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Species Identification of Inuit Skin and Fur Clothing: Analyses of DNA, Hair Microscopy, and Macroscopical Identification

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ABSTRACT. From approximately 1830 to 1940, through various expeditions to Siberia, Arctic North America, and Greenland, and through donations, the National Museum of Denmark acquired its collection of historical Inuit skin clothing. Unfortunately, original provenance information has been lost for 14% of the garments. In order to document the extensive collection, this study investigates three methods for species identification of animal skin: microscopy of hair, macroscopic identification, and DNA validation. Thus, the present study has two aims: first, to optimise and test hair microscopy for species identification by validating identifications by DNA analyses, and second, to use species identification to estimate the geographic and cultural provenance of Inuit skin clothing.

Based on a dataset of well-documented clothing (for positive controls), this study describes an optimised species identification protocol via hair microscopy using transmitted light microscopy (TLM). We demonstrate that the TLM hair protocol is a reliable and inexpensive alternative to molecular approaches when macroscopic identification is doubtful and DNA validation or protein analyses are impossible. In this study we used photomicrographs to document the identifications of caribou (*Rangifer tarandus*), musk ox (*Ovibos moschatus*), species of the true seal family (Phocidae), domestic dog (*Canis lupus familiaris*), wolf (*Canis lupus*), Arctic fox (*Vulpes lagopus*), polar bear (*Ursus maritimus*), wolverine (*Gulo gulo*), ground squirrel (*Urocitellus parryii richardsonii*), ermine (*Mustela erminea*), and cattle (*Bos taurus*); these identifications can be used for future reference. We conclude that species identification analyses secure the documentation of garments and allow most objects to be contextualized by culture and geography. The studied garments are accessible at the museum website.

Keywords: species identification; hair microscopy; macroscopic identification; DNA analysis; hair photomicrographs; Inuit material culture

RÉSUMÉ. La collection historique de vêtements inuits en peau et en fourrure du musée national du Danemark a été constituée de 1830 à 1940 environ, et ce, grâce à diverses expéditions en Sibérie, dans les régions arctiques de l'Amérique du Nord et au Groenland ainsi que grâce à divers dons. Malheureusement, les informations originales sur la provenance de 14 % des vêtements demeurent introuvables. Afin de documenter cette collection d'envergure, la présente étude examine trois méthodes d'identification des peaux et des fourrures : microscopie des poils, identification macroscopique et validation de l'ADN. La présente étude compte deux objectifs : le premier objectif consiste à optimiser et à tester l'analyse microscopique des poils dans le but d'identifier les espèces en validant les identifications au moyen d'analyses d'ADN; le second consiste à estimer la provenance géographique et culturelle des vêtements inuits en peau ou en fourrure en s'appuyant sur les identifications d'espèces.

En se fondant sur une série de données bien documentées au sujet des vêtements (afin de disposer de contrôles positifs), la présente étude décrit un protocole d'identification optimisé des espèces au moyen de la microscopie des poils par lumière transmise (TLM). Nous démontrons que le protocole TLM constitue une option fiable et peu onéreuse comparativement aux méthodes moléculaires lorsque l'identification macroscopique est incertaine et que la validation de l'ADN ou les analyses protéiniques s'avèrent impossibles. Dans le cadre de cette étude, nous avons utilisé des microphotographies pour documenter les identifications de caribou (*Rangifer tarandus*), de bœuf musqué (*Ovibos moschatus*), d'espèces de la famille des vrais phoques (phocidés), de chien domestique (*Canis lupus familiaris*), de loup (*Canis lupus*), de renard polaire (*Vulpes lagopus*), d'ours polaire (*Ursus maritimus*), de glouton (*Gulo gulo*), de spermophile (*Urocitellus parryii richardsonii*), d'hermine (*Mustela erminea*) et de bovins (*Bos taurus*). Ces identifications pourront servir de référence à l'avenir. La conclusion générale que nous en tirons est que les analyses d'identification des espèces consolident la documentation sur les vêtements et permettent de placer la plupart des objets dans un contexte géographique et culturel. Les vêtements étudiés sont accessibles sur le site du musée.

Mots-clés : identification des espèces; microscopie des poils; identification macroscopique; analyse de l'ADN; microphotographies des poils; culture matérielle inuite

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INTRODUCTION

In museum collections, objects that have lost their original accession numbers or metadata have no connection to the archives. The National Museum of Denmark (NMD) holds an extensive collection of Inuit skin clothing from the Bering Strait region, through Arctic Canada, to Greenland. From 1830 to 1940, donors and various expeditions acquired the garments for the NMD. However, 14% (164 of 1177 garments) of the historical collection is currently without data. Thus, the connection to vital information, such as geographical and cultural affiliation, acquisition date, material, use, gender affiliation, original designation, for example, is missing. Such objects have consequently lost most of their cultural value and significance. To regain relevant archival information and restore historical and cultural value, the NMD aims to rediscover (or discover) the provenance and cultural affiliation of unrecorded or poorly documented Inuit skin and fur clothing.

The clothing consists of various elements of animal skin: fur skin or de-haired skin (with or without epidermis) and tissue covering hollow organs, such as the stomach, urinary bladder, and intestines (gut skin). In several cases, the visual appearance of clothing items clearly indicates that clothing makers integrate materials from more than one animal species. The availability of species, and hence, skins for clothing varied among the different groups of Inuit who hunted both terrestrial and marine animals and birds. By identifying the species used, we can gain insights into the provenance of Inuit garments. The outcome of our study demonstrates that species identification of skins is a crucial parameter that indicates the origin of a garment, and thus the Inuit group that produced it and its geographical region of origin.

In museums, species identification of animal fur and skin has a long tradition, initially relying on archival information from the collector, manufacturer, or donor, together with macroscopic identification performed with the naked eye, and manual inspection by the museum registrar. For the past 10 years, biomolecular technologies, such as ancient DNA and protein sequencing analyses of archaeological (e.g., Brandt et al., 2014) and historical material (e.g., Pangallo et al., 2010; Kirby et al., 2013) have supplemented, or nearly outperformed, macroscopic and microscopic identification. Although these current methods are objective and valid, this article reintroduces and modernizes a traditional qualitative means of fur-skin species identification: examining hair morphology using transmitted light microscopy (hair TLM). Microscopy uses no hazardous chemicals and is much cheaper than molecular methods. Hair TLM requires a few hair strands, and if sampling is done gently, the process leaves no visible impact on the fur-skin. Moreover, many institutions, public or private, have access to a standard microscope. Preparing hair for microscopy is easy. However, for hair TLM, they will need professionally embedded, ultra thin-cut, stained cross-sections of hair. A prerequisite is comprehensive, species-confirmed reference material combined with the relevant literature. The microscopy itself is easy to conduct after methodological instruction (Schmidt, 2022). During the twentieth century, scientists used the hair microscopy method for forensic science, archaeology, industrial technology, for example. (e.g., Hausman, 1920; Wildman, 1954; Stoves, 1957). In the twenty-first century, hair microscopy still provides an alternative (e.g., Teerink, 2003; Carrlee and Horelick, 2011; Galatík et al., 2011; Tridico, 2014) when other species identification methods are not possible or inconclusive. Based on those advantages, it is relevant to maintain hair TLM as a commonly acknowledged method of species identification in museums and private collections. This paper evaluates TLM results, with DNA cross-validation, of sub-sampled skin sections compared to initial macroscopic identification.

