HIGH SCHOOL EDITION
Journal of Student Research

Volume 12 Issue 4 (2023)

The Return of Organic Soft Tissue Preservation Abilities and the "Bog Body" Phenomenon in MLTT Restored Peatlands

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ABSTRACT

Climate change and human manipulation in peatlands threatens peatland health, presaging the loss of instrumental peatland functions including carbon sequestration or the bog body mummification function. In response, peatland ecologists are studying restoration methods to revive degenerating bogs, including the Rochefort Moss Layer Transfer Technique (MLTT). Since the advent of these studies, questions regarding the return of lost peatland functions have arisen. This study employed a qualitative experimental study of mammal soft tissue samples in a controlled incubatory environment mimicking an MLTT restored peatland to discern if the MLTT method induced the return of the bog body mummification function. The findings indicate that the function does appear to return, which crucially implies that restorative efforts in peatland ecology have a valid prospect with promising returns, therefore this field is worthwhile to continue because this study shows that it is possible to save peatlands and their functions, further permitting the archaeological community to save the artifacts found in peatlands.

Introduction

In 1950, on the Jutland Peninsula in Denmark, a male body was found buried nearly 2.5 meters under boggy peatland (Eisenbeiss 2016). Curled in the fetal position, the man, now known as the famous Tollund Man, had a rope around his peculiarly preserved neck (Figure 1) (Museum Silkeborg n.d.). Despite the logical assumption of foul play, the the macabre finding was not to spark a serious investigation of dark murder. Rather, it would begin the fascinating and indispensable archeological study of peatland bog bodies. His impeccable preservation, provided by his burial in the Bjældskovdal Peat Bog, allowed consultant archaeologists to determine the 2,400- to 2,200-year-old cadaver dated to the Pre-Roman Iron Age (400 BCE to 800 AD). He was estimated at 30 to 40 years old, donning a bonnet-like sheepskin hat and once standing at 161 centimeters in height (Museum Silkeborg n.d.). It was clear the ancient man was hanged. Medical examination by physicians Dr. Christian Bastrup and Dr. Bjovulf Vimtrup concluded the Tollund Man's neck vertebrae were intact, indicating his cause of death was not cervical dislocation, but instead asphyxiation (Museum Silkeborg n.d.). The physicians removed the man's internal organs; according to Dr. Nina H. Nielsen from the Museum Silkeborg, examinations suggested the Tollund Man ate barley porridge with pale persicaria and flax (Nielsen et al. 2021). In fact, the details ecologically engraved on the Tollund Man's well-preserved person were so fine, Bastrup and Vimtrup postulated the Tollund Man had eaten 12-14 hours before his hanging (Museum Silkeborg n.d.).

Fig 1. The Tollund Man (Wikimedia)

The Tollund Man is one example of an occurrence in physiological ecology known as the bog body phenomenon. The first bog body was identified in 1754 (Eisenbeiss 2016), and since then, upwards of 500 specimens have been recovered from Denmark, alongside numerous others from peatland sites in the United Kingdom, the Netherlands, Germany, and Ireland (Dell'Amore 2014). Some other well-known specimens of bog bodies are "The Girl from Uchter Moor", a 17–20-year-old female who was determined to have died sometime around 700 BCE when she was discovered in 2004 in Lower Saxony, Germany, and the Grauballe Man found in 1952 (Eisenbeiss 2016 & Lynnerup 2015). These and many other radical bog body finds gave the archaeological community exceptional insight into Northern Europe's Iron Age. The bodies serve as rare, time capsule-like artifacts representative of early civilizations.

Literature Review

Peatland Chemistry and Preservation Abilities

"Bog bodies" are naturally mummified organisms that provide glimpses into the past, such as those developed from the Pre-Roman Iron age (Museum Silkeborg n.d.).

Permitting forensic anthropologists to discern such minute details, which would have otherwise been lost to decomposition, were the bog bodies' unique burial sites: peatlands. Peatlands, also called bogs, are terrestrial marshy wetlands comprised of variegated vegetation and peat. Peat is the accumulation of partially decayed organic matter resulting from heavy water saturation. The water saturation is induced by the most notable of the various vegetation genus found in peatlands, *sphagnum*, a bryophyte moss which blankets peatland grounds (Xu 2021). These ecosystems are associated with cooler temperatures in the boreal Northern Hemisphere, endemic to the UK, Canada, and Scandinavian states (National Geographic 2022).

Many of peatlands' trademark characteristics are born of sphagnum moss. According to Mancini (2021), *sphagnum*'s sheet-like spread prevents the peat from fully decomposing by retaining precipitation, restricting oxygen entry to vegetation and soil layers such that microorganisms cannot break down dead plant matter. Concurrently, sphagnum moss absorbs calcium, nitrogen, and magnesium cations from soil and water, which renders peatlands highly acidic. Acidic and deoxidized environments are inhospitable to microorganisms that accelerate organic decay (P. Sheridan, personal communication, September 30, 2022). These circumstances impede organic plant matter decomposition causing decaying vegetation to accumulate into peat over time.

