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Time of Submergence Using Aquatic Invertebrate Succession and Decompositional Changes

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ABSTRACT: Pig carcasses were placed in pond and stream habitats in the Malcolm Knapp Research Forest in Maple Ridge, B.C. for approximately one year, to examine the development, species, and sequence of invertebrates associated with the carrion. An invertebrate successional database was created for pond and stream habitats for potential use in estimating time of submergence in water related death investigations. Analysis has shown that a predictable succession of invertebrates colonize the carrion. However, whether or not this succession is carrion dependent or seasonal is unknown. There is a difference in the species composition between pond and stream habitats. Habitats influence invertebrate fauna, therefore, species colonizing carrion are habitat-specific. In both habitats, no one organism can determine time of submergence alone. Decompositional descriptions from this research were compared with 15 freshwater related death investigations. Similarities were seen in the earlier decompositional characteristics including bloat, discoloration, and nail shedding; however, the human descriptions were so vague that they had little value in determining time of submergence and hence time of death.

KEYWORDS: forensic science, forensic entomology, decomposition, insects, freshwater, submerged bodies

Colonization of a substrate in water is predictable, has been documented over time on various inert substances (1,2), and has recently been applied to forensic cases (3,4). However, colonization by aquatic invertebrates on substrates depends on many factors, such as size, texture, and position of the object, flow of water, water temperature, current speed, water depth, and presence of aquatic flora and fauna (1,5). Once an organism has located a substrate, the substrate's characteristics will determine whether the organism remains. The substrate may act as an anchoring site, a food resource, or may afford protection (6,7). Several factors may be used to determine the time of submergence of an object, such as carrion, including succession of aquatic invertebrates in the habitat, seasonal indicators, and indicator species.

Entomological evidence is widely accepted in criminal investigations to determine the postmortem interval (PMI) in terrestrial situations; however, estimating PMI in an aquatic environment is largely unexplored. Numerous investigations have involved entomological evidence on wholly or partially submerged corpses (4,8–15). However, these are all case studies involving single time observations, and PMI has rarely been estimated by entomological evidence alone. Neither decompositional studies nor forensic investigations have provided evidence that could lead to a predictable sequence of invertebrate succession. A few studies have examined the decompositional rates of human corpses in aquatic environments (7,15–26).

Factors that affect decomposition and colonization of aquatic invertebrates, and hence estimations of PMI include: season of immersion (27), water temperature (28–31), water acidity (27,28), presence of clothing (27,28,32), and biotic variables (27), including amount of body fat (32), and scavenging (28–31,33).

The objective of this work was to evaluate whether data on aquatic invertebrate development and succession on carrion has the potential to be used in determining time of death or submergence, as an aid in freshwater death investigations.

Materials and Methods

The research was conducted at the University of British Columbia's Malcolm Knapp Research Forest in Maple Ridge, B.C. Pig *Sus scrofa L.* carcasses were submerged or partially submerged in four still ponds and four sites along a flowing stream (34,35).

Two weeks prior to commencing the research, heavy metal cages were placed at each of the eight sites, with care taken to minimize any disturbance to the aquatic fauna. On August 31, 1996, eight pigs were killed with a single shot to the head from a 15 cm pin gun. The pig carcasses ranged in size from 6.8 to 32.3 kg in the pond habitat with a mean of 17.5 kg. Carcasses in the stream habitat ranged from 8.6 to 26.8 kg with a mean of 18.1 kg. Within 2 h of death, the carcasses were transported to the research sites, weighed, partially clothed, and placed in the middle of a cage. Clothing consisted of a T-shirt, underwear or shorts and socks, so that half the pig was naked and half covered in clothing. The cages protected carcasses from large predators but did not impede the entry of small fish, invertebrates, and small vertebrates (36), or restrict the natural rise and fall of the carcass during decomposition.

Three of four carcasses per habitat were sampled for invertebrates. The fourth carcass was used as a control to assess visually whether frequent sampling disrupted the natural decomposition process. Carcasses were examined two days after death, then approximately every nine days for nine weeks, once a month from December to April and then every two weeks until the eighth of September.

On each sampling date, all carcasses were photographed, visually examined, and observations recorded (34,35). At this time, living dipteran larvae were collected from the carcass and transferred to the laboratory where they could be reared to adulthood for iden-

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tification. The percentage of exposed carcass was calculated by dividing the pig carcass into eighths and those parts exposed were converted to a percentage (Fig. 1).

One week prior to placement of the carcasses, and on each sampling date, a 250 mL plastic container was held approximately 45 cm below the surface, allowed to fill with water, rinsed, and refilled again with the sample water. This was done within each cage and control site. These water samples were immediately transferred to the laboratory and analyzed for CO_2 content and pH (37). Carbon dioxide was calculated by titrating NaOH into a mixture of water sample and Phenolphthalein Indicator as specified in (37). The pH was measured by pH meter scale following methods listed in (37).

