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Decomposition of carrion in the marine environment in British Columbia, Canada

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Abstract Decomposition of carrion in the marine environment is not well understood. This research involved the decomposition of pig carcasses in Howe Sound in British Columbia. Freshly killed pigs were submerged at two depths, 7.6 m and 15.2 m. The carcasses were tethered so that they could float or sink, but not drift away. Observations were made from May until October. Decomposition was more greatly influenced by sediment type of the sea floor and whether the carcass remained floating, than by depth. Decomposition stages were modified in the marine environment from that seen on land, or in freshwater and were similar to those reported in human death investigations in the marine environment.

Keywords Decomposition · Marine · Aquatic · Carrion · Canada

Introduction

The stages of decomposition and the sequence of arthropods that colonize a corpse in a terrestrial environment are generally well understood, with considerable research being conducted in many areas of the world [1, 2].

These data are not only ecologically valuable, as carrion is a nutritionally rich but ephemeral resource, but can also be used in forensic death investigations. When local, seasonal data are available, the sequence of insects colonizing a homicide victim can be used to determine the elapsed time since death. However, decomposition of carrion in the marine environment is not well studied [3]. The majority of information in this area is confined to reports of individual cases, rather than structured research [4, 5, 6, 7, 8, 9]. This paper reports on the decompositional changes seen in pig carcasses over time in the marine environment of Howe Sound, close to Vancouver, British Columbia, Canada.

This paper will discuss primarily the decompositional changes and artifacts created by fauna, as reports of the faunal sequence of colonization and differences in microhabitats will or have already been published separately [10].

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Materials and methods

The research site was in Howe Sound close to a small private island. A total of 6 sites were established prior to carcass deposition, 3 at a depth of 7.6 m and 3 at 15.2 m (plus or minus natural tidal fluctuations). Each site was separated by at least 100 m. A heavy concrete anchor was placed at each site, with 2 m of nylon rope attached. The experiment began in May and was completed 6 months later in October.

Pig (*Sus scrofa* L.) carcasses were utilized as the carrion as most terrestrial decomposition studies have utilized pig carcasses, allowing direct comparisons. As well, they are frequently used as models for human decomposition, so data gathered from them may be used in forensic investigations. Pigs have similar skin and gut fauna to humans and are considered to be an excellent model for human decomposition [11]. The 6 pig carcasses weighing 20–25 kg each, and which had been killed using a pin-gun, were immediately transferred to the research site by boat. Divers attached the carcasses to each anchor and tethered them with the length of rope, which allowed each carcass to float or sink naturally, depending on decompositional stage.

Divers examined the carcasses at varying time intervals depending on decompositional rate, diver availability and boat accessibility. In the early postmortem interval, the carcasses were examined every few hours, then every few days, then every 2–3 weeks, when little remained of the carrion. At each examination, underwater video and still photographs were taken and samples were collected. In some cases, carcasses were put into a plastic container and then brought to the surface for a more thorough examination. Experiments were terminated when only scattered bones remained.

Results

In terrestrial environments in British Columbia, pig carcasses and human bodies pass through easily recognized stages, such as fresh, bloat, active decay, advanced and

Table 1 Comparison of decomposition between carcasses submerged in the marine environment, still and running freshwater (modified from [15]) and those decomposed on land (modified from [12])