The same phenomena that produce peat also preserve foreign samples of mammal organic soft tissue matter, like that of bog bodies, in peatlands. For the purpose of my study, the operational definition of organic soft tissue matter refers to the skin and muscle tissues of mammals placed in a peatland with potential to be mummified as a bog body under the appropriate aforementioned conditions.

A telltale sign of *sphagnum*'s contact with soft mammal tissue is a tanned hide and dyed hair follicles (P. Sheridan, personal communication, September 30, 2022). The chemical make-up of *sphagnum* includes the glycuronoglycan similar to pectin known as *sphagnan,* which, due to its high levels of tannins, initiates a Maillard reaction to symptomatically produce the appearance of browned, leathery skin (Giles 2020; Lynnerup 2015; Painter 1991).

Problem & Relevance

According to Chimner et al. (2017), peatlands have been abused as a natural resource for centuries. Human manipulation, including organized burning, draining, grazing, and extraction for use in energy and heat production exploit peatland ecosystems to a detrimental extent. The Environmental Defense Fund (EDF 2022) asserts peatlands cover about 3% of Earth's surface area, yet, according to el-Sheikh (2022), about 12% of peatland surface area has undergone human manipulation in the form of drainage alone, while the EDF (2022) estimates it could be nearly 15%. Unfortunately, peatlands are infamously fragile, meaning slight artificial interference could drastically disorganize the specialized conditions that conserve bog bodies (O'Grady 2020).

Moreover, climate change presents another obstacle in mitigating preexisting damage to peatlands. Dr. Doria Gordon (as cited in EDF 2022) suggests global heating and drying of peatlands could irrevocably damage them as well as another of their particular functions that is similar to the mummifcation function: carbon sequestration. Carbon sequestration occurs when the amalgamation of peat stores carbon from the atmosphere and retains it, never fully decomposing to release it (Xu 2021). Because of this, peatlands are referred to as carbon sinks; in fact, up to 30% of the world's carbon supply is stored in peatlands (EDF 2022). Due to peatlands' frailty, even minimal disturbance to a peatland could deter carbon sequestration. Losing carbon sequestration could precipitate catastrophic releases of carbon into the atmosphere, inducing exponential greenhouse gas (GHG) production when consequent global warming further damages peatlands (Andersen, cited by Williams 2021).

Other researchers, however, such as Ward et al. (2015), suggest ambient temperatures of peatlands do not have as negative an impact as suggested by the EDF and Andersen (as cited by Williams 2021). For example, in Ward's study (2015), the team concluded the composition of vegetation in a peatland more strongly impacts the peatland's rate of plant decomposition/accumulation of peat than climate warming. Ward achieved this conclusion by examining different combinations of vegetation arrangements in specific temperatures in a peat bog over two years. Nonetheless, many researchers, including Schrier-Uijl et al. (2014), conclude human manipulation and damage to peatlands will result in GHG and carbon emissions. Schrier-Uijl's team observed GHG emissions from three peatlands that were manipulated intensively, extensively, and rewetted, respectively. In the manipulated sites, emissions were at 8 and above 6 (g CO2-eq m-2 d-1). In the rewetted site, emission rates dropped to -2 (g CO2-eq m-2 d-1), meaning it began to absorb GHGs once again (Schrier-Uijl 2014). This confirms damaged peatlands disperse GHGs while healthy sites absorb them.

For the archaeological community, damage to peatlands represents a major risk towards critical excavation sites and artifacts. Human manipulation and climate change stress the bog's qualities that serve as protective layers to organic material underneath, permitting oxygen to access previously encased under-layers of the marsh, where it facilitates fungi and bacteria growth. These fungi and bacteria decay the remaining tissue, assisted by the infiltrating oxygen that allows it to grow. As a result, the bog can no longer adequately preserve soft mammal tissue (O'Grady 2020). If peatlands lose this capacity, historians lose the archaeological boon of exquisite long-term mammal preservation. This is evidenced by archaeologist Adam Boethius from Lund University (cited by O'Grady 2020), who comparatively studied decay rates of different bones from Ageröd, a Swedish peatland. Boethius and his colleagues determined bones excavated from the bog in the 1940s and 1970s were in better condition than bones removed from the site in 2019, a finding that contradicts the expectation that the bogs would better preserve the bones. As cited by O'Grady (2020), wetland archaeologist Benjamin Gearey believes continued peatland degradation would force archaeologists to exhume the irreplaceable artifacts buried in th non-functioning peatlands. Thus, the significance of addressing this is twofold: further research on peatland health is necessary to improve our current understanding of these special ecosystems such that we can mitigate catastrophic climate change *and* preserve rare relics of the past that drive the studies of archaeology and anthropology.

Restoration Efforts

In response to this problem, ecologists are studying restoration methods to revive degenerated bogs. The difficulty in restoring peat bogs stems from our nominal understanding of them and their slow regeneration period (O'Grady 2020). Additionally, individual types of peatlands and unique damages require different approaches: some existing methods for restoration are rewetting, blocking, and gully restoration, which all employ hydrology to holistically rebuild the ecosystem (Chimner et al. 2017).