Bottom dwelling fauna in pond sites were sampled from the sediment in a control area and within the cage (34). This was accomplished by filling a 250 mL plastic container with sediment. This sediment sample was transported to the laboratory where organisms were separated out and placed in a vial of 95% ethanol for later identification (38). In the stream, a control sample of invertebrates was collected by a surber (39). The surber was dropped in three different locations along the stream bed, at least 2 m from the cages, every sampling time (34). The organisms and debris collected in the surber were rinsed with 95% ethanol into a plastic container and transported to laboratory for further identification. On each sampling date, an aquatic net (40) lined with muslin, was used to sweep the area within each cage as well as at the control locations for water sampling (34,35). The muslin was placed in a plastic bag, taken to the laboratory, and then rinsed with distilled water into a dissecting tray. All invertebrates were collected and preserved in 95% ethanol and later identified.

A chi-square test was preformed to determine if some species of insects were carrion associated for both pond and stream habitats by comparing their distributions between the cage and control sampling sites.

To date, postmortem intervals determined in water death investigations tend to be subjective and unreliable for legal testimony. Invertebrate succession and decompositional descriptions determined by this research were compared with observations made from 15 fresh water death investigations that occurred in British Columbia in 1996 (41), and for which the PMI was >72 h (42). Excluded from this comparison were investigations where bodies were not recovered and those cases with insufficient descriptions of the bodies to allow adequate comparisons.

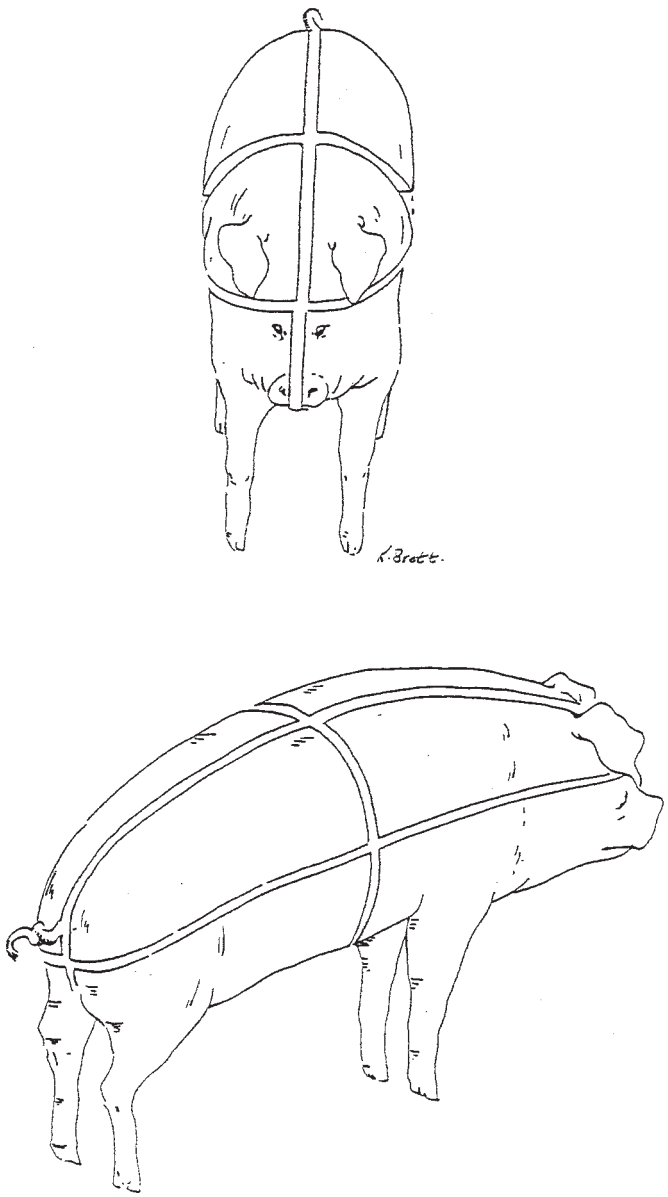

FIG. 1—*Method of determining the percentage of carcass exposed to air by dividing pig carcass into eighths.*

Results

In the pond habitat, changes in CO_2 levels within and outside the cage were offset from the control by approximately seven days (Fig. 2). In both habitats, peak CO_2 levels were associated with accumulations of detritus, which in turn were associated with higher water levels and not related to the pig carcasses (34,35).

In the stream habitat, the water samples from the control sites displayed similar peaks in CO_2 levels as those in the pond habitat. However, within the cage CO_2 levels rose gradually for 43 days and did not fluctuate with water level or amount of detritus (34,35).

In both habitats, pH levels were fairly consistent at 5 to 5.5 for both cage and control sites (Fig. 3). In the stream habitat, pH rose on one occasion (Day 28) due to an accumulation of detritus. In both habitats, acidity of the water and high CO_2 levels appear to cause saponification, the breakdown of the fatty tissues of the carcass.

Differences in the percentage of exposed carcass were observed throughout the decompositional stages for each habitat (Fig. 4). No similarities were detected for carcasses within the same habitat. In the stream habitat pig carcasses varied from completely submerged to 50% exposed; carcasses in the pond habitat ranged from completely submerged to two thirds exposed. Depth of stream and pond habitats did not influence carcass exposure, however, did influence decomposition. Duration of each decompositional stage was recorded for each carcass in both habitats (Table 1).

