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Soft Tissue Decomposition of Submerged, Dismembered Pig Limbs Enclosed in Plastic Bags*

ABSTRACT: This study examines underwater soft tissue decomposition of dismembered pig limbs deposited in polyethylene plastic bags. The research evaluates the level of influence that disposal method has on underwater decomposition processes and details observations specific to this scenario. To our knowledge, no other study has yet investigated decomposing, dismembered, and enclosed remains in water environments. The total sample size consisted of 120 dismembered pig limbs, divided into a subsample of 30 pig limbs per recovery period (34 and 71 days) for each treatment. The two treatments simulated non-enclosed and plastic enclosed disposal methods in a water context. The remains were completely submerged in Lake Ontario for 34 and 71 days. In both recovery periods, the non-enclosed samples lost soft tissue to a significantly greater extent than their plastic enclosed counterparts. Disposal of remains in plastic bags therefore results in preservation, most likely caused by bacterial inhibition and reduced oxygen levels.

KEYWORDS: forensic science, forensic anthropology, taphonomy, soft tissue decomposition, aqueous environment, plastic bags, submersion, dismemberment

Submersion and enclosed environments, whether natural or man-made, slow decomposition due to low temperatures and the retardation of oxidative processes (1). Forensic studies related to water environments involve single bone fluvial transport, the effects of water depth and sediment on decomposition, processes of disarticulation, entomology, invertebrate succession, individual cases, and adipocere formation (2–18). This study examines underwater soft tissue decomposition of dismembered pig limbs deposited in plastic bags. The research evaluates the level of influence that disposal method has on underwater decomposition processes and details observations specific to this scenario. It is hypothesized that soft tissue remains enclosed in plastic will experience a decreased level of decomposition compared with the decomposition of soft tissue remains not enclosed in plastic. To our knowledge, no other study has yet investigated decomposing, dismembered, and enclosed remains in water environments. ''Enclosure'' in this context refers to the deposition of soft tissue remains in a manner that causes protection from the external environment. In this study, plastic polyethylene bags were utilized.

Decomposition rates depend on the extent of internal and external environmental interactions experienced by a decomposing body, as influenced by body disposal method (1). The external environment is regularly comprised of the local area's flora, fauna, and microbiota (1). In water environments, fish, turtles, and crustaceans may either remove flesh from underwater corpses or feed on bodily fluids (1). The following factors affect the progress of decomposition in water and can be easily altered by disposal method: clothing, perimortem trauma, access to the water surface, energy of water movement, biodiversity, floor substrate and geology, body weight, water and air temperature, moisture, pH, partial pressure of O_2 and other gases, and the local chemical environment (1,8,18,19). By depositing remains in plastic bags, the enclosed environment inhibits bacterial action and slows tissue degradation, resulting in artifactual preservation. Artifactual preservation refers to body or tissue preservation via the action of chemical substances or the destruction of bacteria, often resulting in the false impression of a short postmortem interval (20). Bodies tightly wrapped in plastic or synthetic fabrics, for example, are regularly associated with high levels of tissue preservation (21).

In 2004, Anderson and Hobischak (8) conducted a study comparing the decomposition of submerged pig carcasses in the following environments: marine, shallow; marine, deep; freshwater, standing; freshwater, running; terrestrial coastal western Hemlock Zone. The study affirmed that remains decomposing in an aquatic environment tend to bloat, shed hair, slough skin, form adipocere, and accumulate algae (8–12). Signs of lividity, skin marbling, flesh decay, silting, and algal bone staining may also occur (8–12). Cases of extensive decomposition end in bone disarticulation and internal organ exposure (8–12).