The focus of my study will be on Rochefort's Moss Layer Transfer Technique (MLTT), which was designed by Dr. Line Rochefort, peatland ecologist from the Université Laval in Canada (Rochefort et al. 2003 & Chimner et al. 2017). It encompasses rewetting the peatlands and adding sphagnum moss diaspores from undamaged peatlands to encourage the regrowth of lost moss foliage. In Rochefort's study, the researchers reintroduced *sphagnum* to the ecosystem with a series of five subsequent steps, being: field preparation, diaspore collection, diaspore introduction, diaspore protection with a mulch mixture, and fertilization with phosphorous. Given an elapsed period of approximately 10-20 years, Rochefort estimates the peatlands would completely regrow thanks to *sphagnum*'s return.

Chimner et al. (2017) suggests a limitation in the MLTT method, acknowledging that it does not offer sufficient opportunities to redevelop biodiversity in a rehabilitating peatland because the method only restores a homogenous moss layer. However, Vitt et al. (2011) claims transferring diaspores, like in MLTT, can encourage peat accumulation, indicating this method is conducive to reestablishing *sphagnum* peatlands.

Addressing the Gap

Based on my preliminary studies, little research exists on what can be done to save bog bodies. Chimner (2017) states following restoration treatment, further research is required to discern what peatland functions return, referring to the function of carbon sequestration. This sentiment is shared by Schrier-Uijl (2014), who questioned if restored peatlands saw the return of carbon sequestration after treatment. Rochefort et al. (2003) also asserts secondary research of the effects of MLTT are necessary. Therefore, considering the lack of existing research emphasizing bog body preservation in damaged peatlands and the affirmed need to research what peatland functions return after rehabilitation, I infer it is necessary to test for the return of the bog body preservation function following restoration treatment. Ergo, the question becomes: How will the Rochefort Moss Layer Transfer Technique (MLTT) impact the peatlands' ability to preserve mammal organic soft tissue matter in regards to the "bog body" phenomenon? This question can address the gap by affirming whether or not the mummification function is salvageable following restoration and satiating this unknown piece of bog body studies.

Assumptions & Hypothesis

In the real-world field of peatland science, research on function salvageability after restoration works under the assumption that the peatland was once damaged, and after the restoration, it is restored to its initial state. In regard to bog body preservation after the MLTT method, I hypothesize if the method fully restores the peatland such that the sample is waterlogged and acidic, then the peatland will intuitively preserve soft tissue once again.

Methodology

The purpose of my study is to determine if burying organic matter in a peatland restored by the MLTT method will alter its rate of decay and if the matter will exhibit signs of natural embalming. Decay is both a qualitative and quantitative concept, as it has numerical consequences in mass change as well as visual indicators. However, while normal decay typically leads to reduction in mass, bog bodies also shrink due to acidity, therefore it is difficult to extrapolate data from mass changes (Lynnerup 2015). As such, I determined the best method for my study would be qualitative to integrate this facet. To test for a specific variable, I had to construct a controlled environment to isolate it, making it an experimental study with an explanatory approach. Additionally, as my topic is generalizable to ecology and archaeology, both sciences, my discipline is scientific; explanatory experiments are staples of the science discipline. When constructing the design of my study, I referenced Carter & Tibbett (2004), researchers who studied decay rates of buried skeletal muscle tissue in incubatory environments, as well as Ellerman (as cited by Andersen & Geertinger 1984; Giles 2020), who was one of the first forensic anthropologists to study skin tissue samples and peat bog mummification in an artificial peatland environment.

Therefore, the basic methodology of my inquiry is a qualitative experimental study of pig matter samples in a controlled incubatory environment mimicking a restored peatland. Because I needed to physically examine mammal samples for traits of mummification and decay, it is necessary to employ an approach such as this to observe these traits in a hands-on manner; this design will allow me to observe differences in mummification symptoms and decay rates between treated and non-treated mammal samples. Before starting, the Institutional Review Board approved my proposal. To begin, I collected the following materials.

Materials

1. 1.483 kg of MLTT peat. To collect this, I contacted Université Laval in Quebec, Canada.
2. A slightly holed rectangular acrylic vivarium with a removable lid. See Figure 4 to see hole size. It maintained a volume of about 8.5 liters of volume. It had both a hygrometer and a Fahrenheit thermometer built in it, as seen in Figure 2.
3.