The fresh stage of decomposition began at death and lasted for 11 to 13 days in both habitats until the first signs of bloat appeared. In the pond habitat where full submersion was possible, the carcasses floated just below the water surface, with either one ear protruding or the abdomen slightly exposed. Caddisfly larvae appeared by the third day on the facial regions of the carcasses, but not on clothed areas. In the stream habitat, blow flies (Calliphoridae) laid eggs along the edges of clothing on the large portions of the carcass that remained above water.

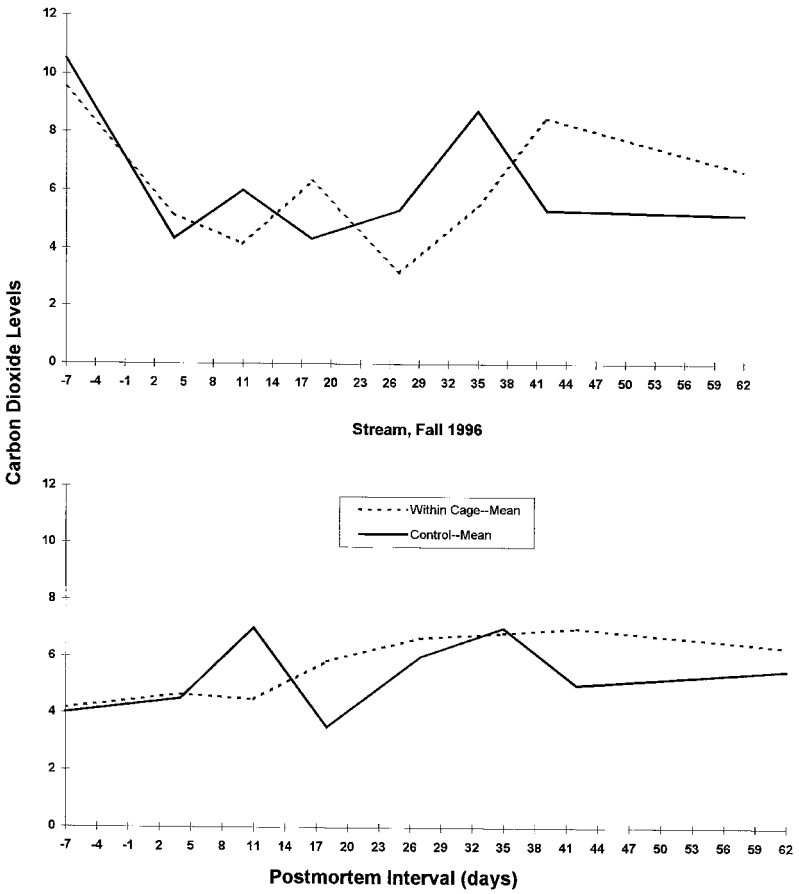

FIG. 2—*Mean carbon dioxide levels for control and cage sites for 62 days postmortem in pond and stream habitats.*

Transition to the **bloat stage** in both habitats was marked by distention in the abdomen, which later assumed a fully inflated balloon-like appearance with a putrid odor becoming evident. These characteristics were indications of bacterial activity in the gastrointestinal tract. In the pond habitat, the abdomens protruded greatly, but tight clothing constricted the overall bloating of the carcass. There were fewer caddisfly larvae on the carcasses than in the fresh stage. The bloat stage lasted 28 days. In the stream habitat, bloated carcasses attracted mink, *Mustela vison,* Schreb., which were observed to scavenge three of the four carcasses during this period (NRH). Exposed portions of carrion were predominately colonized by blow flies and carrion beetles (Silphidae) whereas, submerged portions remained uncolonized. Duration of the bloat stage was more variable than in the stream habitat, lasting from 23 to 37 days.

The **decay stage** began when a bloated carcass deflated by a slow release of gases through natural orifices or wounds caused by scavenging. Hair and skin flaked off and hooves became detached. There was a strong odor associated with the carcass at this stage. Fewer living blow fly larvae were observed in both habitats, but dead larvae were not evident. Adipocere formation began during this stage, at first resembling pale, rancid butter, and later hardening to provide a protective coating for the internal structures. In three carcasses in the pond habitat the decay stage lasted from 98 to 331 days. In the stream habitat, one carcass was in the decay stage for only nine days. Two other carcasses remained in the decay stage for 48 and 89 days, and for the fourth carcass, which was heavily scavenged by mink, both the decay stage and the succeeding post decay stage did not occur at all.

By the **post decay** stage, much of the flesh, except for the skin, had been removed by invertebrate scavengers, e.g., crayfish, caddisflies and maggots, if not previously scavenged by mink. Invertebrate populations inhabiting the carrion were very diverse. In the pond habitat, the three carcasses, which entered this stage, remained in it for 161 to 233 days. Only one carcass in the stream habitat experienced a post decay period, which lasted for 161 days.