Remains in terrestrial environments undergo specific stages of decomposition: fresh, bloat, active decay, advanced dry, or remains (13). These stages are discrete yet slightly modified in remains decomposing in freshwater (8,10,11). In contrast, remains decomposing in marine environments often exhibit bloat, active, and advanced decay stages simultaneously (8). Remains decomposing in either freshwater or marine environments experience a longer bloat stage than remains decomposing on land since Calliphoridae larvae (Diptera: Calliphoridae) do not penetrate the carcass (8,13). Marine bound remains also accumulate a great deal of intestinal gases, permitting bloat and flotation. Freshwater remains tend to appear bloated for several weeks after the true bloat stage due to tissue hardening caused by adipocere formation (8). Although adipocere formation commonly forms on remains in both marine

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and freshwater environments, the time period required for adipocere to form is extremely variable (4,6,8,10–12).

As this study specifically focuses on dismemberment and a particular type of disposal method, it is most representative of a situation involving homicide and subsequent body deposition. On a national level, the number of homicides in Canada increased in 2004 by 13% and then rose an additional 4% in 2005, from 624 to 658 homicides, respectively (22). According to S. Sgt. John Badowski (personal communication, 2008) of the Toronto Police Service Marine Unit, cases involving dismemberment and plastic bag deposition in Lake Ontario are infrequent, occurring roughly once per year. Although this scenario is not a common occurrence in Lake Ontario, the increasing rate of homicide in Canada (22) and the proximity of inhabited areas to fresh water throughout the country suggest that a growing number of homicides will involve water deposition and variations found therein. Similarly, the higher rates of homicide in the United States, and the proximity of major city centers to bodies of water, suggests the results of this analysis will prove useful to police agencies around the world.

Methods

The sample consisted of 120 dismembered pig (*Sus scrofa* L.) limbs, divided into subsamples of 30 pig limbs per recovery period for each treatment. The sample consists of 40 pig limbs—cut in half with a hacksaw—and an additional 40 hocks purchased from a local grocery store. Pig limbs were used to model human decomposition in this experiment as pig carcasses are commonly used in terrestrial decomposition studies and are known to decompose in a manner similar to human bodies, especially in terms of associated skin and gut fauna (8,23).

Most samples involved the following bones: the carpals, the metacarpals, and the phalanges. Sample submersion occurred on August 30, 2007. As freezing temperatures cause soft tissue preservation, the samples were retrieved prior to the onset of winter at 34 and 71 days after submersion; *c*. 1 and 2 months in duration. Samples were submerged in the freshwater environment of Lake Ontario at the Toronto Police Service Marine Unit located in Toronto, ON, Canada. Non-enclosed and plastic enclosed disposal methods were used as treatments. The plastic bags were store bought, green colored, and constructed of polyethylene—the type of plastic most commonly used in household garbage bags. Two bags encased each enclosed soft tissue treatment sample.

Initial and final sample measurements of weight, length, diameter, and largest circumference area were measured in order to quantify soft tissue loss. Using an Ohaus® Precision Plus scale (OHAUS Canada, M&L Testing Equipment 1995 Inc., Dundas, Ontario, Canada), weight was measured to the nearest 100th of a gram. Length, diameter, and largest circumference were measured to the nearest millimeter using a tape measure. Weight was the only quantitative measure subjected to statistical analyses since extensive decomposition prevented the application of length, diameter, and largest circumference measurements across all groups.

Qualitative measures of decomposition were recorded as either ''absent'' or ''present'' and included the following characteristics: hair, liquification, discoloration, skin slippage, wrinkling, marbling, and postmortem hemolysis. Observations of soft tissue presence were based upon a modified Haglund scoring system using the following criteria: 0 = all soft tissue complete; 1 = partial bone exposure due to the loss of overlying soft tissue in some areas; 2 = total bone exposure due to the loss of all overlying soft tissues with ligament attachments still in place; 3 = total bone exposure with complete destruction of ligament attachments (2).