Stage	Marine, shallow	Marine, deep	Freshwater, standing	Freshwater, running	Terrestrial coastal western Hemlock Zone
Fresh	0–3 days ETSD Body floated at first, head towards ground, then sank after ~18 h. Feeding from small crustacea and fish all over body, not just at wounds	0–3 days ETSD Body floated at first, with head towards ground, then sank after 18–28 h. Lividity visible on some. Feeding damage on unbroken skin	0–9 days ETSD Mostly submerged. Larval caddis flies colonizing submerged areas	0–9 days ETSD Mostly submerged, but some parts exposed. Fly eggs laid at edge of clothing where exposed	0–1 days ETSD No odour or sign of bloat. Wound sites and natural orifices colonized first. Lividity and rigor present
Bloat	3–11+ days ETSD Bloat appeared to start at day 3, with silt building up and areas of active decay, with possible adipocere formation. This stage seems to overlap with active decay. Animals feeding at all areas of body. Bone exposed in places. Bloat still present in some carcasses for more than 11 days	3–11+ days ETSD Bloat appeared to be starting at 3 days, areas of body showing active decay with muscles and bone exposed in some cases, even when bloat persisted. Silt building up, legs removed in some cases, hair falling off. Bloat still present in most carcasses for more than 11 days	9–35 days ETSD Still partially floating, exposed skin hardened. Coleopteran and Dipteran colonization on exposed tissue and under clothing. Aquatic colonization submerged areas	9–35 days ETSD Still partially floating, exposed skin pale in colour, submerged skin dark. No colonization at orifices. Adipocere formation on head. Coleopteran and Dipteran colonization on exposed tissue and under clothing. Terrestrial vertebrate scavenging, resulted in sinking	2–10 days ETSD Gases inflate abdomen, then entire carcass
Active	>11–30+ days ETSD Parts of carcass completely skeletonized, or missing, but stomach and intestine still bloated, so carcass still floating in some cases. Decomposition stage includes advanced and active decay, but still has appearance of bloat. By 30 days, mostly just skeletonized, but still some flotation	>11–30+ days ETSD Parts of carcass completely skeletonized, or missing, but stomach and intestine still bloated, so carcass still floating. Ribs, skull and spine exposed. Some hair still present on one	42–105 days ETSD Hair and skin sloughing off. Adipocere formation throughout. Still appears a little bloated, probably due to hardened outer tissue. Terrestrial insects no longer present. Exposed skin mummified	42–105 days ETSD Hair sloughing. Some terrestrial insects present at first. Adipocere formation, outer skin hardened and mummified where exposed. Some further terrestrial vertebrate scavenging	11–16 days ETSD Gases released, carcass deflates. Carcass very wet. Maggot masses present, large quantities of tissue removed. Decomposition concentrated near wound, orifices and gut
Advanced	No delineation clear between active and advanced decay	No delineation clear between active and advanced decay	105–280 days ETSD Partially exposed. Submerged parts shredded by invertebrates. Torn tissue colonized by aquatic organisms. Submerged extremities and head skeletonized. Algal formation on submerged skin	105–182 days ETSD Few organisms visible. Some disarticulation. Adipocere still present	17–42 days ETSD Most flesh removed. Bones exposed. Maggots have left body but still extensive insect activity present
Remains	40+ days ETSD Adipocere tissues present by 47 days. Mostly skeletonized, but still floating due to gases in intestines in 1 case at 47 days. Remains still present and recovered at 140 days ETSD in 2/3 cases. Some fauna still associated with remains	40+ days ETSD Internal organs exposed, if present. Bones exposed. Adipocere tissue formed. Solid organs exposed in stomach wall. Scavenging injuries on neck areas. Bodies still floating in 2/3 cases until 47–54 days. Remains still present and recovered at 140 days ETSD in 2/3 cases. Some fauna still associated with remains	280–336 days ETSD Skeletonization by aquatic organisms	280–336 days ETSD Totally submerged. Typical benthic fauna now present	43+ days ETSD Only skin, bones and cartilage remain. Experiment terminated 271 days ETSD. Only dry bones and incidental insect species present

Marine carcasses were submerged at two depths, shallow (7.6 m) and deep (15.2 m). Time is given in days elapsed since death (ETSD).

dry or remains stages [12]. These stages were present but modified in freshwater experiments [13, 14]. In the marine environment, clear decompositional stages were present, but different in duration and appearance from those seen in the previous environments (Table 1). Traditional bloat was a clear stage, although the carcasses appeared bloated and were elevated by the presence of gases in the intestines for many weeks after death, which could be mistaken for true bloat. The decomposition stages on land are relatively clearly delineated, but in the marine environment, only the first and last stages were discrete, with carcasses showing clear signs of bloat, active and advanced decay at the same time.

There were few consistent differences between carcasses submerged at 7.6 m versus those submerged at 15 m (Table 1). Greater differences were observed between decomposition of carcasses which floated versus those that had contact with the sediment for the majority of the experiment. Also, a difference was noted between carcasses that had contact with rocks versus those that sank onto sand. The area was a mixture of rock and sand, so the type of surface the carcass rested on was coincidence. However, those carcasses that rested on sand were scavenged much faster than those on rock, presumably due to the more abundant and greater diversity of animals which lived within the sand.