The aims of the present study are to:

1. Test the reliability of hair TLM for species identification by validating identifications by DNA analyses to cross-check reliability. Recent studies of archaeological fur have shown that hair microscopy has poor credibility when not confirmed by other analyses, such as DNA or protein sequence analysis (Schmidt et al., 2012; Brandt et al., 2014; Sinding et al., 2015).
2. Use species identification to estimate the geographic and cultural provenance of unidentified fur and hair samples. Animal species native to the Bering Strait/Alaskan, Canadian Arctic, and Greenland region are natural, meaning locally sourced, while non-native species indicate fur exchange, trade, or travel (Brandt et al., 2022).

BACKGROUND

For thousands of years, skins from marine and terrestrial mammals, birds, and fish have been essential for human life in the Arctic (Issenman, 1997). The animals provided Inuit families with the necessary materials for housing and transportation, in addition to food, heating, tools, and of course, clothing (Krabbe, 1929). In his doctoral thesis, Morten Meldgaard stated that Inuit subsistence strategies relied generally on four principles: "(1) a high degree of mobility, (2) a highly developed storage strategy, (3) dependence on a broad range of resources, and (4) a highly flexible hunting strategy. By adhering to these principles, the Inuit maximized their chances of long-term survival in an ever-changing and unpredictable environment" (Meldgaard 2004:55). However, Meldgaard (2004) also notes that in the Arctic, there is generally low species diversity (Meldgaard 2004).

Information about the species used for fur and skin in clothing provides knowledge about geographical differences and the possible use of uncommon animal skins, particularly when provenance can be ascertained. This study focuses on Inuit clothing in the NMD collection

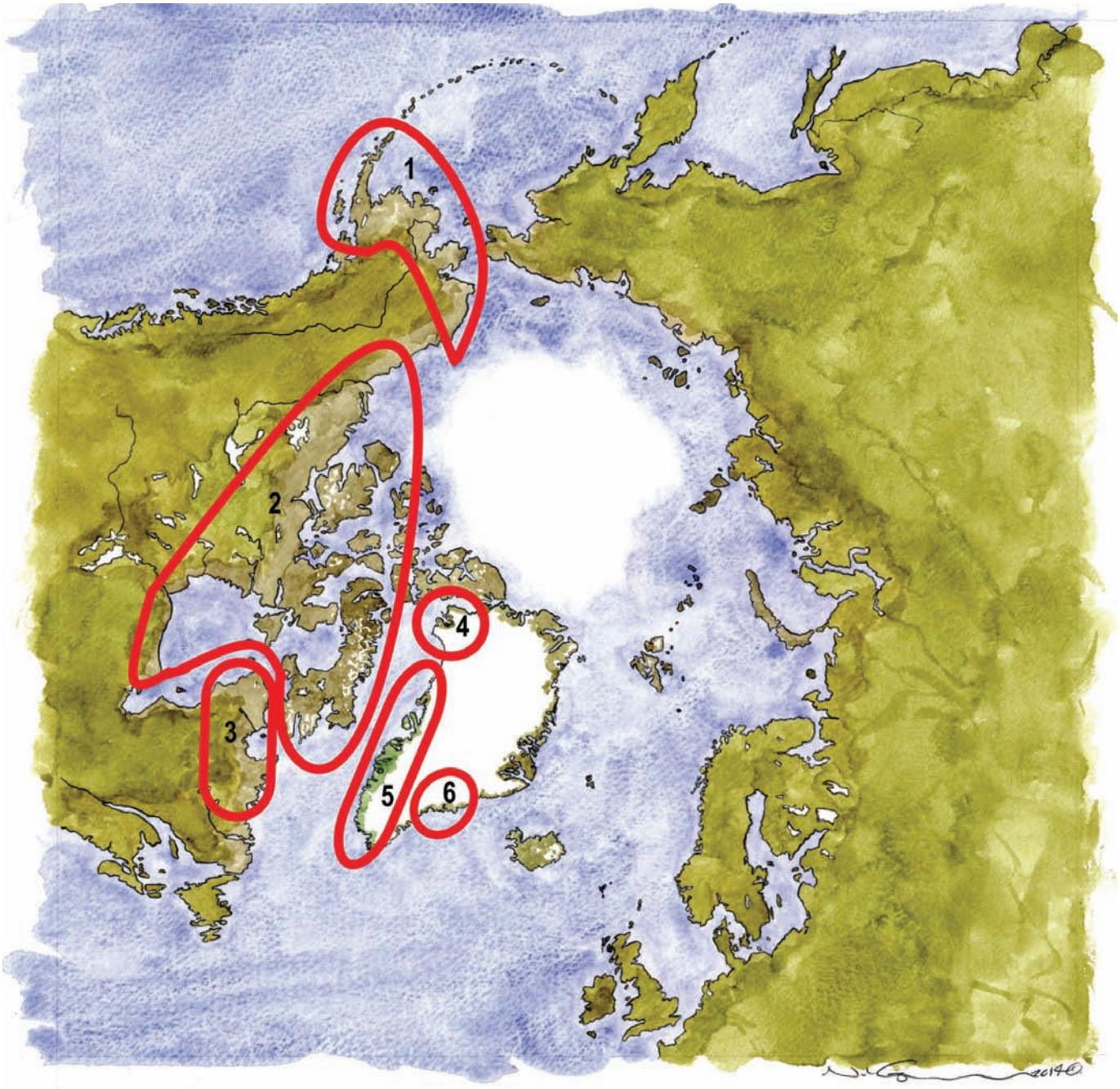

FIG. 1. Distribution of Inuit groups. Western Inuit: (1) Alutiit* on the Alaskan Peninsula and southern coast, Yupiit* in western Alaska, Yupiget* on St. Lawrence Island and in Siberia, and Inupiat and Iñupiat* in northern Alaska. Central Inuit, in Arctic Canada: (2) Inuvialuit, Inuinnait*, Netsilingmiut*, Aivilimmiut, Kivallirmiut*, Iglulingmiut*, and Nunatsiarmiut. (3) On the Labrador Peninsula: Nunavimmiut and Nunatsiavummiut*. Eastern Inuit, in Greenland: (4) Inughuit* in North Greenland. (5) Kalaallit*in West Greenland. (6) Iivit* in East Greenland where Iivit is the currently used name. * Indicates Inuit groups whose garments we consider in this study. Watercolour: Konrad Nuka Godtfredsen, 2014.

dating from approximately 1830 to 1940. From the mid-twentieth century, the traditional use of fur and skin for everyday wear gradually became obsolete among the Inuit (Issenman, 1997). In this paper, we follow Issenman (1997:7) in using the term Inuit to refer to ”the current inhabitants of the area from the Chukotka coast in Siberia to Kalaallit Nunaat (Greenland) and their immediate ancestors descended from the Thule cultural people.” Unless otherwise stated, names of larger Inuit groups follow Igor Krupnik (2016) (see Fig. 1), though we have updated them to the current spellings. Traditionally, those who study Inuit clothing designate three Inuit groups by region: Western Inuit living in the Bering Strait and Alaska region, Central Inuit in Arctic Canada, and Eastern Inuit in Greenland (Balikci, 1970). Issenman (1997) updated these designations by arguing that floating boundaries between regional groupings are preferable, particularly with regards to Nunavimmiut and Nunatsiavummiut on the Labrador

TABLE 1. Geographical origin of the National Museum of Denmark's collection of 1171 Inuit garments.