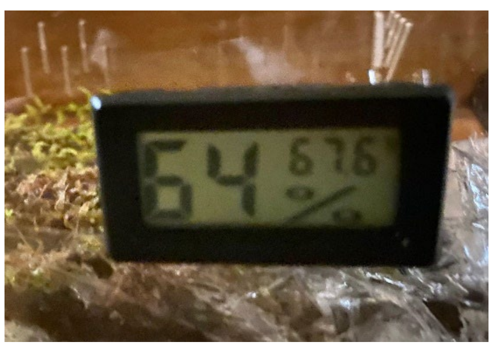


Fig 2. Hydrometer and Thermometer on Vivarium

4. 1.079 kg of a natural sandy dirt mixture.
5. I purchased samples of generic pork fatback and pig loin chops from a general grocery store to serve as organic mammal matter. I did this because it was easily available to me, and, according to Luo et al. (2012), pigs are anatomically, genetically, and physiologically similar to humans. The fatback is analogous to the soft tissue of skin and fat of a bog body, while the loin chops are representative of muscle tissue. I selected four slabs of

refrigerated pork fatback, at 50g, 65g, 85g, and 72g. Then, I collected four slabs of refrigerated pork loins, weighing at 63g, 60g, 47g, and 47g grams.

6. 104 grams of sphagnum moss (Fig. 3), as well as saran wrap, household lime juice, distilled water, and pH indicator testing strips.

Fig. 3 Sphagnum Moss On Top of Moss On Top of Peat

Preparations

1. To avoid leakage in my vivarium, I layered the bottom surface in saran wrap. I placed the MLTT peat and natural sandy dirt in varying layers in the vivarium to mimic the peaty soil mixtures of peatlands. Officially, I layered it with 576g, 457g, and 46g of dirt, alternated with 646g, 505g, and 332g of peat.
2. I gently packed the mixture in then soaked it with about 240g of distilled water. This mimics the waterlogged environment of a peatland. I spread out the sphagnum moss evenly on top of the peat mixture and added about another 120g of distilled water.
3. I tested for initial temperature, humidity, and pH of the ecosystem. The setup of the vivarium can be seen in Figure 4.

Fig. 4 Vivarium Setup

Finally, I allowed the ecosystem to rest for about 48 hours to reach a rested state of equilibrium.

4. I gathered my pig samples. All samples were previously refrigerated and potentially frozen. This likely has no impact on my results as it was uniformly done to all samples, and it is not unlike the possibility that real world bog bodies are frozen or chilled annually in the cold temperature of their native northern regions. I made sure to

rinse the fatback samples of all salt with lukewarm water and pat them dry to avoid influence of salt preservatives. I then weighed each sample and photographed them for reference data.

5. Taking a 50g fatback and a 47g muscle sample, I dug two small holes in the vivarium's peat about 6.35cm apart, as far apart as the vivarium allowed. I placed the fatback and muscle into each gap. Then, I covered the samples with the peat/dirt mixture, disturbing the sphagnum as minimally as possible. I patted the surface back into its packed position and soaked the ecosystem with 240g of distilled water to maintain heavy waterlogging in the ecosystem. The buried samples are Test Group A, the experimental group.
6. I placed the remaining fatback and muscle samples in a small tray, and lay them distantly from each other. I placed the tray on top of the peat and closed the vivarium lid. These samples served as the control for the experiment, and they will be referred to as Test Group B. They were placed within the vivarium to expose them to the same ambient conditions as Test Group A and isolate the independent variable of burial in the peat. This entire set up will be referred to as Test Group 1, as this process will be replicated and called Test Group 2.
7. After 31 days, I removed Test Group 1, and replicated the procedure with the remaining fatback and muscles samples starting at Step 3, above. This replication is known as Test Group 2.

Procedure

I continually monitored the ecosystem for 31 days, adding a standard approximate 120g of water daily to maintain a humidity around 65-90%, in accordance with care parameters suggested by Bantum. Earth, as this implied waterlog. For reference on the recorded conditions of each replication in my study, see Appendices A and B. On Day 20 of Test Group 1, when I noticed difficulty in upholding necessary soil acidity, I began adding 5g of lime juice, mixed with the water, daily to maintain a pH around 6 to 6.5. For consistency, I added lime juice to Test Group 2 starting on Day 20 as well. While I occasionally had to relocate the vivarium, it was consistently kept in regular daylight conditions. From Day 15 to Day 30, the Test Group 1 vivarium was placed in a fume hood to avoid putrid odors. I maintained these conditions in accordance with instructions I gathered from the nursery where I retrieved the sphagnum moss.

Variables

In sum, the dependent variable of this experiment is the rate of decay and the indications of bog body mummification of the Test Groups. The independent variables is whether or not the Test Group was buried in a peatland. The constants of uniformity were time period and the external conditions of humidity and temperature.

Data Collection

On the 31st day, I removed all samples from the vivarium and rinsed Test Group A as much as possible without disrupting their surface appearances. I weighed and photographed them once again, comparatively examining their mass, their visual appearances, apparent symptoms of mummification, and states of decay.

Data Analysis

To qualitatively analyze my data, I summarized the Australian Museum's *Stages of Decomposition* (2020) synthesized with *Evaluation of Postmortem Changes* from Almulhim & Menzies (2022) to discern the states of decay of the samples (Table 1). To determine symptoms of bog body mummification, I summarized the descriptions of the phenomenon provided by Lynnerup (2015) (Table 2). I will refer to these charts to examine the signs of bog body mummification by searching for the visual indicators they describe on the samples and identifying them. I did this to standardize my evaluations to an objective and credible categorization of the qualitative components I examined, making the analysis uniform in any replication.

