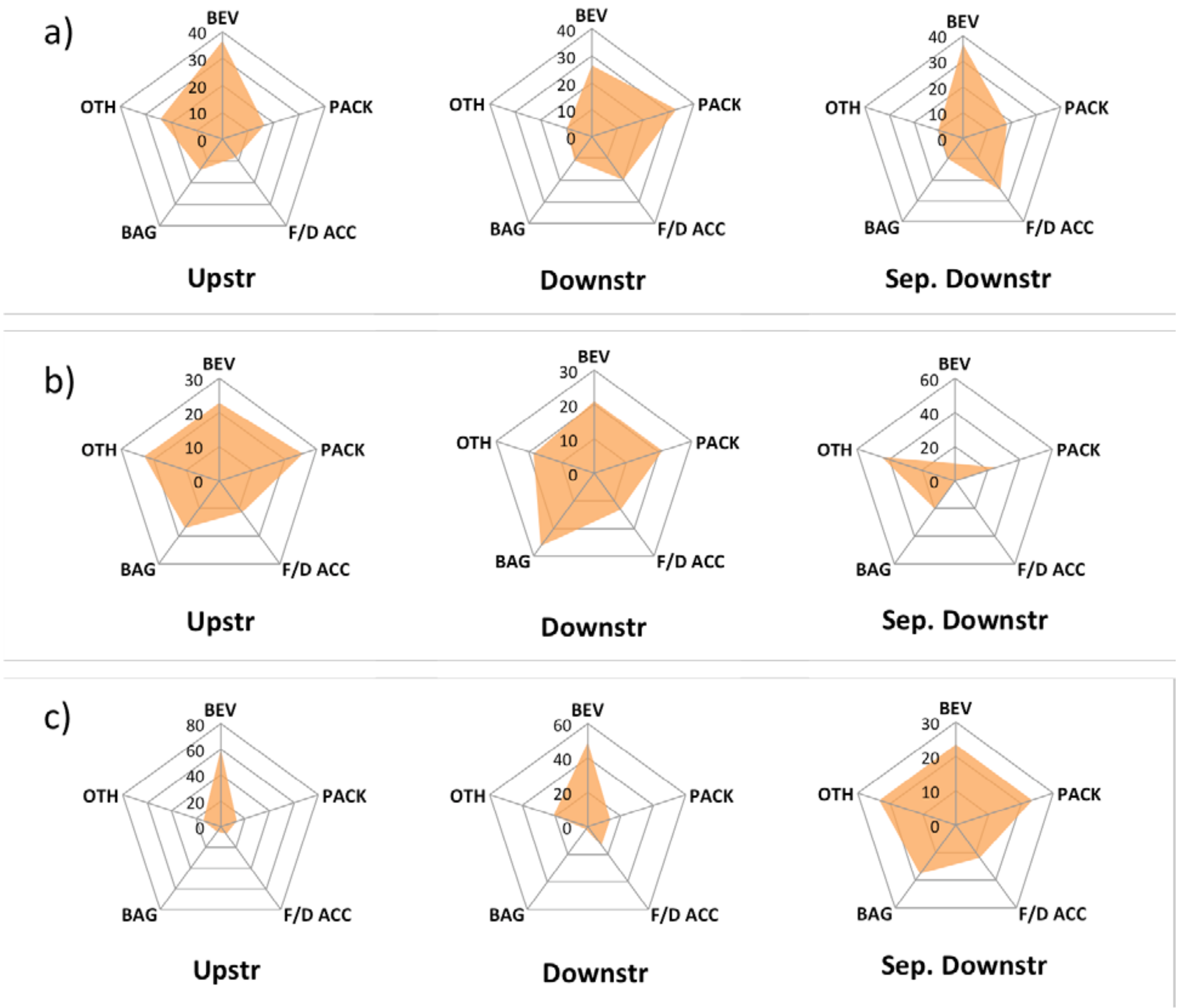
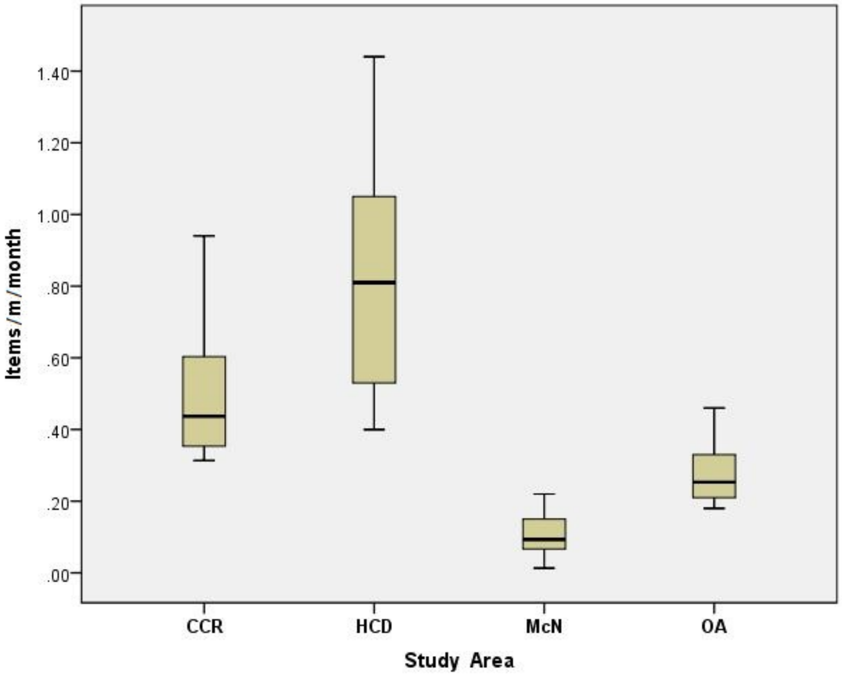