Geographical region: Inuit groups	Female adult	Male adult	Gender undefined children	Total
Western Inuit in the Bering Strait region and Alaska:				
Alutiit, Yupiit, Yupiget, Inupiat, and Iñupiat	18	69	59	146
Central Inuit in Arctic Canada:				
Inuinnait, Netsilingmiut, Kivallirmiut, Iglulingmiut, and Nunatsiavummiut	88	223	112	423
Eastern Inuit in Greenland:				
Inughuit, Kalaallit, and Iivit	215	220	167	602

Peninsula, and Inughuit in Greenland. Before that, scholars considered these groups to be either Central or Eastern Inuit (Damas, 1984). For practical reasons, for the present paper, the relevant designations of regional groups, with floating boundaries, only apply to Western Inuit in the Bering Strait and the Alaska region, Central Inuit in Arctic Canada, and Eastern Inuit in Greenland.

Despite the extensiveness of the NMD clothing collection, we should emphasize that there are some empirical shortcomings. The Western Inuit collection (146 garments) is less extensive than the Central Inuit (423 garments) and Eastern Inuit (602 garments) collections (see Table 1). The 146 garments do not constitute a complete representation of Western Inuit with regards to gender, adults vs children, and the associations among clothing items.

Animal Species Used in Inuit Clothing

Until the mid-twentieth century, skin and fur from caribou in North America, or reindeer in Greenland (i.e., *Rangifer tarandus*; hereafter, caribou), were the essential material for clothing for the indigenous population groups in the Arctic (Hatt, 1969), except for Central Inuit in East Arctic Canada and Eastern Inuit in Greenland, who favoured sealskin (Hatt, 1969). Inuit used caribou and sealskins, with fur or de-haired (Issenman, 1997). Among Western Inuit, skin from domesticated dogs was a valued material for trimmings (Issenman, 1997), while, among Central Inuit, the Kivallirmiut excluded the use of dog skin for clothing "due to the aversion of the Eskimos to it" (Birket-Smith, 1929:191). Among Eastern Inuit, the Inughuit used dog skin for clothing (Birket-Smith, 1924), while southern Kalaallit regarded the use of dog skin as a sign of poverty (Dalager, 1915). Iivit saw dog skin as having a connotation of fertility (Buijs, 2004). In addition, depending on their hunting opportunities and traditions, the Inuit used skins from polar bear, wolverine, wolf, Arctic fox, musk ox, polar hare, ground squirrel, marmot, and other mammals, as well as from various birds and sea mammals (Issenman, 1997).

Species availability depends on the local climate and environment (Rosing-Asvid, 2011). Local extinction or diminishing of species has had severe consequences, as seen, for example, in East Greenland in the nineteenth century, where caribou diminished due to overhunting (Winge, 1902; Thalbitzer, 2010), and the population of the hooded seal also declined (Winge, 1902).

Fur Trade

From the seventeenth until the early twentieth century, the European fur trade influenced Inuit clothing differentially depending on geographical region (Bockstoce, 2009). Various carnivore furs not generally used in Inuit skin clothing, but that became marketable and valuable in this period, were traded in the Bering Strait region and Alaska. In central Arctic Canada and northern Greenland, the fur trade influenced the use of Arctic fox in traditional clothing. Inuit's most common clothing skins (i.e., from caribou and seals) were largely unaffected by the fur trade.

EMPIRICAL MATERIAL

Appropriate reference material for hair TLM (i.e., hair specimens sampled from biologically identified skins and well-documented Inuit clothing) is essential for the reliable identification of both animal species and Inuit culture. This study's metadata regarding the Inuit garments came from the NMD's archive. The original information on macroscopic identification was either collected in situ (by the collector, from the skin garment maker) or as information acquired from intermediaries. However, many records likely contained inaccuracies, and species identifications of materials were often random. In practice, museum registrars (those overseeing the museum collection) generally deemed skin and fur from seals and caribou easy to identify macroscopically, whereas those from other species were seen as less reliably identifiable. A recent study sampled, for genetic analysis, 53 Arctic fur garments from the NMD (from Indigenous peoples in Siberia, North America, and Greenland) initially recorded as domestic dog-fur skins (*Canis lupus familiaris*). The study revealed that only 31 garments derived from dog or wolf (*Canis lupus*) fur. The rest came from an array of taxa, including wolverine (*Gulo gulo*), red fox (*Vulpes vulpes*), lynx (*Lynx lynx*), polar bear (*Ursus maritimus*), the Daurian ground squirrel (*Spermophilus dauricus*), caribou, and unidentified species (Harris et al., 2020). As a result, erroneous identifications pose a problem in museum collections, and macroscopic misidentification can bias the representation of tradition and history that such objects express.

Sample Selection for Species Identification

The NMD Inuit clothing collection encompasses 1171 garments representing an everyday clothing tradition, where animal skin was the primary clothing material. The collection contains parkas, trousers, footwear, mittens, hoods, caps, for example. A pair of shoes, boots, or mittens is counted as one object. Since 1987, NMD staff have electronically recorded items in the ethnographic collection (Larsen, 1988; Rold, 1995). Registrars registered items without accession numbers according to their assumed origin and labelled them with a preliminary number indicating that the original accession number had disappeared. As of January 2022, 86% of the garments had intact accession numbers connected to provenance, affiliation, gender, animal species, donor, for example. The remaining 14% of the collection (164 garments) are currently without original numbers. Table 1 lists all garments. As mentioned, the NMD's Western Inuit collection has the smallest number of items, whereas the Central and Eastern Inuit collections are well distributed, and garments can be associated with one another (i.e., can comprise a whole set of parka, trousers, and footwear). In the Western and Central Inuit collections, 25 of the 569 garments are without their accession numbers (4%). In the Greenlandic Inuit collection, 135 of 602 garments have lost their accession numbers (22%).

Selection criteria for the empirical material were as follows: intact accession number, dating from the end of the nineteenth century to the beginning of the twentieth century, and an equal number of men's and women's garments, preferably forming a whole set of clothing (i.e., parka, trousers, and footwear). This study analysed 77 Inuit garments encompassing fur skin, de-haired skin, gut skin, and sinew (thread material). Of the 77 garments, 72 were associated garments making 24 whole clothing sets: one set from Western Inuit, 10 from Central Inuit, and 13 from Eastern Inuit (see Table 2).