The most critical point of analysis will be the appearance of Maillard tanning. As aforementioned, Maillard tanning causes the appearance of browned, leathery tissue on samples, according to Giles (2020 Lynnerup (2015), and Painter (1991). This unique trait of bog bodies is most indicative of healthy *sphagnum* within a healthily functioning peatland. As such, the appearance of brown pigment on the samples will be necessary to suggest functional peat.

Table 1: Synthesis of Australian Museum's *Stages of Decomposition* (2020) and *Evaluation of Postmortem Changes* (Almulhim & Menezes 2022).

Stage 1: The Live Organism	Organism is functioning naturally
Stage 2: Initial Decay/The Fresh Stage, 0-3 Days Post-mortem	Algor Mortis- Body temperature equalizes ambient temperature Livor Mortis- Blood pools in parts of the organism closest the ground as a result of gravity Rigor Mortis-Body becomes rigid as muscles stiffen
Stage 3: Putrefaction/Active Decay, 4-10 Days Post-mortem	Bloating Skin discoloration, often green or black Hair detaches Marbling of skin from blood vessels Flaccidity temporarily returns after rigor mortis
Stage 4: Black Putrefaction/Advanced Decay, 10-20 Days Postmortem	Bloating collapses Flesh maintains soft, cream-like texture
Stage 5: Butyric Fermentation/Advanced Decay, 20-50 Days Postmortem	Mold propagates Butyric acid produces a smell reminiscent of cheese All flesh is removed
Stage 6: Dry Decay/Skeletal Stage, 50-365+ Days Post-mortem	Extremely dried Presence of mold and microorganisms depletes remaining tissue Extensive bone exposure Little soft tissue remains

Table 2: Synthesis of Lynnerup's Bog Body Mummification Characteristics

Tanned, browned hide - Indicative of Maillard reaction
No epidermal keratin
Soft, pliable consistency
Shrunken, shriveled appearance
Waterlogged

Results

The following chapter will divulge the changes in the samples in Tables 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, and 13. Figure 3 demonstrates what fatback and muscle samples looked like before the study period, given as a reference for the changes seen post study period.

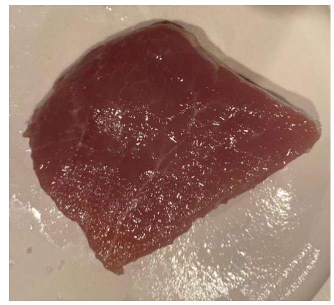
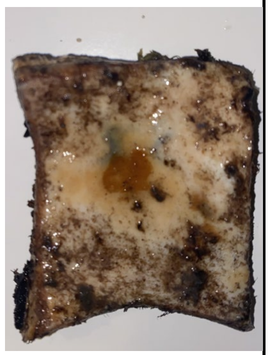
Fatback	Muscle
	

Fig. 3: Images of Fatback and Muscle Before Manipulation

Table 3: Images of Test Group 1 After 31 Days of Peat Burial

Fatback Experimental Sample | Test Group 1A		Fatback Control Sample | Test Group 1B	
Muscle Experimental Sample | Test Group 1A		Muscle Control Sample | Test Group 1B	

Table 4: Images of Test Group 2 After 31 Days of Peat Burial

Fatback Experimental Sample | Test Group 2A		Fatback Control Sample | Test Group 2B	
Muscle Experimental Sample | Test Group 2A	After: 	Muscle Control Samples | Test Group 2B	

Tables 3 and 4 depict the holistic transformation of Test Groups 1 and 2 after the study's period of 31 days. I discuss the characteristics of each individual sample further in the following tables.

Table 5: Changes in Test Group 1A | Experimental Sample Fatback

	Pre-Test	Post-Test
Mass	85g	58g
Visual/Perceivable Characteristics	Thick, waxy consistency Cream, light colored epidermis Dry and rough exterior, simultaneously hydrated Dense but somewhat flexible	Pliable, soft, and mushy consistency, bloated and spongy Visible brown lines and tan shading developed on epidermis Gelled, creamy film Putrid smell

Table 6: Changes in Test Group 1A | Experimental Sample Muscle

	Pre-Test	Post-Test
Mass	47g	39g
Visual/Perceivable	Warm pink hue Tender and flaccid yet dense White lines of fat Moist	Pale, bleached color on wide surfaces, with a visible creamy, opaque film Pinkish red color still visible on narrow sides Moist, malleable, squishy, and wet Crevices tanned and shaded, darkened contrast against pale color Putrid smell

Table 7: Test Group 1B | Control Sample Fatback

	Pre-Test	Post-Test
Mass	72g	64g
Visual/Perceivable Characteristics	Thick, waxy consistency Cream, light colored epidermis Dry and rough exterior Dense but somewhat flexible	Dotted with spots of white mold Adamantine, stiff, and dry Darkened exterior, but still maintaining a pale cream-colored base