The **sunken remains** stage occurred for only one carcass in the pond habitat, and in three carcasses in the stream habitat. Sunken remains were carcasses that had completely submerged. Bottom fauna started to colonize the nutrient rich area, increasing the diversity of organisms, e.g., earthworms, snails, and nymphal mayflies and stoneflies. The odor at this time was less potent than in the previous three stages. On the scavenged carcasses, most of the tissue was removed by mink; therefore only the bones with greasy decomposed tissue remained at the bottom of the cages. In the scavenged carcass the remains stage was entered on Day 89, bypassing the post decay stage. The most heavily scavenged carcass entered the remains stage on Day 34, bypassing the two preceding stages.

Scavenging by mink was concentrated on the lower and unclothed portions of carcasses in the stream habitat. On exposed carcasses, invertebrates tended to feed under the clothing where they were protected. Conversely, on submerged carcasses, invertebrates tended to colonize and feed on the nonclothed portions.

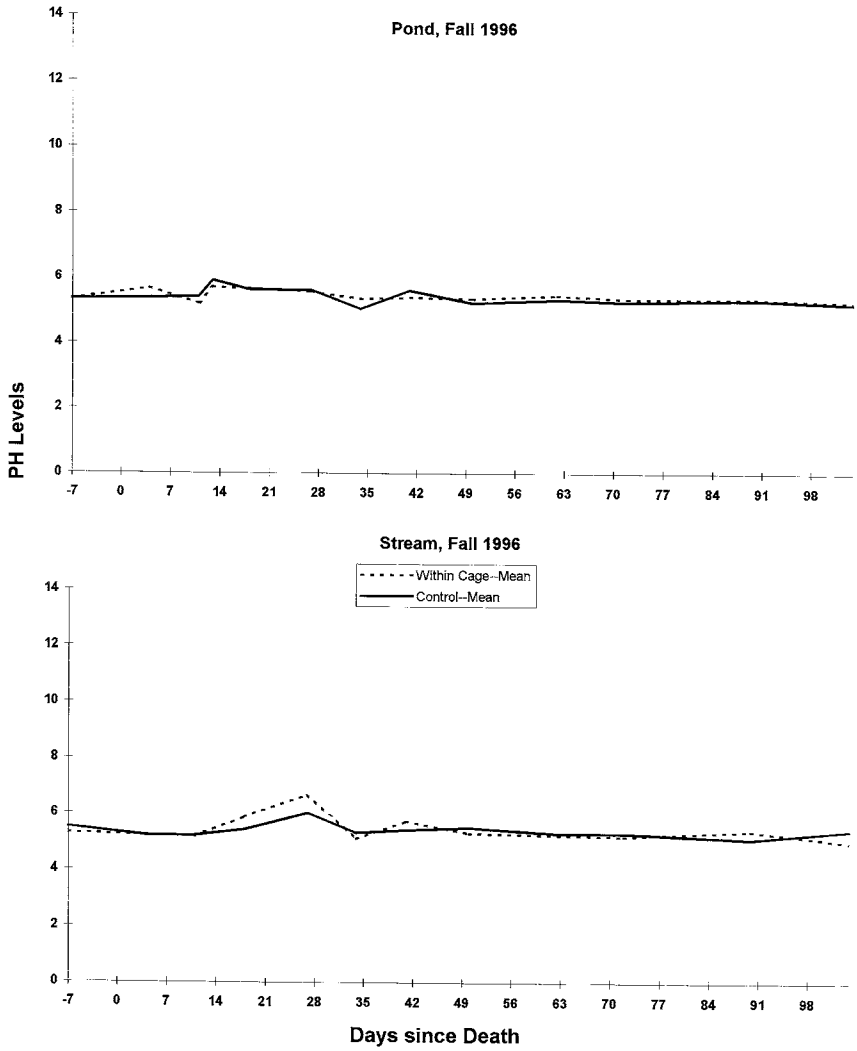

FIG. 3—*Mean pH levels for control and cage sites for 98 days postmortem in pond and stream habitats.*

TABLE 1—*Duration of decompositional stages for pond and stream habitat.*

	Pond				Stream			
Stage	1	2	3	4	1	2	3	4
Fresh	13	13	13	13	11	13	11	11
Bloat	28	28	28	28	30	37	30	23*
Decay	98	132	98	331	48*	89	9	0
Post decay	233	199	171	0	0	161	Missing	0
Sunken remains	0	0	72	0	283*	72	Missing	338*

* Scavenged carcass. Experiment was terminated after 372 days.

All invertebrates found on the carcass within the cage and at the control sites in both the pond and stream habitats were identified for a total of 17 orders, 35 families, and 46 genera (34). Invertebrates (excluding insects) displayed no distinct pattern in times of arrival, or tenure (Tables 2 and 3).

Oligacheates were present during mostly decompositional stages for the pond habitat. *Hydrozetes* sp. and *Gyraulus* sp. were also present but in different habitats and decompositional stages.