We took 81 samples from the 77 garments mentioned above. Besides the empirical material, this study analysed an additional 15 garments selected for their uncommon fur, which yielded 18 samples. Thus, this study encompassed 92 garments, equivalent to 99 samples. Of these, 85 samples had a macroscopical species identification. Fur/hair was present on 72 samples; of these, we identified 64 of these by hair TLM. In total, we conducted DNA analysis on 98 samples (see Appendix 1).

METHODOLOGY

Sampling

After documenting the sampling site on the garment, the authors took samples using sterile tools: for fur, we took a few hair strands for TLM analysis; for skin, we extracted approximately 25 mg from beneath the fur for DNA analysis; and for de-hairing skin, gut skin, and thread material, we took a similar amount for DNA analysis. We wrapped samples in aluminum foil and polyethylene sample bags and stored them at room temperature until preparation.

Transmitted Light Microscopy of Hair

This study developed an improved species identification method for hair using TLM. We mounted hair strands, which had been rinsed in acetone, in Pertex Mounting Media on a microscope slide beneath a coverslip. Traditional preparation methods for cross-sections required straightened hair bundles mounted on a metal plate or embedded in a mounting media (e.g., cellulose acetate) or glued to adhesive tape. The traditional cross-sections used specially designed microtomes or razor blades (Wildman, 1954; Stoves, 1957; Teerink, 2003). These older methods demanded lots of sample material, time, and skill to produce a thin section. In the present study, for cross-section, we embedded the cleansed hair strands perpendicular to the hair direction in EPON epoxy resin. We cut the cured epoxy into sections with a thickness of 1 mm, stained them with 1% toluidine blue, and likewise mounted them with Pertex Mounting Media (Schmidt, 2023).

The morphological species-specific characteristics emerged in the undyed longitudinal mounts and the blue-stained cross-sections. We categorized hair as primary, intermediate, or secondary based on hair diameter (i.e., the largest measure of the cross-sectioned hair, regardless of shape). Primary hair had a diameter over approximately 60 mm, intermediate hair, from approximately 30–60 mm, and secondary hair, approimately 10–30 mm. We analysed the outer shape of the hair, the medulla morphology, and the ratio cortex width, as these are the most characteristic traits of hair width that are studied in common Arctic mammals, including caribou, musk ox, members of the true seal family, dog family, the polar bear, and wolverine (Schmidt, 2022).

Assessment of epidermal scale patterns is traditionally considered a valid identification parameter. For example, Wildman (1954) and Teerink (2003) described the casting method. The analysis requires extra material and is time-consuming. This study deemed the method unnecessary, as cross-sections and longitudinal mounts provided secure identification (Schmidt, 2022). However, we did assess and identify the epidermal scale pattern in the longitudinal mount when this was possible (Schmidt, 2022). The reference material included hairs from 18 whole fur skins of 12 Arctic mammals, kindly provided by the Natural History Museum of Denmark (NHMD). Hair specimens are derived from the back, abdomen, and, occasionally, the limbs. From ruminants, we received hair specimens from caribou (one skin) and musk ox (*Ovibos moschatus,* one skin). From the true seal family (Phocidae), specimens came from five species including harp seal (*Pagophilus groenlandicus,* three skins), hooded seal (*Cystophora cristata,* two skins), bearded seal (*Erignathus barbatus*, one skin), ringed seal (*Phoca hispida,* two skins), and harbour seal (*Phoca vitulina,*

TABLE 2. Empirical material from 77 Inuit garments: 24 parkas, trousers, and footwear are associated clothing sets.

					PARKAS		TROUSERS		FOOTWEAR	
Inuit region	Geographical region	Inuit group	Gender	Clothing name	Accession number	Accession year	Accession number	Accession year	Accession number	Accession year
West	Bering Strait, Siberia	Yupiget	Male	AsM1	Kc.99	1860	–	–	–	–
West	Southern Alaska	Yupiit	Male	AlM1	P.152	1913	–	–	P.1677	1939
West	Alaska	Inupiat	Female	AlF1	P32.1	1926	–	–	P32.11ab	1926
West	Northern Alaska	Iñupiat	Male	AlM2	P32.5	1926	P32.4	1926	P32.9a-b	1926
Central	Arctic Canada	Inuinnait	Female	CoF1	P30.15	1927	P30.30	1927	P30.43a-b	1927
Central	Arctic Canada	Inuinnait	Male	CoM1	P30.2	1927	P30.25	1927	P30.42a-b	1927
Central	Arctic Canada	Netsilingmiut	Female	NeF1	P29.10	1924	P29.18	1924	P29.28a-d	1924
Central	Arctic Canada	Netsilingmiut	Male	NeM1	P29.8	1924	P29.17	1924	P.37	1908
Central	Arctic Canada	Kivallirmiut	Female	CaF1	P28.10	1924	P28.18	1924	P28.34a-b	1924
Central	Arctic Canada	Kivallirmiut	Male	CaM1	P28.6	1924	P28.14	1924	P28.31a-b	1924
Central	Arctic Canada	Iglulingmiut	Female	IgF1	P27.453	1924	P27.454	1924	P27.457	1924
Central	Arctic Canada	Iglulingmiut	Male	IgM1	P27.410	1924	P27.420	1924	P27.439	1924
Central	Arctic Canada, Labrador	Nunatsiavummiut	Female	LaF1	P.230a	1922	P.230b	1922	P.231c	1922
Central	Arctic Canada, Labrador	Nunatsiavummiut	Male	LaM1	P26.18	1924	P26.19	1924	P26.20	1924
East	North Greenland	Inughuit	Female	NGF1	X.233	1921	L.4354	1909	L.9271	1924
East	North Greenland	Inughuit	Female	NGF2	L.9554	1928	L.9555	1928	L.9556	1928
East	North Greenland	Inughuit	Male	NGM1	L.9549	1928	L.9550	1928	L.9551	1928
East	North Greenland	Inughuit	Male	NGM2	L.2097	1905	L.2098	1905	L.2104	1905
East	West Greenland	Kalaallit	Female	WGF1	L.7819	1918	L.7818b	1918	L.7818c	1918
East	West Greenland	Kalaallit	Female	WGF2	Ld.32a	1883	Ld.32b	1883	Ld.32c	1883
East	West Greenland	Kalaallit	Female	WGF3	Lc.187a	1844	Lc.187b	1844	Lc.187d	1844
East	West Greenland	Kalaallit	Female	WGF4	L18.140a	1938	L18.140e	1938	L18.140f	1938
East	West Greenland	Kalaallit	Male	WGM1	Ld.31a	1883	Ld.31b	1883	Ld.31c	1883
East	East Greenland	Iivit	Female	EGF1	L.5064	1911	L.5072	1911	L.5082	1911
East	East Greenland	Iivit	Female	EGF2	L.5066	1911	Ld.133.9	1892	L.1545.2	1897
East	East Greenland	Iivit	Male	EGM1	Ld.17	1881	Ld.162	1894	Ld.66c	1886
East	East Greenland	Iivit	Male	EGM2	L.4990	1911	L.5013	1911	L.5024	1911

one skin). And from carnivores, specimens were from domestic dog (*Canis lupus familiaris,* one skin), wolf (*Canis lupus,* one skin), Arctic fox (*Vulpes lagopus,* three skins), polar bear (*Ursus maritimus,* one skin), and wolverine (*Gulo gulo,* one skin). Figures 2a and 2b show examples of cross-sectioned hairs obtained from NHMD.