Table 8: Test Group 1B | Control Sample Muscle

	Pre-Test	Post-Test
Mass	47g	16g
Visual/Perceivable Characteristics	Warm pink hue Tender and flaccid yet dense White lines of fat Moist	Hardened, crusted, stiff, rock-like Extremely darkened to a maroon, blood red color Wrinkled and shriveled Dry Lines of fat thickened and swollen Molded

Table 9: Test Group 2A | Experimental Sample Fatback

	Pre-Test	Post-Test
Mass	50g	45g
Visual/Perceivable Characteristics	Thick, waxy consistency Cream, light colored epidermis Dry and rough exterior Dense but somewhat flexible	Slimy film developed, appears shiny Deeply concentrated splotches of brown tanning Moist, soggy Shrunken and collapsed

Table 10: Test Group 2A | Experimental Sample Muscle

	Pre-Test	Post-Test
Mass	60g	42g
Visual/Perceivable Characteristics	Warm pink hue Tender and flaccid yet dense White lines of fat Moist	Wrinkled exterior, likely due to vasoconstriction in watery environment Stressed highlighting of muscle grain (more obvious streaks of white) Deep tanning in crevices, heavy clustered of tanning near poles of sample Untanned regions demonstrate bleached, lighter pink color

Table 11: Test Group 2B | Control Sample Fatback

	Pre-Test	Post-Test
Mass	65g	62g
Visual/Perceivable Characteristics	Thick, waxy consistency Cream, light colored epidermis Dry and rough exterior Dense but somewhat flexible	Dry, stiff White mold Splotches of darkening Epidermis is tight

Table 12: Test Group 2B | Control Sample Muscle

	Pre-Test	Post-Test
Mass	63g	32g
Visual/Perceivable Characteristics	Warm pink hue Tender and flaccid yet dense White lines of fat Moist	Extremely molded, variety of mold appearances Deeply maroon hue Sections of fat are lighter, thicker

Discussion

The purpose of my study was to learn whether or not peat developed in a restored peatland from Rochefort's MLTT method could regain its ability to preserve organic soft tissue matter as exemplified by bog body mummification. I initially hypothesized the MLTT peat, when maintained in necessary waterlogged and acidic conditions, would regain its mummification abilities. Following my study, results indicate beginning signs of mummification, meaning MLTT peat regained its ability to mummify organic soft mammal tissue. The following chapter will analyze the changes in each sample based on Tables 1 and 2. These results answer the research inquiry by evidencing the conclusion the MLTT method impacts a peatland's mummification function by categorically encouraging the abilities' return.

Changes in Test Group 1A | Experimental Sample Fatback

Table 13 | Experimental Sample Fatback Analysis
Represents the experimental fatback analogous to bog body skin and fat tissue

Pliable, soft, and mushy consistency, bloated and spongy Visible brown lines and tan shading developed on epidermis Gelled, creamy film Putrid smell	The obvious tanning marks suggest a Maillard reaction occurred in the presence of *sphagnan*, meaning the peat was active in mummifying the samples. Additionally, the sample's simultaneously shrunken yet waterlogged state is also evidence of functional mummification processes, as the type of environment that produces these characteristics is conducive to long term preservation. In regards to the general rate of decay, it can be deduced that this sample was between Stages 4 and 5, due to its collapsed structure and creamy consistency as well as its stark stench.

Changes in Test Group 1A | Experimental Sample Muscle

Table 14 | Experimental Sample Muscle Analysis
Represents the experimental muscle analogous to bog body muscle tissue

Pale, bleached color on wide surfaces, with a visible creamy, opaque film Pinkish red color still visible on narrow sides Moist, malleable, squishy, and wet Crevices tanned and shaded, darkened contrast against pale color Putrid smell	The signs of darkening in the crevices imply the functionality of Maillard reactions and *sphagnan* tanning, proving the initiation of mummification. Its development of a creamy film is also a sign of mummification. For its decay, the sample is likely in between Stages 4 and 5 as evidenced by its waterlog and opaque film.

Changes in Test Group 1B | Control Sample Fatback

Table 15 | Control Sample Fatback Analysis

Represents the non-experimental fatback analogous to regularly decayed soft organic tissue matter

Dotted with spots of white mold Adamantine, stiff, and dry Darkened exterior, but still maintaining a pale cream-colored base	As this sample was not buried in peat, it would show no signs of mummification. However, it serves as a clear reference to changes in the experimentally buried fatback that highlights the evidence of *sphagnan* tanning. The darkened, discolored exterior differs from the bleached yet spottily tanned experimental sample, while the stiffness of the control sample contrasts the experimental's shrunken, flimsy state of waterlog. Finally, I presume this control fatback sample to be between Stages 5 and 6 of decay, as it has much mold, is very dry, and extremely stiff.