Letter and number codes ensured proper tracking of the specimens throughout the experiment, minimizing error, and facilitating easy comparisons between samples. All samples were placed in individual mesh laundry nets to prevent the loss of remains during the decomposition process. To reduce sampling bias, dismembered parts were randomly selected before being placed in the nets. Four wooden sample holders were used, each holding 30 netted samples underwater. Each holder resembled a six rung ladder, where five samples hung from each rung. Two holders contained the non-enclosed samples while the other two holders contained the enclosed samples. All holders were weighted to ensure total sample submersion to an equal depth relative to one another, reducing experimental variability. Samples were submerged just below the surface of the water. All enclosed samples were double bagged in plastic of the same brand, manufacturer, color, and size.

The lake's temperature and pH were monitored weekly. Local weather reports were similarly monitored to identify factors other than enclosure that may have an effect on decomposition processes. All samples were from pigs slaughtered for the purpose of food processing, thereby not violating ethical standards of animal welfare. All remains were appropriately disposed of using organic waste processing sites, reducing the experiment's impact on the environment.

Results

The lowest and greatest standard deviations belonged to the 2-month enclosed and 2-month non-enclosed groups, valued at 13.599 and 42.103 g, respectively. Overall, samples from the 1-month enclosed and 2-month enclosed groups experienced smaller standard deviations of mean weight loss when compared with their non-enclosed counterparts. Similarly, when reviewing weight loss percentage graphs, a clear trend exists: non-enclosed samples experience wide fluctuations in weight loss. In contrast, enclosed samples experience comparatively more controlled and less fluctuating patterns of weight loss (see Figs. 1–3 and Tables 1 and 2 for information pertaining to sample weight loss).

Due to extensive decomposition primarily seen in the non-enclosed samples, measurements of length, diameter, and largest circumference proved extremely inaccurate. In general, soft tissues shrank slightly in size over the course of the experiment regardless of disposal method. Non-enclosed samples regularly showed greater

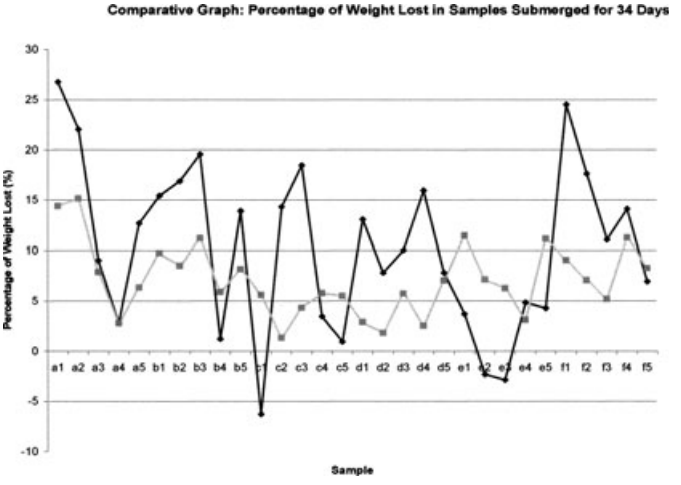

FIG. 1—*Comparative line graph depicting the percentage of weight lost in samples submerged for 1 month, as recovered on Wednesday October 3, 2007.*

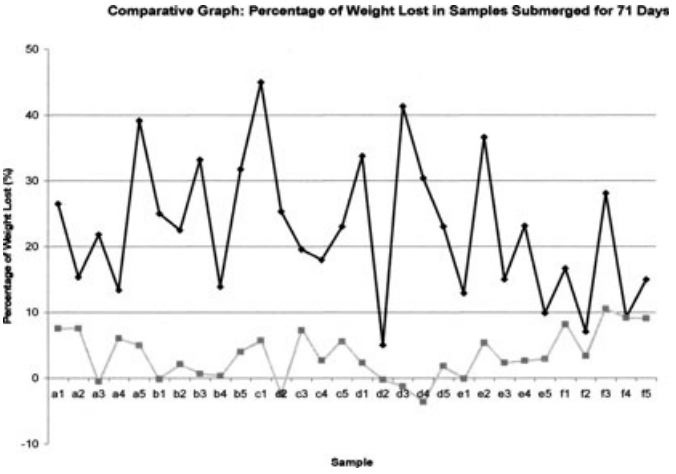

FIG. 2—*Comparative line graph depicting the percentage of weight lost in samples submerged for 2 months, as recovered on Friday November 9, 2007.*