Fig. 3.4. Radar charts of plastic use type proportions among sites within areas. The proportion increases the further the line is from the center of the diagram, and the area for each study area equals 100%. BEV is beverages, PACK is packaging, F/D ACC is food/drink accessories, BAG is bags, and OTH is other items. a) Country Club Road; b) McNair; c) Old Alton.



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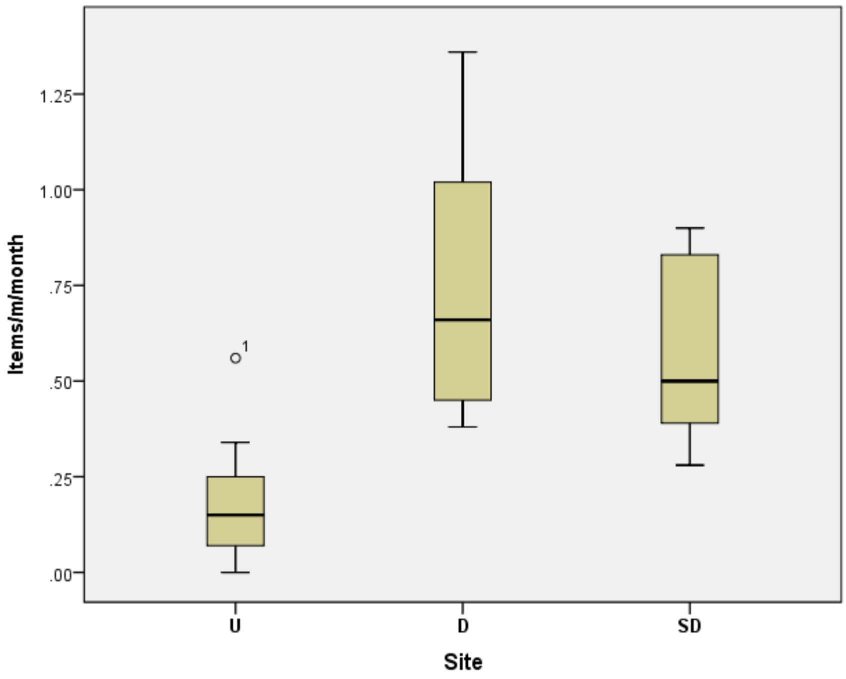


Fig. 3.6. Boxplots of litter density between sites within Country Club Road. Litter density is measured as the number of items per meter per month. U is upstream, D is downstream, and SD is separate downstream. The Kruskal-Wallis results indicate that the upstream site is significantly different from both the downstream and separate downstream site.