Insects specimens in 10 orders, 28 families and 39 genera were recovered (34). Among them were necrophagous species, predators, parasites, and apparently incidental species. Factors including habitat, decompositional stage, scavenging and presence of clothing caused a diversity of insects and patterns in arrival times and duration of stay.

In the pond habitat, calliphorids dominated the exposed portions of carrion during the entire bloat stage (Table 4). Also, numbers of Staphylinidae, Silphidae, and Leptodiridae became numerous. Caddisfly larvae dominated submerged portions of unclothed carrion. Chironomid larvae were also present during the bloat stage, but populations remained constant for the entire

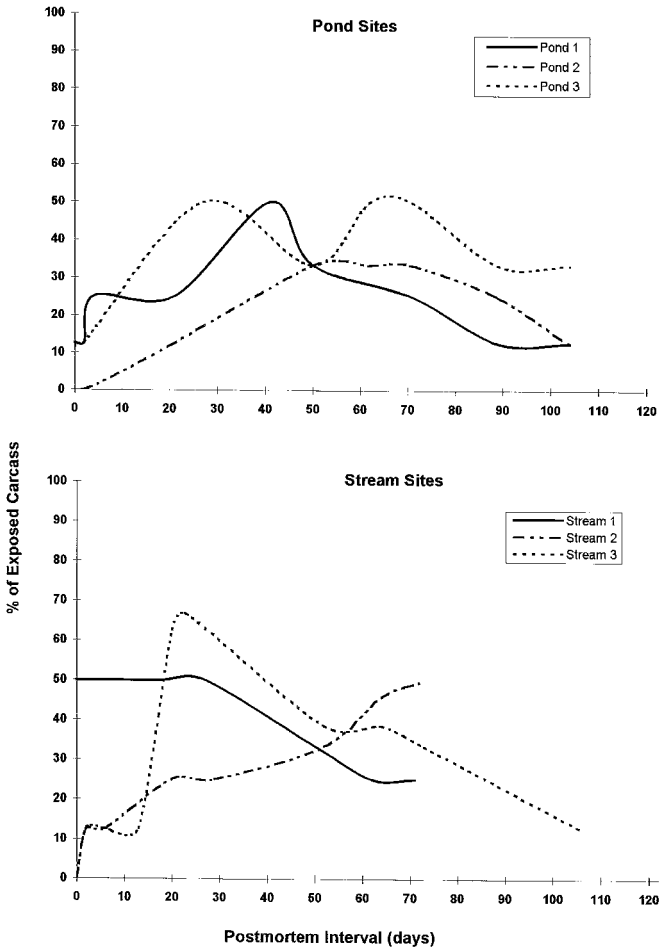

FIG. 4—*Percent of carcass exposed to air during decomposition in pond and stream habitats. (Due to technical difficulties, Site 4 in pond and stream habitats were not monitored).*

TABLE 2—*Succession of invertebrate species (excluding Class Insecta) collected on carcasses from the pond habitat.*

Order and Family	Genus and Species or Common Name	P	F	B	D	PD	S
Lumbriculida							
Lumbriculidae	Oligochaetes	A		A	A	A	A
Oribatei							
Eremaeidae	*Hydrozetes* sp.					A	
Pelecypoda							
Unknown	Bivalve	A				A	
Podocopa							
Unknown	Seed shrimp		A			A	
Spirobdolida							
Unknown	Millipede				A		

P = pre-experiment, F = fresh, B = bloat, D = decay, PD = post decay, S = skeletal remains, A = adult.

experiment with the exception of the month of November, when they were absent.

During the decay stage, *Homaeotarsus sellatus* (LeConte), (Staphylinidae) and very few third instar calliphorid larvae remained on exposed, clothed portions of carcasses. *Homaeotarsus sellatus* (LeConte) was still present during the post decay stage. On submerged portions of a carcass, stonefly larvae were numerous for

TABLE 3—*Succession of invertebrate species (excluding Class Insecta) collected on carcasses from the stream habitat.*

Order and Family	Genus and Species or Common Name	P	F	B	D	PD	S
Gnathobdellia							
Hiudinidae	Leech		A				
Limnophila							
Planorbidae	*Gyraulus* sp.			A			
Lumbriculida							
Lumbriculidae	Oligochaetes						A

P = pre-experiment, F = fresh, B = bloat, D = decay, PD = post decay, S = skeletal remains, A = adult.

approximately two months, whereas caddisfly larvae and diving beetles remained until the termination of the experiment.

In the stream habitat, calliphorids dominated the exposed portions of a carcass during the fresh and bloat stages (Table 5). Species in the Leptodiridae and Staphylinidae became evident during the bloat stage. Chironomid larvae were evident during the bloat stage but remained numerous throughout the experiment, feeding both underneath clothing and on unclothed portions of submerged carrion. During the spring, either post decay or sunken remains stages, mayfly and stonefly larvae dominated submerged portions of carrion, whereas caddisfly larvae were in low numbers.