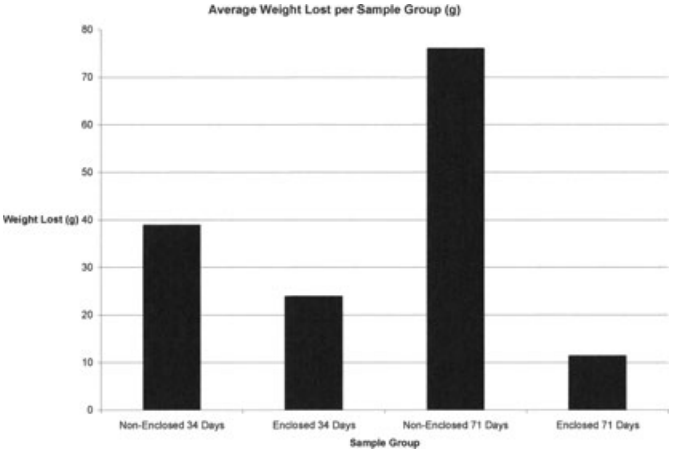

FIG. 3—*Comparative bar graph depicting the average weight lost per sample group for both the 1- and 2-month recovery periods measured in grams.*

TABLE 1—*Table depicting the highest and lowest percentages of weight loss in non-enclosed and plastic enclosed samples per recovery period.*

Treatment, Duration	Lowest Percentage	Highest Percentage	Percent Difference
Non-Enclosed, 34 Days	−6.282	26.741	33.023
Non-Enclosed, 71 Days	5.028	45.010	39.982
Enclosed, 34 Days	1.340	15.145	13.805
Enclosed, 71 Days	−3.611	10.551	14.162

TABLE 2—*The mean, standard deviation, minimum value, maximum value, and median in grams for non-enclosed and plastic enclosed sample weights per recovery period.*

Measure	Non-Enclosed, 34 Days (g)	Enclosed, 34 Days (g)	Non-Enclosed, 71 Days (g)	Enclosed, 71 Days (g)
Mean	−38.870	−23.856	−76.013	−11.340
SD	36.932	18.573	42.103	13.5995
Minimum	−132.0	−74.2	−176.6	−51.3
Maximum	15.8	−3.4	−12.2	10
Median	−27.3	−19.7	−68.9	−9.45

differences in initial and final length, diameter, and largest circumference measurements when compared with their enclosed counterparts, but decomposition made it impossible to establish standard landmarks for reproducible measurements.

The modified Haglund score was consistently higher in non-enclosed samples compared with enclosed samples, reflecting greater levels of soft tissue destruction in non-enclosed samples. All enclosed samples scored 0, regardless of submersion length. Non-enclosed samples scored across the 0–3 range depending upon submersion time. For 34 days of submersion, the non-enclosed samples scored within the range of 0–2, with a median score of 1. For 71 days of submersion, the non-enclosed samples scored within the range of 2–3, with a median score of 3. Only non-enclosed samples decomposed to the point of extreme soft tissue loss, bone exposure, and disarticulation. The structural integrity of enclosed samples was retained throughout both recovery periods, while non-enclosed samples regularly failed to retain structural integrity, especially with an increase in submersion time.

Skin marbling was not observed in any of the samples, but extensive liquification occurred in both sample groups. The liquification of enclosed samples was internalized and did not affect the appearance and consistency of outer soft tissues. Skin slippage and external soft tissue liquification occurred to a greater extent in non-enclosed samples compared to plastic enclosed samples. The frequency of skin slippage and external liquification decreased over time due to soft tissue loss (see Tables 3 and 4 for information pertaining to skin slippage and liquification, respectively).