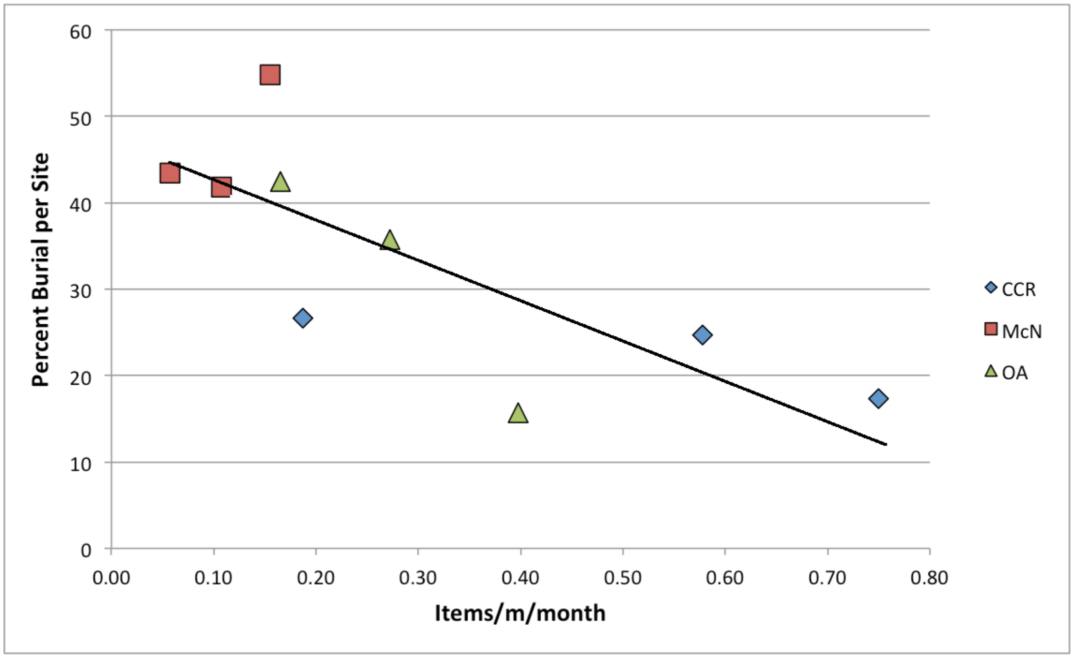


Fig. 3.7. Scatterplot diagram of burial percent and density for each site. Each shape represents a different study area, and each data point is a different site within that area. A significant correlation was found using Spearman's rho.