In the pond habitat, *Chyranda centralis, Helichus* sp., *Calliphora vomitoria, Homeotarsus sellatus, Catoptrichus frankenhaussen, Aquarius remigis,* and *Phormia regina* were all found to be carrion associated using a chi-square test (Table 6). However, *Calliphora vomitoria, Chironomus* sp., and *Homeotarsus sellatus* were determined to be significantly carrion associated in the stream habitat.

Table 7 lists decompositional characteristics seen in human death investigations. Table 8 summarizes observations from this research and compares traits to 15 human death investigations for which there was sufficient documentation to allow a comparison to be made (34,42).

Discussion

An increase in carbon dioxide as a byproduct of decomposition was expected near the carcasses; however, no such increase was observed (Fig. 2). Photosynthetic algae and bacteria became abundant, which may have prevented the carbon dioxide from accumulating to expected levels (43). The pH was determined to be 5 to 5.5 in both habitats. This acidity was enough to facilitate saponification of the carcass (44).

Differences in exposure of carcasses in the stream habitat compared with the pond habitat may have been attributed in part to the depth of water. Shallow water in September 1996 may not have covered an entire fresh carcass. Size of pig may also have influenced exposure. Pig size varied from 6.8 to 32 kg, and size has a direct relationship with CO_2 production which causes refloat (45). The variation in percentage of exposed carcass was similar to that of O'Brien (21) on three carcasses, two of which floated when placed in water, and one of which sank and remained submerged for three months. The removal of tissues by scavengers increased decomposition rate, causing scavenged carcasses to submerge faster than unscavenged carcasses.

Traditionally, the rate of decomposition in both above-ground and buried carrion has been determined by measuring loss of weight

TABLE 4—*Succession of insect species collected on carcasses from the pond habitat.*

Order and Family	Genus and Species or Common Name	Decompositional Stage					
		P	F	B	D	PD	S
Coleoptera							
Dytiscidae	*Acilius* sp.			A			
Dytiscidae	*Hydroporous* sp.				A		
Elmidae	*Stenelmis* sp.			A	A		
Hydrophilidae	*Hydrochara* sp.				A		A
Leptodiridae	*Catoptrichus frankenhaussen* (Mannh.)			A	A		
Silphidae	*Nicrophorus* sp.				A		
Staphylinidae	*Homaeotarsus sellatus* (LeConte)			A			
Collembola							
Isotomidae	*Isotomurus tricolor* (Packard)				A		
Diptera							
Calliphoridae	*Calliphora vomitoria* (L.)			I/A			
Chironomidae	*Chironomus* sp.					I	
	Heterotrissoclodius sp.	I	I	I/P	I	I/P	I
	Polypedilum sp.			I/A			
Muscidae	Undetermined species			I/A			
Sciaridae	*Sciara* sp.			A			
Tanyderidae	*Protanyderus* sp.				A		
Emphmeroptera							
Emphemerellidae	*Emphemerellida* sp.					I	
	Serratella sp.					I	I
	Paraleptophlebia sp.		I				I
Hemiptera							
Gerridae	*Aquarius remigis* (Say)			A		A	
Hymenoptera							
Braconidae	Undetermined species			A			
Mymaridae	*Caraphractus cinctus* (Walker)			A			
Odonata							
Libellulidae	*Libellula* sp.						
Plecoptera							
Nemouridae	*Prostoila besametsa* (Ricker)					A	
	Isoperla sp.					I	
Tricoptera							
Branchycentridae	*Micrasema* sp.					I	
Limnephilidae	*Chyranda centralis* (Banks)	I	I	I	I	I	I/P
	Limnephilus sp.					I	I
	Moselyana comosa (Denning)					I	
	Pseudostenophylax sp.					I	I

P = pre-experiment, F = fresh, B = bloat, D = decay, PD = post decay, S = skeletal remains, E = egg, I = immature, P = pupae, A = adult.

over time (36,46–49). Loss of weight has been attributed to release of body fluids, maggot migration, and decomposition (46). However, in an aquatic environment, weight loss measurements would be confounded by water taken up by a carcass. This phenomenon was also observed in terrestial carcasses due to clothing taking up water (36) and rehydration of the skin (47). Therefore, observational determination of decompositional stages can be very important and can serve as a guide in determining time of submergence or death.

Decomposition was delayed in both aquatic habitats compared with that in terrestrial habitats in the same season and geographic location (36,50). These delays may have been due to the absence of maggot masses and cool water temperatures. Durations were 11 to 13 days in fresh, 23 to 37 days in bloat, 0 to 331 days in decay, 0 to 233 days in post decay and 0 to 338 days in sunken remains stage in water, compared with approximately 7 days in the fresh stage, 18 days in bloat, 11 days in decay, and 116 in post decay (36).

Scavenging by mink was observed on all carcasses in the stream habitat, and was severe on two carcasses. Decomposition of carrion during the fall in a shaded terrestrial environment was also reported to be primarily propelled by scavenging activity (36). Scavenging apparently increased the rate of decomposition and limited the diversity and number of invertebrates (until the sunken remains stage), as in terrestrial environments (36). Because of the accelerated decomposition in scavenged carcasses and the complete bypassing of the decay stage in one carcass, and both the decay and post-decay stages in another (Table 1), great care should be exercised in interpreting decomposition in forensic investigations that involve scavenged carcasses in aquatic habitats.