DNA Analysis

We performed all DNA pre-amplification work in ancient DNA facilities at the Globe Institute, University of Copenhagen, Denmark, following ancient DNA guidelines (Orlando et al., 2013); for practical reasons, this undertaking lasted six years. We performed genetic species identification using a combination mix of: 1) mitochondrial Amplicon amplification and Sanger sequencing and 2) mitochondrial wide variation, obtained via shotgun sequencing. In the DNA work, we conducted a total of 155 analyses on the 98 samples. See Table 2, as well as Appendix 1.

Amplicon-Based Identification

We initially investigated 114 samples using an Amplicon-based approach. Prior to DNA extraction, we washed subsamples of ~3x3 mm of skin (with or without hair) in dilute hydrochloric acid baths to remove contamination of extraneous DNA present on the surface. Samples were flowingly digested, and we extracted DNA according to Vuissoz et al. (2007). We used the primer set 16SA&M (Rasmussen et al., 2009) to amplify an approximate 122 bp long Amplicon (including primers). As Sanger sequencing data usually has low quality at the beginning and end of an Amplicon, we performed an additional extension of the Amplicons to 261 bp with the extension primers Fusion_extended_F&R (Brandt, 2015). We determined the affinity of amplified products using the NCBI blast algorithm (Johnson et al., 2008).

Shotgun-Based Identification

Of the 75 samples identified to family level via Amplicon based identification, we re-sampled and reanalysed 12 objects using a shotgun sequencing approach. We also analysed 29 more samples such that, in total, we used shotgun-based identification on 41 samples. Of those samples, nine had previously been published (Ameen et al., 2019; Harris et al., 2020). We washed subsamples of ~3x3 mm skin (with or without hair) in dilute hydrochloric acid and rinsed them with ethanol and water, before digestion in a proteinase K–based buffer, following Gilbert et al. (2007). Following the manufacturer's guidelines, we purified the supernatant using Monarch Spin-columns (New England Biolabs) in combination with a modified binding buffer optimised for binding small DNA molecules (Allentoft et al., 2015). We modified DNA extracts into libraries using NEBNext DNA Sample Prep Master MixSet 2 (E6070S, New England Biolabs Inc., Beverly, MA, USA) and Illumina-specific adapters (Meyer and Kircher, 2010), and conducted sequencing on an Illumina HiSeq 2500 platform using 100 bp single read chemistry.

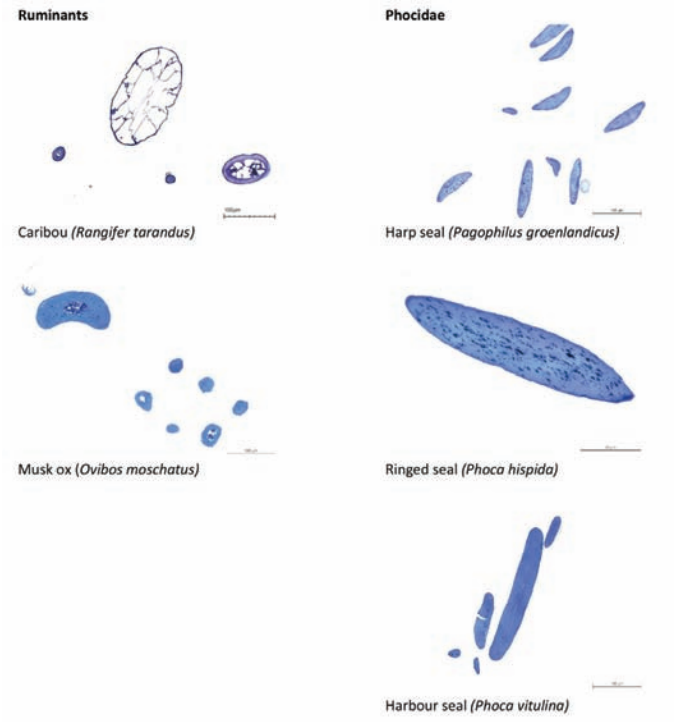

FIG. 2. a) Cross-section of hairs from ruminants: caribou and musk ox and Phocidae: harp seal, ringed seal, and harbour seal. Reference samples from the Natural History Museum of Denmark. Caribou sample from the National Museum of Denmark, Lc.187a, female parka from Kalaallit.

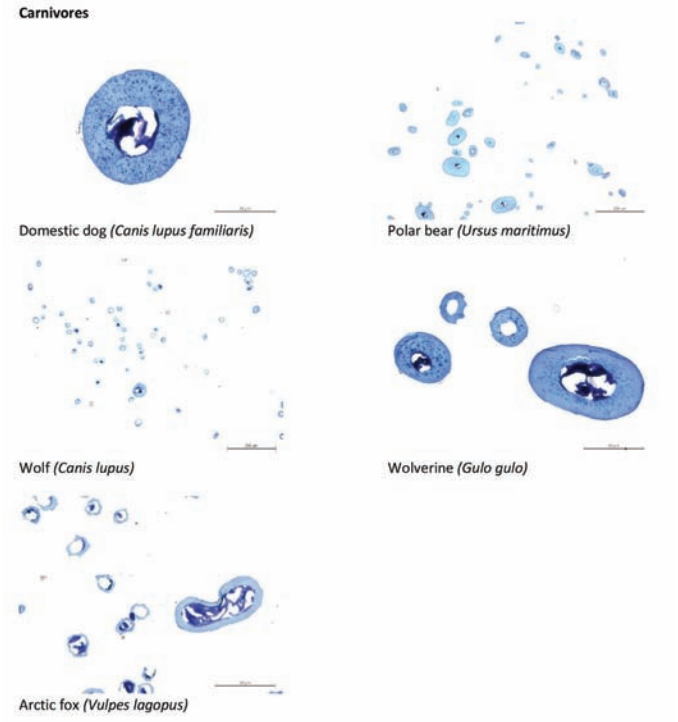

FIG. 2 b) Cross-section of hairs from carnivores: domestic dog, wolf, Arctic fox, polar bear, and wolverine. Reference samples from the Natural History Museum of Denmark.

We processed sequencing reads using the PALEOMIX pipeline (Schubert et al., 2014), with mapping processing, as performed in Sinding et al. (2017), against a diverse reference of mammalian mitochondrial genomes, after which we affiliated mitochondrial-wide assemblies with species context using the NCBI blast algorithm (Johnson et al., 2008).