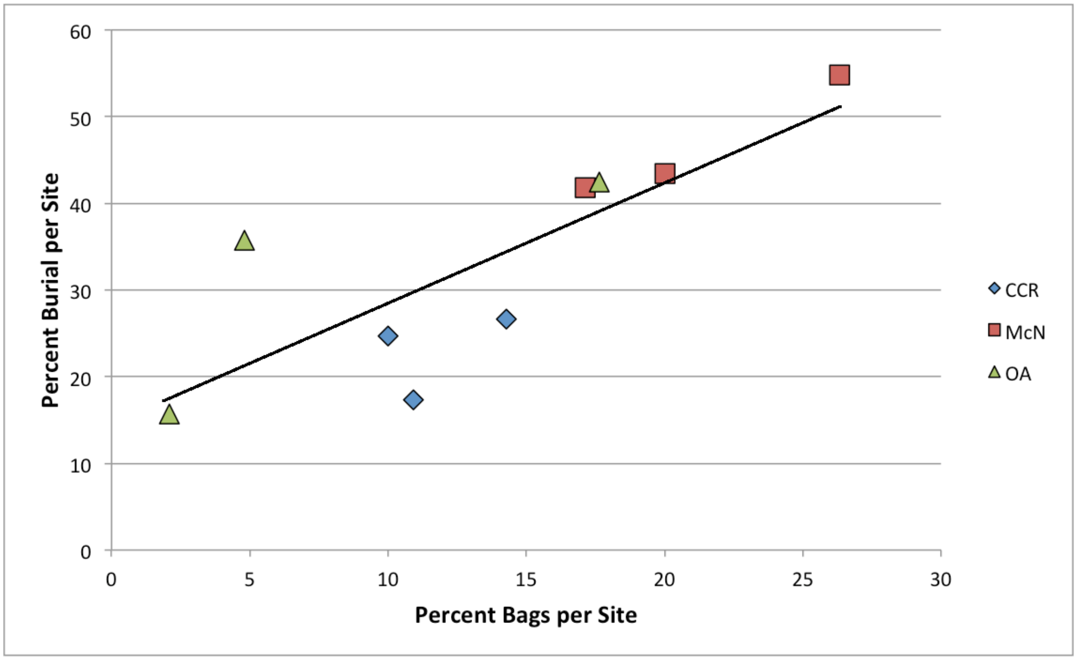


Fig. 3.8. Scatterplot diagram of burial percent and percent bags for each site. Each shape represents a different study area, and each data point is a different site within that area. A significant correlation was found using Spearman's rho.

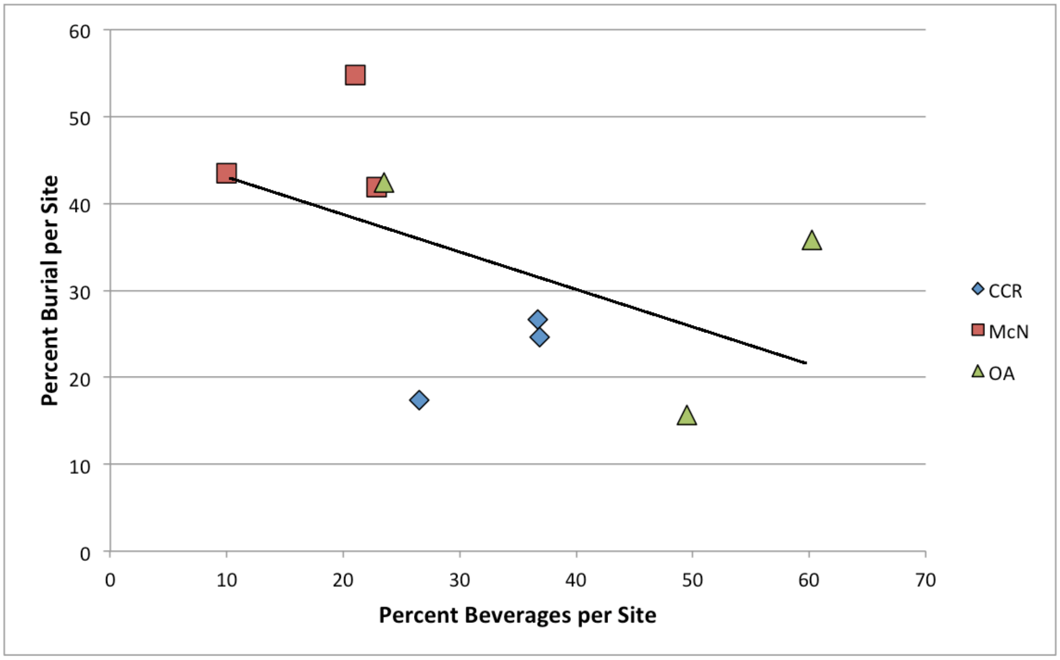


Fig. 3.9. Scatterplot diagram of burial percent and percent beverages for each site. Each shape represents a different study area, and each data point is a different site within that area. A significant correlation was found using Spearman's rho.