Changes in Test Group 1B | Control Sample Muscle

Table 16 | Control Sample Muscle Analysis

Represents the non-experimental muscle analogous to regularly decayed soft organic tissue matter

Hardened, crusted, stiff, rock-like Extremely darkened to a maroon, blood red color Wrinkled and shriveled Dry Lines of fat thickened and swollen Molded	As this sample was not buried in peat, it would show no signs of mummification. However, it also serves as a clear reference to changes in the experimentally buried muscle that highlights the evidence of *sphagnan* tanning. Its extremely shrunken size is dwarfed by the experimental sample's bloated, although collapsed, state of moisture. As the color of this control sample deeply darkened, the experimental sample was largely bleach and contoured by deep tanning in its crevices. This control sample is likely also in Stages 5 to 6 of decay as shown by its heavy mold, drastic mass loss, and rock-like stiffness.

Changes in Test Group 2A | Experimental Sample Fatback

Table 17 | Experimental Sample Fatback Analysis
Represents the experimental fatback analogous to bog body skin and fat tissue

Slimy film developed, appears shiny Deeply concentrated splotches of brown tanning Moist, soggy Shrunken and collapsed	The browning tanning suggests a Maillard reaction similar to that of real bog bodies, meaning the process of mummification has begun. Its sogginess is also characteristic of the mummification process. For decay, the sample its likely in Stage 4, as it is certainly not in dry decay (Stage 6), and it has the creamy-film consistency associated with Stage 4.

Changes in Test Group 2A | Experimental Sample Muscle

Table 18 | Experimental Sample Muscle Analysis
Represents the experimental muscle analogous to bog body muscle tissue

Wrinkled exterior, likely due to vasoconstriction in watery environment Stressed highlighting of muscle grain (more obvious streaks of white) Deep tanning in crevices, heavy clustered of tanning near poles of sample Untanned regions demonstrate bleached, lighter pink color	The wrinkles induced by vasoconstriction (narrowing of blood vessels) water indicate the waterlog similar to mummified bog bodies. Additionally, the tanning in each crevice suggests a fledging tanned hide. In decay, its probable the sample is in Stage 4 due to its collapsed, wrinkly bloat and slimy film.

Changes in Test Group 2B | Control Sample Fatback

Table 19 | Control Sample Fatback Analysis
Represents the non-experimental fatback analogous to regularly decayed soft organic tissue matter

Dry, stiff White mold Splotches of darkening Epidermis is tight Foul smell	This sample, as a control, would not show signs of mummification, having not undergone the independent variable of burial in peat. Comparing it to the experimental fatback, its lack of tanning confirms that the agent causing the tanning on the experimental was the peat, implying a mummification capability in the restored peat. For decay the sample is likely in Stage 5; it has mold growth,and the epidermal layer is receding, as suggested its tightness.

Changes in Test Group 2B | Control Sample Muscle

Table 20 | Control Sample Muscle Analysis
Represents the non-experimental muscle analogous to regularly decayed soft organic tissue matter

Extremely molded, variety of mold appearances Deeply maroon hue Sections of fat are lighter, thicker Foul smell	As this sample was so heavily molded, it can easily be categorized as being in Stage 5 of Decay, during which mold develops most exponentially. This also induced the trademark foul smell of Stage 5. The mold kept the sample in a moister state, eliminating the possibility of the sample being in Stage 6.

General Analysis

As described in Tables 13-20, a pattern exists in the general determination of decay stages, where experimentally buried samples are in an earlier stage of decay than the control samples. For example, in Table 13, the fatback sample of Test Group 1A was suggested to be in between Stages 4 and 5 on decay. Comparatively, in Table 15, the fatback of Test Group 1B was estimated at Stages 5 to 6, with a much stiffer, dryer exterior indicative of dry decay. A similar finding is recorded in the fatback samples of Test Group 2, meaning there is a consistency in this result (Tables 17, 19). In Test Group 2, control samples were typically one stage of decay ahead of the experimental samples. Moreover, the appearance of dark tanning splotches differs from the control samples, suggesting the restored peat caused Maillard reaction tanning. Tables 3 and 4 demonstrate visual reference of this phenomenon in the strongest examples, which are the experimental fatbacks from both Test Groups. According to Table 2, this evidences a mummification tendency in the restored peat. The ostensible *sphagnan* tanning in the experimental samples is a telltale sign of healthy peat that functionally preserves soft organic tissue matter such that a tanned bog body is produced. When approaching my conclusion, I reasoned that because the experimental samples had consistently decayed less than the control samples, and the experimental samples also all had Maillard tanning, the evidence strongly suggests, based on the reasoning of Giles (2020), Lynnerup (2015), Ellerman, the Australian Museum (2020) and Almulhim and Menzes (2022), that the peat was beginning to mummify the samples. Therefore, I can conclude the MLTT method seems to restore peatlands such that they can mummify a mammal's organic soft tissue matter.

Contribution to Existing Body of Knowledge & Implications

This finding that the restored peat regained its mummification ability expands on the ideas of Chimner et al. (2017), who inquired about the return of peatland functions post-restoration; this study suggests the function of soft organic tissue matter preservation returns. This finding also adds to Rochefort et al. (2003); the MLTT method originates from Rochefort's study, thus these findings elaborating on the MLTT method's impact on peatland functions build on the understanding and veritability of Rochefort's technique. These findings coincide with the study by Schrier Uijl et al. (2014) who tested for the return of carbon sequestration and the reduction of GHG emission following a restoration method that consisted of rewetting and reducing human manipulation. Both this study and Schrier Uijl et al. (2014) indicate the return of lost peatland functions.