RESULTS

Hair TLM, Macroscopic Identification, and DNA Analyses

Tables 3a and 3b present the results of species identifications. Macro id columns show the original species identification based on archival information, referred to as macroscopic identification. TLM id columns give the results of hair microscopy, and DNA columns show results from DNA analyses of skin. In addition to fur skin, we performed DNA analysis for de-haired skin and gut skin, and thread material. For clarity, we include the results from these materials in the table, as they provide essential information on the geographical use of the animal species.

DNA Analyses

A total of 155 DNA analyses of 98 samples from 91 garments identified 60% (59 samples) to either family or species level. Despite reanalyses, 40% (39 samples) still failed. Thus, these samples were not speciated by means of DNA analysis. Figure 3 shows the success rate of the analyses.

Regardless of the results (i.e., either identified to family or species level or failed), we did not repeat 55 of the 155 analyses. Of 55 single analyses, we did not repeat 26 failed analyses. We reanalysed 48 samples twice and 43 samples three times. We reanalysed previously analysed samples three times, making four analyses total (see Fig. 4). The reanalyses failed in three samples, but prior analyses were successful at the family level. Six samples failed in both preliminary analyses and reanalyses.

Amplicon-Based Identification

Of 114 analyses (including reanalyses), 83 proved successful, while 31 analyses did not reveal the species due to low-quality DNA. The identified families were deer (Cervidae), Phocidae, dog (Canidae), and bear (Ursidae), and the identified species were musk ox (*O. moschatus),* bearded seal (*E. barbatus),* domestic dog, and wolverine.

Shotgun-Based Identification

Of 41 analyses (including reanalyses), 17 failed while we successfully identified 24 to species level: caribou (*R. tarandus),* ringed seal (*P. hispida),* harbour seal *(P. vitulina),* harp seal (*P. groenlandicus),* domestic dog, wolf *(C. lupus),* Arctic fox (*V. lagopus),* and ground squirrel (*Urocitellus parryii richardsonii).* However, we interpret the latter with

TABLE 3. a) Empirical material: species identification in 38 garments from Western and Central Inuit (PARKAS).

Gender	Inuit group	Suit	Accession	Identification number	Sample	Macro identification	TLM identification	DNA identification
Male	Yupiget Western Iniut	AsM1	Kc.99	90710_a	Hood band, fur	Wolverine[5]	*C. lupus familiaris*[5]	DNA failed
Male	Yupiget Western Iniut	AsM1	Kc.99	90710_b	Lower trimming, fur	Wolverine[5]	*G. gulo*[5]	*G. gulo*[5]
Male	Yupiget Western Iniut	AsM1	Kc.99	90710_c	Sleeve trimming, fur	Wolverine[5]	*C. lupus familiaris*[5]	*C. lupus familiaris*[5]
Male	Alutiit Western Iniut	A1M1	P.152	36332_a	Collar, gut	Unspecified species	(No hair)	Maybe sea lion
Female	Yupiit Western Iniut	A1F1	P32.1	36958_a	Hood band, fur	Wolverine?[5]	Canidae[5]	Canidae[5]
Male	Yupiit Western Iniut	A1M2	P32.5	36962_a	Lower trimming, de-haired	Seal[4]	(No hair)	DNA failed
Female	Inuinnait Central Inuit	CoF1	P30.15	37357_a	Front, fur	Caribou/reindeer[1]	*R. tarandus*[1]	Cervidae[1]
Male	Inuinnait Central Inuit	CoM1	P30.2	37444_a	Hood, fur	Caribou/reindeer[1]	*R. tarandus*[1]	DNA failed
Female	Netsilingmiut Central Inuit	NeF1	P29.10	35238_a	Hood, fur	Caribou/reindeer[1]	*R. tarandus*[1]	Cervidae[1]
Male	Netsilingmiut Central Inuit	NeM1	P29.8	35236_a	Hood, fur	Seal[3]	*P. vitulina*[3]	*P. vitulina*[3]
Female	Kivallirmiut Central Inuit	CaF1	P28.10	34949_a	Sleeve, de-haired lace	Caribou/ reindeer[2]	(No hair)	Cervidae[2]
Male	Kivallirmiut Central Inuit	CaM1	P28.6	34945_a	Lower trimming, fur	Caribou/reindeer[1]	*R. tarandus*[1]	Cervidae[1]
Female	Iglulingmiut Central Inuit	IgF1	P27.453	34594_a	Sleeve, thread	Unspecified species	(No hair)	DNA failed
Male	Iglulingmiut Central Inuit	IgM1	P27.410	34549_a	Front, fur	Caribou/reindeer[1]	*R. tarandus*[1]	*R. tarandus*[1]
Female	Nunat-siavummiut Central Inuit	LaF1	P.230a	36416_a	Hood, fur	Harbour seal[3]	*P. hispida*[3]	DNA failed
Male	Nunat-siavummiut Central Inuit	LaM1	P26.18	69944_a	Hood band, fur	Dog[5]	Canidae[5]	Canidae[5]

[1] Ruminant (with fur)
[2] Ruminant (de-haired skin or sinew thread)
[3] Phocidae (with fur)
[4] Phocidae (de-haired skin or gut skin)
[5] Carnivore (with fur)

caution as only a few *Urocitellus* species are available as reference data, and the genetic structure of this species is unexplored. Hence, the specific sample may be another but closely related species of ground squirrel. The remaining species are abundantly represented and unambiguous.

Appendix 2 presents photomicrographs of hairs from caribou, musk ox, Phocidae, Canidae, polar bear, wolverine, ermine (*Mustela erminea)*, ground squirrel (possibly *U. parryii richardsonii),* and cattle *(B. taurus).*

DISCUSSION

DNA Analyses

In the genetic identification study, 51 out of 155 analyses failed to provide endogenous DNA in biochemical processing and sequencing or provided data of insufficient quality (see Fig. 3). The exact reason for failure can be complex and cannot be specifically identified. Test items originated from clothing collected from 1844 to 1938. The garments were exhibited or stored at NMD under unsuitable conditions with changing humidity (including water damage), poor space, random inspections, and massive pest infestations. For pest control, the collection was customarily treated with large quantities of botanical extracts, heavy metals, metal salts, and organochlorine biocides such as DDT, Lindane, and methoxychlor (Schmidt, 2001). The pesticides may have had a major impact on DNA preservation or pre-sequencing DNA processing, resulting in degradation of the endogenous DNA. In this specific case, due to the treatment of the garments, the endogenous DNA was degraded and thus prone to error (Prendini et al., 2002). Prolonged exposure to daylight and repeated fungal attacks may also have degraded the DNA. However, no specific factor in the museum's history of Inuit skin clothing can explain the damaged DNA.