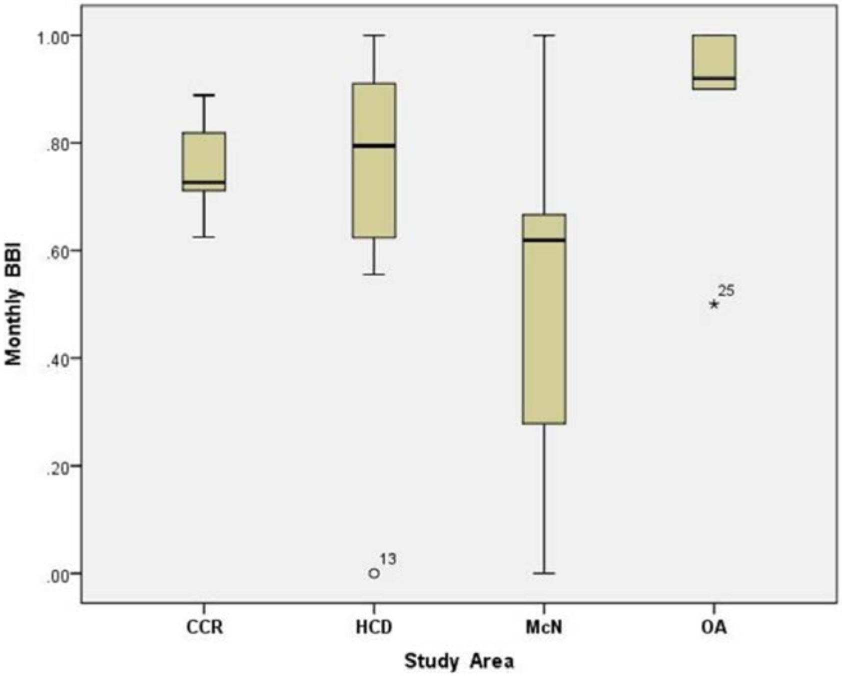


Fig. 4.1. Boxplots of monthly beverage-bag index (BBI) scores across areas. A BBI score of 1.00 indicates only beverages, no bags for that month, and a score of .00 indicates only bags, no beverages.