Plastic enclosed samples submerged for 71 days exhibited green staining on the outer surface of soft tissues and, in some cases, had folding marks reflecting the sample's enclosure. Bone reddening as a by-product of postmortem hemolysis was exhibited to a greater extent in enclosed samples than non-enclosed samples. The frequency of bone reddening increased over time (see Table 5 for bone reddening frequencies).

With an increase in decomposition and submersion time there was an increase in organism colonization for both treatments. Only two different types of organisms were found on the samples: a red colored nematode species measuring 1 cm in length and 1 mm in width and an unknown, brown shrimp-like invertebrate species measuring *c*. 1 cm in length and 3 mm in width. The number of organisms remained low across all treatment groups and recovery periods. Although organism colonization increased over time, the number of colonized samples was approximately equal between treatment groups.

The organisms were found only on the external areas of the samples and simply fell away from the samples upon handling. The species were not observed on the samples during weighing and as a result, did not affect the recorded sample weights. Further, the species produced no macroscopically visible signs of active feeding. This is in contrast to remains in marine environments, where animals feed directly on intact skin and ultimately create postmortem artifacts that resemble perimortem wounds (8). Principles of insect succession could not be applied to this experiment since its design prevented the sequential documentation of carrion feeders, if present considering the lack of feeding evidence. As a result, a forensic entomologist was not called upon to identify the species. In retrospect, species identification would have helped to determine the nature of the organisms and future studies should consider including entomology, even if the main focus is on other decomposition processes.

Dismemberment sites—the areas where the limbs were cut, exposing internal tissues—did not show disproportional decomposition. Marine fauna exhibit a similar lack of preference for wound

TABLE 3—*The frequency and percentage of skin slippage observed in non-enclosed and plastic enclosed samples for both the 34- and 71-day recovery periods.*

Treatment	Recovery Period (days)	Raw Number of Affected Samples	Total Samples	Percentage of Skin Slippage	Total Number of Affected Samples Overall	Total Percentage of Skin Slippage
Non-Enclosed	34	19	30	63.3	36/120	30
	71	17	30	56.6		
Enclosed	34	0	30	0	0/120	0
	71	0	30	0		

TABLE 4—*The frequency and percentage of liquification observed in non-enclosed and plastic enclosed samples for both the 34- and 71-day recovery periods.*

Treatment	Recovery Period (days)	Raw Number of Affected Samples	Total Samples	Percentage of Liquification	Total Number of Affected Samples Overall	Total Percentage of Liquification
Non-Enclosed	34	19	30	63.3	36/120	30
	71	17	30	56.6		
Enclosed	34	1	30	3.3	31/120	25.83
	71	30	30	100		

No distinction was made between external and internal liquification.

TABLE 5—*The frequency and percentage of bone reddening observed in non-enclosed and plastic enclosed samples for both the 34- and 71-day recovery periods.*

Treatment	Recovery Period (days)	Raw Number of Affected Samples	Total Samples	Percentage of Bone Reddening	Total Number of Reddened Samples Overall	Total Percentage of Reddening
Non-Enclosed	34	1	30	3.3	1/120	0.0083
	71	0	30	0.0		
Enclosed	34	5	30	16.7	14/120	11.67
	71	9	30	30		

sites, feeding on either abraded or nonabraded skin (8). Samples that initially had digits and/or hair were recovered with digits and/or hair intact. The hair and the hoof, however, required only a light touch to be removed from the sample. Adipocere, a soapy fatty acid compound often referred to as "grave wax" (24), rarely formed and showed no patterned frequency with either sample group.