The presence or absence of clothing may also influence the interpretation of the role of associated invertebrates on submerged or exposed carrion. For example, on the submerged portions of carcasses, clothing prevented feeding by invertebrates such as crayfish, and on exposed portions of carrion clothing provided shelter for insects such as dipteran larvae.

Maggot masses are frequently found on carrion on land; however, no such masses ever formed in this study. This was probably due to high moisture in the environment. If high moisture levels and low temperatures occur, larval development may be retarded (i.e., larvae may remain as third instars for months), which will affect estimation of time of submergence or death (34). Also there is an extremely high mortality rate of prepupal larvae; therefore pupal cases are usually not recovered from cloth-

TABLE 5—*Succession of insect species collected on carcasses from the stream habitat.*

Order and Family	Genus and Species or Common Name	Decompositional Stage					
		P	F	B	D	PD	S
Coleoptera							
Curculionidae	*Stenopelmus* sp.			A			
Dryopidae	*Helichus* sp.			A			
Hydrophilidae	*Hydrochara* sp.			A			
Leptodiridae	*Catoptrichus frankenhaussen* (Mannh.)			A			
Leiodidae	*Catops basilaris* (Say)			A			A
Staphylinidae	*Homaeotarsus sellatus* (LeConte)			A			A
Collembola							
Isotomidae	*Isotomurus tricolor* (Packard)						A
Diptera							
Calliphoridae	*Calliphora vomitoria* (L.)	I/A	E/I				
	Phormia regina (Meigen)	I	I				
Chaoboridae	*Mochlonyx* sp.	I					
Chironomidae	*Chironomus* sp.					I	I
	Heterotrissoclodius sp.						I
	Polypedilum sp.			I		I	
Muscidae	Undetermined species			I/A			
Sciomyzidae	*Dictya* sp.					A	
Emphmeroptera							
Emphemerellidae	*Emphemerellida* sp.					I	I
	Serratella sp.			I		I	I
	Paraleptophlebia sp.			I			I
Hemiptera							
Gerridae	*Aquarius remigis* (Say)		A	A			
Lepidoptera							
Noctuidae	*Archanara oblong* (Grote)			I			
Plecoptera							
Capniidae	*Bolshecapnia* sp.			A			
Nemouridae	*Prostoia besametsa* (Ricker)						A
Perlodidae	*Isoperla* sp.			I		I	I
Tricoptera							
Limnephilidae	*Chyranda centralis* (Banks)			I			I
	Pseudostenophylax sp.					I	I
	Undetermined species						I

P = pre-experiment, F = fresh, B = bloat, D = decay, PD = post decay, S = skeletal remains, E = egg, I = immature, P = pupae, A = adult.

ing or carcasses in water (34). In human death investigations larvae taken from corpses in water have suffered >95% mortality, when reared in the laboratory (34). Unlike terrestrial cases where evidence can be found around a carcass months after death, dead larvae or pupal cases are rapidly washed away by rain or fast flowing water.

Observations (Tables 4 and 5) suggest that there is a predictable succession of invertebrates that colonize carrion in aquatic habitats. However, discretion must be used when evaluating succession for the use of determining time of submergence or death.

Differences in species found in the habitat were due to environmental conditions and the preferences of the organism. For example, the habitat itself may influence the species present, such as poorly oxygenated pond water or in oxygen-rich stream water. The opportunity to exploit the presence of carrion may be a secondary determinant of the species that are present.

Calliphora vomitoria, Enicita sp., and *Phormia regina* were found on shaded, unclothed portions of a carcass in the bloated stage. Later colonization occurred by *Catops basilaris* (Leiodidae), and *Nicrophorus* sp. (Silphidae) occurred which was similar to previous terrestrial research (36), however, Staphylinidae differed.

Insect species were different and less diverse than those observed by Payne and King (51), who also observed the maggots migrating off the carcass. They also found more insect species on the carcasses in water than on land and predicted richer fauna including truly aquatic insects if experiments were done in natural conditions rather than in an artificial tank. In contrast, this research found numbers of insect species and families were significantly lower in the aquatic habitats than in terrestrial habitats in the same forest (36).

Haskell et al. (6) predicted that chironomid midges (Diptera: Chironomidae) and the caddisflies (Trichoptera) could be used to determine time intervals of submergence. According to Hobischak (34) and Hobischak and Anderson (42) in the pond habitat, *Polypedilum* sp. (Chironomidae) was present throughout the year except for November, January, and February. *Heterotrissocladius* sp. (Chironomidae) was present on carrion September, October, and February to July. *Chyranda centralis* (Trichoptera) was present on carrion September, October, and from February to July. With such large intervals of time when the species are present on the carrion, this information alone will not be enough to indicate time of submergence. Species present and relative numbers need to be used in conjunction with decompositional descriptions of carcasses in order to determine time of submergence.