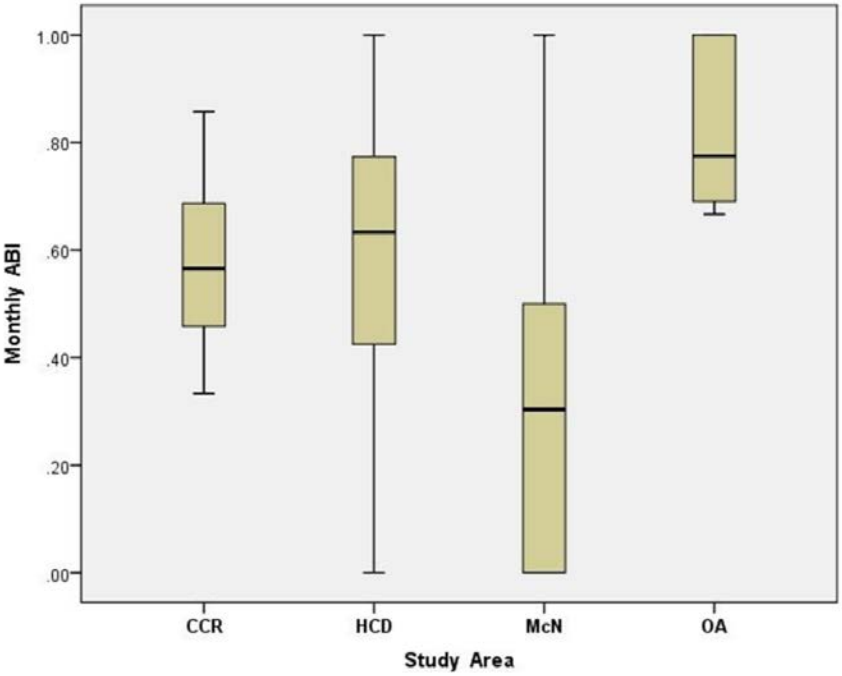
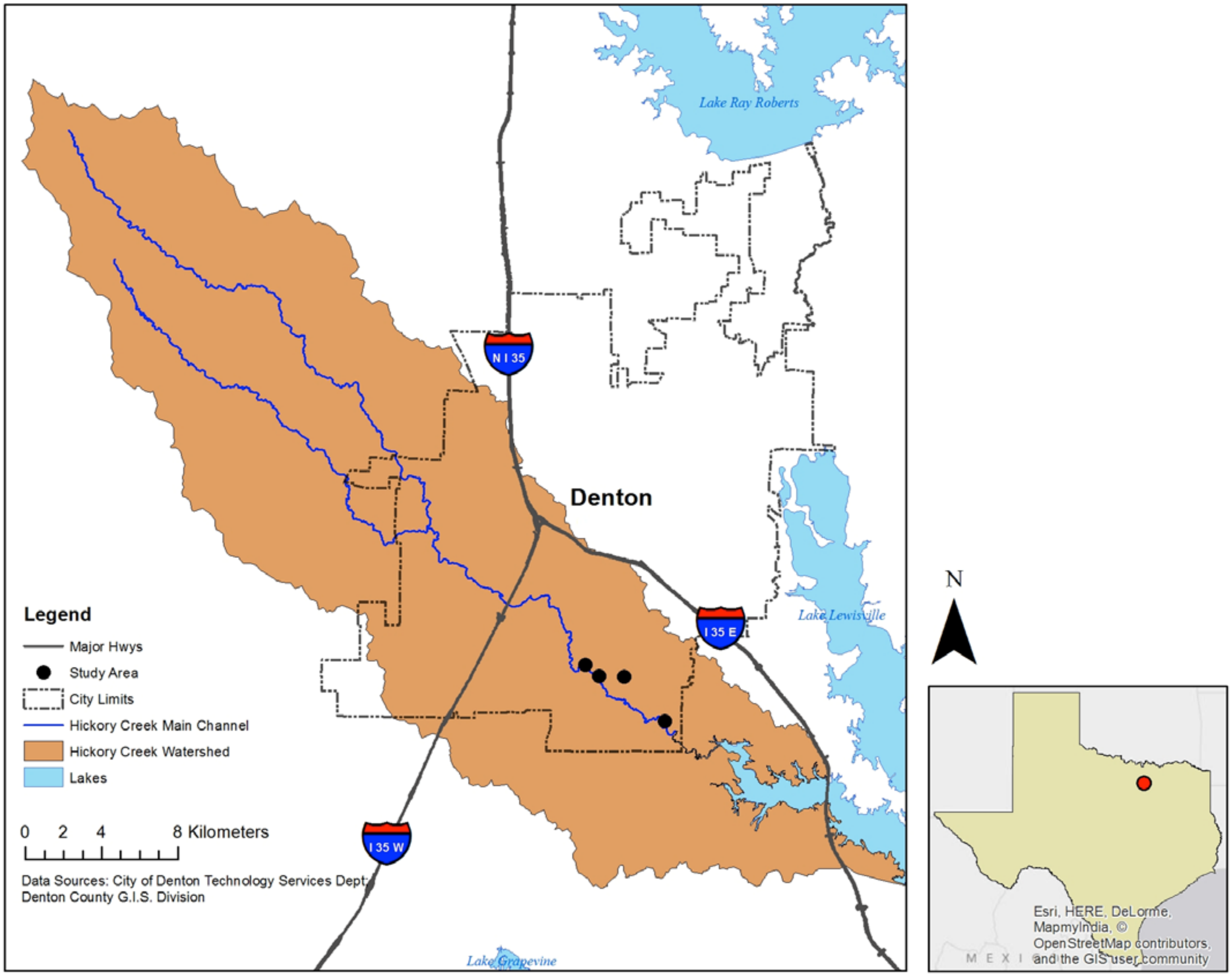


Fig. 4.2. Boxplots of monthly aluminum-bag index (ABI) scores across areas. An ABI score of 1.00 indicates only aluminum, no bags for that month, and a score of .00 indicates only bags, no aluminum.



Data Sources: City of Denton Technology Services Dept; Denton County G.I.S. Division

Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

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APPENDIX

SAMPLE FIELD SHEET

Date ______________
Site ______________
Month ______________

Exposed/Partially Buried
1=EX
2=PB

Whole/Fragmented
1=whole
2=frg

Use Type
WB (water bottle)
OB (other beverage)
FD (food/drink accessory)
PA (packaging)
BG (bag)
OT (other)

Area	Transect	Material	EX/PB	Whole/Frg	Use Type	Resin Code	Notes

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