The only wound deliberately inflicted on the carcasses was the death wound, a small round wound in the skull, caused by the butcher's pin-gun. However, several of the carcasses had other injuries, including a cut ear, prolapsed bowel, and sores on the shoulders and hind quarters. Within hours, a species of whelk, the wrinkled amphissa, (*Strongylocentrotus droebachiensis*), was attracted to the head wounds. However, other than this early colonization, the wound sites were no more attractive to fauna than non-wound sites. Abraded and non-abraded skin was equally attractive to animals, and many species created openings or abraded areas in the skin. The sunflower sea star (*Pycnopodia helianthoides*) in particular, caused large abraded areas, which in some cases, abraded the tissue down to muscle and tendons. In some cases, whelks bored into the skin and muscle, creating artifacts that, in a human death investigation, might be mistaken for premortem wounds.

Discussion

Typical decompositional characteristics associated with aquatic habitats were observed including lividity, bloating, marbling, hair shedding, skin sloughing, scavenging, adipocere formation, flesh decaying, exposure of internal organs, algae accumulation, silting, disarticulation of bones, and algae staining on bones [1, 10, 13, 14, 15, 16].

The bloat stage ended in carcasses on land due primarily to the activities of Calliphoridae larvae (Diptera: Calliphoridae) which penetrated the carcass [12]. However, in both the marine and freshwater environments, no such penetration occurred. Even when the marine carcasses were almost skeletonized, gases caught in the intestine still allowed the carcasses to float. This extended bloat period was also seen in the freshwater environment, but the appearance of bloat lasted for weeks longer primarily due to the hardening of the exposed tissue due to adipocere formation, rather than gas presence. Whether the marine carcasses sank or floated may have had a major impact on decomposition rate and faunal colonization, as carcasses that float are only accessible to organisms which float or swim. Many predators, such as crustaceans are primarily associated with sediment, therefore, they would not feed on remains that were not in contact with the ground. It was noted that carcasses which sank and stayed in contact with the sediment, were much more scavenged and more rapidly skeletonized than those that floated. In freshwater experiments, terrestrial vertebrate scavengers were attracted only to the exposed regions of floating carcasses in running water [15]. Once the freshwater carcasses were scavenged, they sank and were then colonized by a much greater number and diversity of aquatic organisms than those that floated [15], presumably again due to the presence of large numbers of benthic organisms in the sediment.

Many variables impact the decomposition of carrion in the marine environment [3]. In this study, the simple fact of either sinking or floating, and the surface that the carcass had contact with, had a greater effect on decomposition and scavenging than did depth of submergence. In freshwater experiments, whether the water was running, such as in a stream, or still, such as in a pond, had an impact on the decompositional stages and faunal colonization. Sorg et al. list a variety of independent variables that can impact the postmortem condition of a human body in the marine environment, including access to the water surface, water and air temperature, clothing, energy of water movement, biodiversity, sea floor substrate, sea floor geology, time of death, and water chemistry [3]. Sea floor geology and substrate had the most impact on decomposition in this experiment; however, greater differences in depth may have a greater influence.

Carcasses in the marine environment were allowed to float or sink, but were not allowed to rise to the surface. Decomposition would probably have been quite different had the remains surfaced. The position of a body in relation to the water line will affect the rate and sequence of soft tissue decomposition and eventual disarticulation of bones [1, 10, 13, 14, 15, 16, 17, 18]. The formation of adipocere tissue was obvious on several of the marine carcasses around 40 days after submergence. This is consistent with that reported in many human cases in the marine environment [7, 18], and also with the onset of adipocere in freshwater environments in B.C. [1, 10, 13, 14, 15]. However, a recent B.C. study of human cases did not report adipocere formation until 105 days post-submergence [16]. This may reflect the small sample size, or the variability of this phenomenon.

Haglund and Sorg [18] presented a table of the taphonomic modifications seen in human bodies submerged in aquatic environments. Many of the features described in humans were clearly evident in the pig carcasses including bioerosion (corrosive processes by organisms), decompo-

sition changes, disarticulation, scavenging and fragmentation.

On land, insects are usually the main colonizers of carrion, and the first to arrive are usually the blow flies (Diptera: Calliphoridae) [12, 19, 20, 21]. These are attracted to a wound site first, or if no wounds are present, the natural orifices [12, 19, 22]. However, in both these experiments, and those in freshwater [1, 10, 13, 14, 15] the wounds were not found to be particularly attractive to animal scavenging. In fact, many animals fed directly on the intact skin and created artifacts that could be misconstrued as a premortem wound.