Discussion and Conclusion

Analysis of initial and final weight measurements indicates that both length of submersion and enclosure do affect sample weight. See Table 6, where all $p < 0.05$ critical values (25). By extension, the extent of sample decomposition is affected by submersion length and enclosure. Certain samples gained weight, disrupting the normality distribution of the factorial analysis of variance (ANOVA) applied in this experiment. As the weight could be identified as the source of the disruption, however, the factorial ANOVA was still used to complete statistical tests.

TABLE 6—*Table depicting the results for the factorial analysis of variance using the computer software program Minitab 14 Student (Minitab Inc., State College, PA).*

Source	DF	SS	MS	*F*	*p*
Duration in water	1	4550	4549.8	4.85	0.030
Enclosure	1	47,621	47,620.8	50.71	0.000
Interaction	1	18,498	18,498.4	19.70	0.000
Error	116	108,929	939.0		
Total	119	179,598			

$S = 30.64$, $R^2 = 39.35\%$, $R^2(\text{adj}) = 37.78\%$. DF, degrees of freedom; SS, sum of squares; MS, mean square.

In this experiment, non-enclosed samples decomposed in an open aqueous system, while enclosed samples decomposed in the relatively closed system of the doubled plastic bags. Surprisingly, enclosed samples lost less weight on average as time increased. Initially, it was hypothesized that these samples gained weight over time through water imbibing and processes resulting in bloating. Water imbibing and bloating, however, are implausible as measurements of length, diameter, and largest circumference indicate that only 3/90 or 0.033% of the 71-day enclosed samples exhibited an increase in size. Air and water temperatures became increasingly cooler as time progressed, subjecting both treatments to the same external environment. Throughout the two recovery periods, the water temperature ranged from 20°C to 8°C and the mean air temperature ranged from 25.3°C to 1.4°C. The explanation must be connected to the relationship between the enclosed soft tissues and the plastic bags. From Rodriguez and Bass (26), it is theorized that the non-enclosed samples experienced continual bacterial action, while the enclosed samples experienced increasingly suppressed bacterial action over time due to waste product accumulation. Based on weight loss (Fig. 3), strong bacterial inhibition can occur as early as 1 month of submersion in fresh water. The effects of bacterial inhibition in plastic enclosures strengthen over time. Continual bacterial action and the subsequent decomposition of soft tissues explain the predictable increase in average weight loss of non-enclosed samples over both recovery periods.

From Figs. 1 and 2, non-enclosed samples clearly experienced greater fluctuations in weight loss compared to their enclosed counterparts. According to Gill-King (1), temperature is the most important factor determining the speed of tissue decomposition. Autolysis is temperature dependent and slows in cool temperatures (3). Due to water's high specific heat, water stabilizes temperature (1). As all samples were subjected to equal depths as well as identical air

and water temperatures, plastic enclosures exerted the greatest level of influence over altering the environment of decomposition. In addition to bacterial activity, it may be possible that the doubled plastic bags kept the remains relatively dry for an unknown period of time—the trapped air being cooler than the surrounding water. As decomposition of the enclosed samples proceeded, bacterial action lowered the oxygen levels within the bag, slowing decomposition while the surrounding water gradually seeped into the bags. As the study was conducted in autumn, both mean air and water temperature lowered as time progressed. Steady decreases in water temperature were especially noticeable after the first recovery period. With the cool air of the bag being gradually replaced with even cooler water, autolysis and decomposition processes slowed to a rate resulting in preservation of the enclosed remains.

Due to low temperatures in both the water and ambient air, adipocere formation was extremely rare and largely nonexistent. The lack of adipocere found in this experiment is reflective of other freshwater and marine studies that exhibit extreme variability in the time required for adipocere to form (6,8–11,21). According to O'Brien's "Goldilocks phenomenon," the temperature range must be "just right" to allow adipocere formation (4). This may be in part due to the fact that adipocere formation is dependent upon a limited temperature that is correlated with the optimal growth temperature of the bacterium *Clostridium perfringens (welchii)* (4,27–30). O'Brien (4) confirmed that moist, nearly anaerobic environments with warm temperatures ranging from 21°C to 45°C suit the requirements of adipocere formation. The highest mean ambient temperature recorded during the soft tissue study was 25.3°C. The highest water temperature reading was 20°C. In this experiment, it is unknown why adipocere did not form. Possible explanations include that the temperature was not optimal, that the samples did not have sufficient fatty tissues, or that the submersion time was not sufficiently long (3,4,6,18,20,21).