In archaeological studies, this finding addresses fears exhibited by O'Grady (2020) and Gearey (as cited by O'Grady 2020), which assert damaged peatlands will inhibit archaeological discoveries, by proffering the MLTT method as a potential solution. However, the method is hindered by its time-consuming execution; artifacts could deteriorate in the time required to redevelop a damaged peatland, a prospect suggested by Boethius (as cited by O'Grady 2020), who asserted even minimal exposure of the artifacts from peat damage could induce an irrevocable process of deterioration. Despite this concern, peatlands containing bog bodies not yet exposed can be protected with MLTT, based on the findings of this study.

Limitations

There were some notable limitations in my study's execution, many of which are a result of my peatland ecosystem being artificially manufactured. Firstly, I was unable to perform many trials due to a lack of space in my vivarium and resources to enlarge it. However, the second replication of data (Test Group 2) displays consistency in results, strengthens the current data, and also proves the replicability of the method itself, suggesting further credibility. However, as the two replications were not performed in simultaneous time periods and thus were not tested under the exact same conditions, they cannot be comparatively interpolated. Maintaining consistent humidity, pH, and temperature in the vivarium was difficult, which could be impactful in the health of the peat and *sphagnum*. This was exaggerated by the location of the vivarium; for a portion of my observation time of Test Group 1, the vivarium was located in my high school laboratory, meaning I did not have access to it over weekends to add the daily 120g of water and 5g of lime juice, meaning the conditions could shift in those unattended periods. However, this is likely excusable due to inevitable changes in a real-world peatland. Additionally, as this peatland was only recently created, there could have been slight damage to the peat while I managed it. Another limitation is the relatively short period of decay; Test Groups 1 and 2 only had 31 days to decompose versus real-world bog bodies' years-long gestation time. However, according to the Australian Museum in New South Wales (2020), the final stage of decay is typically achieved around 50 days after death. This means the meat samples had sufficient time to decay, but it is uncertain if Test Group A would have had sufficient time to embalm. Finally, the soft tissue I tested were mere samples of tissue and were not actual carcasses nor organisms that were buried and began decay immediately postmortem. Therefore, my analysis of decay rates is limited in that it does not exactly emulate the decay rates of a full cadaver. Additionally, this study only looked at mammal bog bodies, and not other organisms that could be mummified in peat. These limitations impact my potential conclusion by possibly impacting my results and analysis, suggesting they may not be as applicable to all real-world bog bodies. Nonetheless, we can make inferences as to how this finding would impact the real-world specimens knowing the peatland itself can induce mummification symptoms.

Conclusion

Implications

As inferred from the results of this study, it can be concluded that the MLTT method seems to restore peat in peatlands such that they can mummify a mammal's soft organic tissue matter, which confirms my initial hypothesis postulating so. This conclusion implies restorative efforts in peatland ecology have a valid prospect with promising returns, therefore this field is worthwhile because it is possible to mitigate peatland damage with restoration methods and restore a peatland function. This implies that because peatland functions appear to return after restoration, bog bodies have hope to be protected by peatlands, and other functions, such as carbon sequestration, can be saved and used to address topical issues such as climate change. As Chimner et al. (2017) asserted, it is needed to research the impacts of restoration and what lost peatland functions return, and this study exemplifies that requested investigation of restoration methods, specifically Rochefort's MLTT method, while also supporting investment in other studies on the topic by suggesting such methods can work. The study also opens the door to efforts of developing effective methods to save endangered bog body specimens, now knowing their natural tombs can be sustained.

Future Research

To expand upon the results of this study, future research should confirm or negate these findings by applying them to other variables, specifically considering MLTT's impact on the return of other peatland functions, such as carbon sequestration or shoreline erosion mitigation. Another angle is studying other restoration methods, such as gully restoration and blocking (Chimner et al. 2017), and their impact on the return of these same functions. Such studies can use my approach of an artificial environment that mimics a peatland. Also, because peatland functions can be restored, studies should research if bog bodies once exposed in now restored peatlands can be salvaged to address MLTT's time limitation and Boethius' fears (as cited by O'Grady 2020).

In terms of replicating my study, future attempts could improve my approach by lengthening the experimental time period to more than 31 days to more accurately mimic the burial time of real bog bodies; expanding the time by multiple years would further solidify any consequent results. Additional improvements include more trials to ensure more consistency; examining for more distinguishing chemical confirmations of Maillard tanning, such as estimating the remaining unbound amino acids after postulating the reaction occurred (Aalaei et al. (2019); and determining how specific factors impact the efficacy of bog body mummification, such as a constant pH, humidity, or temperature. Such positive alterations would help to severalize our comprehension of bog body minutiae and ameliorate this field for posterity. In sum, the understanding this study produces predicts a sustainable future in bog body archaeology and peatland science by demonstrating the positive return investment of restoration studies.

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