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References

1. Anderson GS (2001) Insect succession on carrion and its relationship to determining time of death. In: Byrd JH, Castner JL (eds) Forensic entomology. The utility of arthropods in legal investigations. CRC Press, Boca Raton, pp 143–175
2. Bourel B, Tournel G, Hedouin V, Gosset D (2004) Entomofauna of buried bodies in France. Int J Legal Med DOI: 10.1007.s00414-004-0449-0
3. Sorg MH, Dearborn JH, Monahan EI, Ryan HF, Sweeney KG, David E (1997) Forensic taphonomy in marine contexts. In: Haglund WD, Sorg MH (eds) Forensic taphonomy. The postmortem fate of human remains. CRC Press, Boca Raton, pp 567–604
4. Haglund WD (1993) Disappearance of soft tissue and the disarticulation of human remains from aqueous environments. J Forensic Sci 38:806–815
5. Ebbesmeyer CC, Haglund WD (1994) Drift trajectories of a floating human body simulated in a hydraulic model of Puget Sound. J Forensic Sci 39:231–240
6. Boyle S, Galloway A, Mason RT (1997) Human aquatic taphonomy in the Monterey Bay area. In: Haglund WD, Sorg, MH (eds) Forensic taphonomy. The postmortem fate of human remains. CRC Press, Boca Raton, p 605–613
7. Kahana T, Almog J, Levy J, Shmeltzer E, Spier Y, Hiss J (1999) Marine taphonomy; adipocere formation in a series of bodies recovered from a single shipwreck. J Forensic Sci 44:897–901
8. Davis JB, Goff ML (2000) Decomposition patterns in terrestrial and intertidal habitats on Oahu Island and Coconut Island, Hawaii. J Forensic Sci 45:836–842
9. Ebbesmeyer CC, Haglund WD (2002) Floating remains on Pacific Northwest waters. In: Haglund WD, Sorg MH, (eds) Advances in forensic taphonomy method, theory and archeological perspectives. CRC Press, Boca Raton, pp 219–240
10. Anderson GS, Hobischak NR (2002) Determination of time of death for humans discovered in saltwater using aquatic organism succession and decomposition rates. Canadian Police Research Centre, Technical Report. Ottawa, ON, p 75
11. Catts EP, Goff ML (1992) Forensic entomology in criminal investigations. Ann Rev Entomol 37:253–272
12. Anderson GS, VanLaerhoven SL (1996) Initial studies on insect succession on carrion in southwestern British Columbia. J Forensic Sci 41:617–625
13. Hobischak NR, Anderson GS (1999) Freshwater-related death investigations in British Columbia in 1995–1996. A review of coroners cases. Can Soc Forensic Sci J 32:97–106
14. Hobischak NR, Anderson GS (2002) Time of submergence using aquatic invertebrate succession and decompositional changes. J. Forensic Sci 47:142–151
15. Hobischak NR (1998) Freshwater invertebrate succession and decompositional studies on carrion in British Columbia. Canadian Police Research Centre, Technical Report, Ottawa, ON. TR-10-98, p 54
16. Petrik MS, Hobischak NR, Anderson GS (2004) Examination of factors surrounding freshwater decomposition in death investigations: a review of body recoveries and coroner cases in British Columbia. Can Soc Forensic Sci J 37(1):9–17
17. Payne JA, King EW (1972) Insect succession and decomposition of pig carcasses in water. J Georgia Entomol Soc 73: 153–162
18. Haglund WD, Sorg MH (eds) (2002) Human remains in water environments. In: Advances in forensic taphonomy method, theory and archeological perspectives. CRC Press, Boca Raton, pp 201–218
19. Nuorteva P (1977) Sarcosaprophagous insects as forensic indicators. In: Tedeschi CG, Eckert WG, Tedeschi LG (eds) Forensic medicine: a study in trauma and environmental hazards. Saunders, Philadelphia, pp 1072–1095
20. Erzinclioglu YZ (1983) The application of entomology to forensic medicine. Med Sci Law 23:57–63
21. Smith KGV (1986) A manual of forensic entomology. Trustees of The British Museum (Nat. Hist.) and Cornell University Press, pp 205
22. Rodriguez WCI (1997) Decomposition of buried and submerged bodies. In: Haglund WD, Sorg MH (eds) Forensic taphonomy. The postmortem fate of human remains. CRC Press, Boca Raton, p 459–467