This research project parallels the observations outlined by Haglund and Sorg (1997) since the plastic enclosures have a preservative effect on the dismembered, submerged pig limbs. Other studies, like that conducted by Rodriguez and Bass in 1986, support the observation that enclosed bodies preserve more effectively than those exposed to the external environment (26). In the 1986 study, body portions were wrapped in doubled plastic bags, buried in shallow graves, and allowed 6 and 9 months to decompose before exhumation (26). The bodies were not dismembered or submerged in water. Ultimately, the covered tissues exhibited a high level of preservation compared to uncovered tissues. Rodriguez and Bass (26) proposed that the preservation was a result of bacterial by-products accumulating in the relatively closed system of the plastic bags; this concept is the basis for the explanations provided above. When organic remains decompose in soil or water, the environment becomes naturally acidic and subsequently triggers the action of hydrolytic enzymes essential to the decomposition process (1,31). Although the bacteria may have initially aided in tissue degradation, ammonia and alcohol by-products increased over time, causing pH changes and a reduction in oxygen that inhibited bacterial action (26).

Implications for Future Research

Red blood cell autolysis, or postmortem hemolysis, results in an internal doughy tissue consistency and the staining of the intima of large blood vessels (3). In this study, postmortem hemolysis specifically refers to the mechanism thought to cause red staining on bone. Further research is required to determine the theoretical and practical significance of bone reddening as evidence of enclosure, both generally and in plastic bags. New research should also investigate the mechanism that causes bone reddening, as it may be dependent on factors other than postmortem hemolysis. Although this study was originally done to investigate body deposition practices related to homicide, studies in postmortem hemolysis specific to bone reddening may prove useful in cases of suicide. It is far more common for plastic bags to be involved in water-related suicides, than homicides involving body deposition in water (Badowski, personal communication, 2008). In some cases in the Queen's Quay Harbor of Lake Ontario adjacent to Toronto, suicidal individuals have tied plastic bags over their heads before jumping into the water in order to ensure their own death. The practice of suicidal head bagging is known to police largely through information provided by witnesses (Badowski, personal communication, 2008). In most instances, the police recover the body without the plastic bag as the bag has either been torn off by the individual prior to death or has been lost due to the action of water-related processes (Badowski, personal communication, 2008). Further research should therefore focus on whether or not determinations of foul play, and specifically suicide, can be made from examining the individual's cranial bones and cervical vertebrae for bone reddening as a result of plastic induced postmortem hemolysis.

This experiment should be repeated over time periods greater than 1 and 2 months in order to test the validity and extent of the conclusion that remains in plastic bags decompose underwater to a lesser extent than remains not enclosed in plastic bags. With more recovery periods covering a longer amount of time and a complete cycle of seasons, it may be possible to establish decomposition rates for bodies and/or body parts enclosed in plastic to provide a better estimate of the postmortem interval in such cases. Repeating this experiment might also definitively address the cause of the unexpected average weight loss pattern seen in enclosed samples over time.

The remains in the plastic bags appeared to have a shorter postmortem interval than the remains not enclosed in the plastic bags. In terms of decomposition trends, the enclosed remains lost weight in a controlled manner, while the non-enclosed remains exhibited a comparatively random and fluctuating pattern of weight loss. The weight loss trend found in the enclosed samples is most likely a result of the synergistic effects of the temperature inside the bags and the remains' interaction with inflowing water. Adipocere rarely formed due to the cool temperatures in which the remains were left to decompose.

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