TABLE 6—*Chi-square analysis to determine carrion association of selected species in pond and stream habitats.*

Species	Pond		Stream	
	X^2	P	X^2	P
Calliphora vomitoria (L.)	12.494	0.000	8.256	0.004
Chironomus sp.	0.119	0.155	6.9	0.009
Phormia regina (Meigen)	4.381	0	1.022	*
Muscidae	1.011	*	2.091	0.148
Heterotrissocladius sp.	0.154	0.695	0.088	0.767
Polypedium sp.	1.287	0.257	9.684	0.731
Acilius sp.	2.028	0.155	NF	NF
Catop basilaris (Say)	2.028	0.155	NF	NF
Catoptrichus frankenhaussen (Mannh.)	7.358	0.007	1.022	*
Dysticidae	2.963	0.086	NF	NF
Helichus sp.	18.254	0.000	NF	NF
Heterlimnius sp.	NF	NF	9.684	0.002
Homeotarsus sellatus (LeConte)	10.746	0.001	4.381	0.037
Hydrochara sp.	0.207	0.649	1.020	*
Nicrophorus sp.	3.101	0.079	NF	NF
Stenelmis sp.	1.001	*	2.091	0.148
Isoperla sp.	0.119	0.731	3.69	0.055
Leuctra sp.	NF	NF	2.091	0.148
Serratella sp.	2.028	0.155	0.088	0.767
Emphemerella sp.	0.000	1.000	0.605	0.340
Paraleptophlebia sp.	0.340	0.560	0.605	0.437
Chyranda centralis (Banks)	40.50	0.000	0.138	0.710
Limnephilius sp.	2.044	0.153	0.000	1.000
Platycentropus sp.	3.064	0.080	NF	NF
Gerridae	5.807	0.016	3.067	0.080

* Chi-square approximation invalid, 2 cells counted less than 1. NF = species not found in habitat.

Colonization by aquatic invertebrates appeared to be influenced by season. This was evident in the mayfly and stonefly nymphs, as well as diving beetles. Experiments initiated in a different season, i.e., spring would indicate whether these trends were due to season or specific to a decompositional stage.

Comparison with Water Death Investigations

The striking absence of detailed descriptions of decomposition in water death investigations limited the comparison of human death investigations and research observations to just 23% (15 cases) of the 65 possible freshwater cases. Of that percentage, only one case mentioned the existence of invertebrates on the body. Four cases mentioned postmortem scavenging activity, presumably by mammals.

Similarities were seen in many early decompositional characteristics including bloat, discoloration, and nail shedding; however, these classifications in the coroner's cases were so vague that they had little value in determining time of submergence and hence time of death. Skin sloughing and hair shedding occurred in death investigations earlier than in the research. However, adipocere was significantly earlier in the research than in human cases. It appeared that the longer the corpse was submerged in water, the more vague the description in the coroner's files would be (42).

More specific categories and a standard description for each trait (or characteristic) may be useful in providing a better baseline to compare cases (34,42). The lack of human death investigations with long PMIs (two cases approximately 90 days and one at 180 days) limited the comparison.

Research is currently being conducted in the marine environ-

TABLE 7—*Summary of decompositional characteristics derived from death investigations.*

Case #	Washer-woman Skin	Bloat-ing	Marb-ling	Discolo--ration	Skin Sloughing	Hair Shedding	Nail Shedding	Tongue Protu-berance	Fluids Leaking	Foul Odor	Postmortem Scavenging	Adipocere	Skeletal Remains	Mold/ Algae	Insects	Silt	PMI (days)
96-001			X	X	X												5
96-002	X	X		X						X	X					X	5
96-003		X			X			X									7
96-004				X	X												9
96-005		X		X						X						X	~10
96-006		X		X	X												13
96-007				X												X	13
96-008	X				X	X					X					X	~30
96-009		X			X	X	X				X					X	37
96-010										X							38
96-011		X	X	X	X			X	X								52
96-012				X	X	X				X							63
96-013													X				~90
96-014				X						X		X					91
96-015												X	X		X		~180

NOTE: More details on circumstances of cases available in Hobischak (1997).

TABLE 8—*Similarities of decompositional characteristics derived by research with human death investigations.*

PMI (Weeks)	Stage	Bloat	Discoloration	Skin Sloughing	Hair Shedding	Hoof Shedding	Foul Odor	Postmortem Mammal Scavenging	Postmortem Insect Scavenging	Mummification	Adipocere	Recent Skeletonization	Disarticulation	Mold/ Algae	Insects
0–1.5	Fresh														S/P
1.5–2.5	Bloat	S/P/H	S/P/H					S/H			S				S/P
3–5										P					S/P
6–7	Decay			S/P	S/P	S/H					P			P	S
9–10							P	S/H		S		S			S
12–15										S/P					
26	Post Decay							S	P	S/P		P			P
30–34							S		P			S/H	S	P/H	S/P/H
37–38								S	P		S		S	P	P
40–43	Sunken Remains						P			P					S/P
46–48															S/P

P = pond, S = stream, H = human death investigations.

ment (52) and a comparison with fresh water habitats will be the focus of a future paper.

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