This highlights weaknesses in DNA analyses. Some material either contains no endogenous DNA, the material is too toxic for current pre-sequencing to function, or the DNA is too degraded to be informative. However, if hairs are present, TLM can always be performed. On the other hand, compared to others, some species are more challenging to identify with satisfying accuracy via hair microscopy and

TABLE 3. a) Empirical material: species identification in 38 garments from Western and Central Inuit (TROUSERS) – *continued*:

Gender	Inuit group	Suit	Accession	Identification number	Sample	Macro identification	TLM identification	DNA identification
Male	Yupiget Western Iniut	AsM1						
Male	Yupiget Western Iniut	AsM1						
Male	Yupiget Western Iniut	AsM1						
Male	Alutiit Western Iniut	A1M1						
Female	Yupiit Western Iniut	A1F1						
Male	Yupiit Western Iniut	A1M2	P32.4	36961_a	Trousers front, fur	Seal[3]	*P. hispida*[3]	*P. hispida*[3]
Female	Inuinnait Central Inuit	CoF1	P30.30	37374_a	Trousers front, de-haired	Caribou/ reindeer[2]	(No hair)	Cervidae[2]
Male	Inuinnait Central Inuit	CoM1	P30.25	37369_a	Trousers front, de-haired lace	Un-specified species	(No hair)	Cervidae[2]
Female	Netsilingmiut Central Inuit	NeF1	P29.18	35246_a	Trousers back, thread	Un-specified species	(No hair)	Cervidae[2]
Male	Netsilingmiut Central Inuit	NeM1	P29.17	35245_a	Trousers front, fur	Musk ox[1]	*O. moschatus*[1]	*O. moschatus*[1]
Female	Kivallirmiut Central Inuit	CaF1	P28.18	34957_a	Waist band, fur	Caribou/reindeer[1]	*R. tarandus*[1]	Cervidae[1]
Male	Kivallirmiut Central Inuit	CaM1	P28.14	34953_a	Trousers leg trimming, fur	Caribou/reindeer[1]	*R. tarandus*[1]	Cervidae[1]
Female	Iglulingmiut Central Inuit	IgF1	P27.454	34595_a	Waist band, thread	Un-specified species	(No hair)	Cervidae[2]
Male	Iglulingmiut Central Inuit	IgM1	P27.420	34559_a	Trousers front	Caribou/reindeer[1]	*R. tarandus*[1]	DNA failed
Female	Nunat-siavummiut Central Inuit	LaF1	P.230b	36417_a	Trousers front, fur	Harbour seal[3]	*P. vitulina*[3]	Phocidae[3]
Male	Nunat-siavummiut Central Inuit	LaM1	P26.19	60971_a	Trousers front, fur	Dog[5]	*C. lupus familiaris*[5]	*C. lupus familiaris*[5]

[1] Ruminant (with fur)
[2] Ruminant (de-haired skin or sinew thread)
[3] Phocidae (with fur)
[4] Phocidae (de-haired skin or gut skin)
[5] Carnivore (with fur)

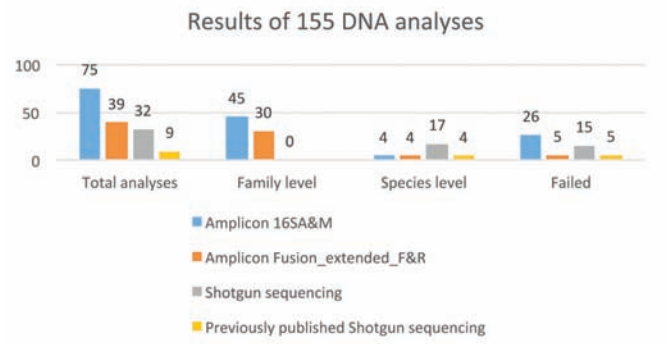

FIG. 3. Of 155 DNA analyses performed, 75 were determined at the family level, and 29 at the species level; 51 analyses failed. Of the 75 Amplicon 16SA&M analyses, 45 speciated to family level, 4 to species level, and 26 failed. Of the 39 Amplicon Fusion_extended_F&R analysed samples, 30 speciated to family level, 4 to species level, and 5 failed. Of the 32 shotgun sequencing–analysed samples, 17 speciated to species level, and 15 failed. Of 9 repeated shotgun sequencing–analysed samples, 4 speciated to species level, and 5 failed.

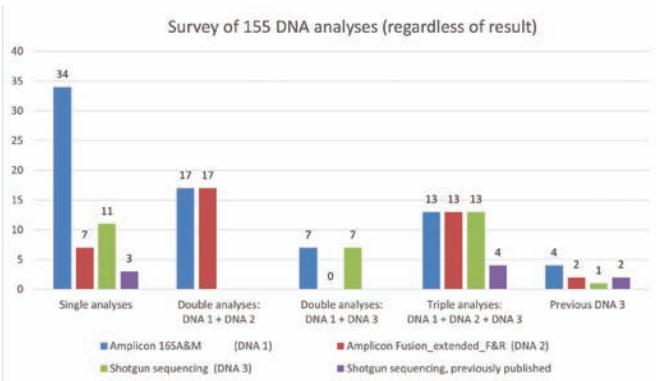

FIG. 4. Survey of DNA analyses: 55 analyses were performed as single analyses, with 34 using Amplicon 16SA&M (DNA 1), 7 using Amplicon Fusion_extended_F&R (DNA 2), 11 using shotgun sequencing (DNA 3), and 3 using shotgun sequencing, previously published; 34 analyses were performed twice, with 17 using DNA 1 and 17 using DNA 2; 14 analyses were performed twice, with 7 using DNA 1, and 7 using DNA 3; and 43 analyses were performed three times, with 13 using DNA 1, 13 using DNA 2, 13 using DNA 3, and 4 using shotgun sequencing, previously published; 9 analyses were previously analysed by shotgun sequencing.

TABLE 3. a) Empirical material: species identification in 38 garments from Western and Central Inuit (FOOTWEAR) – *continued*:

Gender	Inuit group	Suit	Accession	Identification number	Sample	Macro identification	TLM identification	DNA identification
Male	Yupiget Western Iniut	AsM1						
Male	Yupiget Western Iniut	AsM1						
Male	Yupiget Western Iniut	AsM1						
Male	Alutiit Western Iniut	A1M1	P.1677	36654_a	Uppers, de-haired	Seal[4]	(No hair)	Phocidae[4]
Female	Yupiit Western Iniut	A1F1	P32.11ab	36968_a	Leg trimming, de-haired	Seal[4]	(No hair)	Phocidae[4]
Male	Yupiit Western Iniut	A1M2	P32.9a-b	36966_a	Leg trimming, de-haired	Seal[4]	(No hair)	DNA failed
Female	Inuinnait Central Inuit	CoF1	P30.43a-b	37388_a	Leg, de-haired	Seal[4]	(No hair)	Phocidae[4]
Male	Inuinnait Central Inuit	CoM1	P30.42a-b	37387_a	Leg, de-haired	Seal[4]	(No hair)	Phocidae[4]
Female	Netsilingmiut Central Inuit	NeF1	P29.28a-d	35263_a	Leg, de-haired lace	Un-specified species	(No hair)	Cervidae[2]
Male	Netsilingmiut Central Inuit	NeM1	P.37	36219_a	Leg, de-haired	Seal[4]	(No hair)	DNA failed
Female	Kivallirmiut Central Inuit	CaF1	P28.34a-b	34973_a	Leg, fur	Caribou/reindeer[1]	*R. tarandus*[1]	Cervidae[1]
Male	Kivallirmiut Central Inuit	CaM1	P28.31a-b	34970_a	Leg, de-haired	Seal[4]	(No hair)	Phocidae[4]
Female	Iglulingmiut Central Inuit	IgF1	P27.457	34598_a	Sole, thread	Un-specified species	(No hair)	Cervidae[2]
Male	Iglulingmiut Central Inuit	IgM1	P27.439	34579_a	Leg, de-haired	Seal[4]	(No hair)	Phocidae[4]
Female	Nunat-siavummiut Central Inuit	LaF1	P.231c	36423_a	Leg, fur	Seal[3]	*P. hispida*[3]	DNA failed
Male	Nunat-siavummiut Central Inuit	LaM1	P26.20	69942_a	Leg, fur	Seal[3]	*P. hispida*[3]	*P. hispida*[3]

[1] Ruminant (with fur)
[2] Ruminant (de-haired skin or sinew thread)
[3] Phocidae (with fur)
[4] Phocidae (de-haired skin or gut skin)
[5] Carnivore (with fur)

TLM. Therefore, we performed a comparison between hair TLM, macroscopic identification, and DNA analysis to ascertain the performance of these methods.

Comparing Species Identification Methods

Our first research aim was to evaluate the species identification methods. In the case of ruminants, caribou showed no discrepancies between TLM results and macroscopic identification. Regarding DNA analysis, we identified specimens as deer family (Cervidae) or caribou. In this context, caribou was equivalent to Cervidae, as caribou is the only probable native deer species in most of the Arctic region in question. Moose are found in a few localities, but the fur is significantly different from a macroscopic perspective, and all species-level DNA results were caribou. Musk ox showed consistent identification to species level. In woman's clothing, L18.140a and L18.140g (WGF4, Table 3b), we initially identified the fur skin of the parka collar and the trimming of the boots macroscopically as domestic dog. However, hair TLM identified fur from cattle. The samples failed in DNA analysis.

We successfully identified Phocidae at the family level, and, when successful, there were no differences between the results of TLM, macroscopic identification, and DNA analysis. Regarding harp seal (*P. groenlandicus),* ringed seal *(P. hispida)*, and harbour seal *(P. vitulina*), we confirmed identification using hair TLM either by macroscopic identification or DNA analysis, or both.

Hair TLM and macroscopic identification of Canidae were consistent with domestic dog and Arctic fox to species level. DNA analysis proved Canidae or the specific species: domestic dog and Arctic fox. We did not confirm the presence of wolf in the empirical material but identified it in the extra garments' material (a man's parka hood and sleeve trimmings, P30.9, see Appendix 1).

Macroscopic identification of Canidae and wolverine showed discrepancies with hair TLM (e.g., Kc99 [AsMi]; Table 3a), where we identified wolverine macroscopically in the trimmings on hood and sleeves and lower edging. However, through DNA analyses, we only identified wolverine in the lower edging and domestic dog at the sleeve trimmings. TLM agreed with the DNA results. DNA analysis failed in the hood trimming; however, TLM showed

TABLE 3. b) Empirical material: species identification in 39 garments from Eastern Inuit (PARKAS).

Gender	Inuit group	Suit	Accession	Identification number	Sample	Macro identification	TLM identification	DNA identification
Female	Inughuit Eastern Inuit	NGF1	X.233	34035_a	Hood band, fur	Arctic fox[5]	*V. lagopus*[5]	Canidae[5]
Female	Inughuit Eastern Inuit	NGF2	L.9554	33009_a	Hood, fur	Seal[3]	*P. hispida*[3]	*P. hispida*[3]
Female	Inughuit Eastern Inuit	NGF2	L.9554	33009_b	Sleeve, fur	Seal[3]	*P. hispida*[3]	*P. hispida*[3]
Male	Inughuit Eastern Inuit	NGM1	L.9549	33005_a	Hood band, fur	Arctic fox[5]	*C. lupus familiaris* or *C. lupus*[5]	Canidae[5]
Male	Inughuit Eastern Inuit	NGM2	L.2097	31588_a	Hood, fur	Un-specified species	*C. lupus familiaris*[5]	DNA failed
Male	Inughuit Eastern Inuit	NGM2	L.2097	31588_b	Lower trimming, fur	Un-specified species	Analysis not performed	DNA failed
Female	Kalaallit Eastern Inuit	WGF1	L.7819	67907_a	Hood, fur	Seal[3]	*P. hispida*[3]	DNA failed
Female	Kalaallit Eastern Inuit	WGF2	Ld.32a	68927_a	Hood, fur	*P. hispida*[3]	*P. hispida*[3]	DNA failed
Female	Kalaallit Eastern Inuit	WGF3	Lc.187a	30492_a	Sleeve, fur	Caribou/reindeer[1]	*R. tarandus*[1]	*R. tarandus*[1]
Female	Kalaallit Eastern Inuit	WGF4	L18.140a	33439_a	Collar, fur	Dog[5]	*B. taurus*[1]	DNA failed
Male	Kalaallit Eastern Inuit	WGM1	Ld.31a	31312_a	Back, fur	Seal[3]	*P. hispida*[3]	DNA failed
Female	Iivit Eastern Inuit	EGF1	L.5064	32162_a	Hood band, fur	Seal[3]	Analysis not performed	DNA failed
Female	Iivit Eastern Inuit	EGF2	L.5066	32164_a	Front, fur	Seal[3]	Phocidae[3]	DNA failed
Male	Iivit Eastern Inuit	EGM1	Ld.17	31299_a	Lower trimming, gut	Seal[4]	(No hair)	E. barbatus4
Male	Iivit Eastern Inuit	EGM2	L.4990	32086_a	Lower trimming, fur	Seal[3]	*P. hispida*[3]	*P. hispida*[3]

[1] Ruminant (with fur)
[2] Ruminant (de-haired skin or sinew thread)
[3] Phocidae (with fur)
[4] Phocidae (de-haired skin or gut skin)
[5] Carnivore (with fur)

Canidae. The trimmings on a woman's hood, P 32.1 (AlF1, Table 3a), showed a similar discrepancy. For polar bear, TLM and macroscopic identification were consistent with the species level. DNA analysis showed bear family (Ursidae) when successful. Despite poor museum environments over the years, the TLM study showed no marked degradation of hair morphology.

Representativeness of Empirical Material

The second research aim was to use species identification to estimate the geographic and cultural provenance of objects in the collection. To illustrate the issue, we validated the representativeness of the empirical material. Current calculations made from the NMD database SkinBase (described in Schmidt, 2016) reveal that approximately 7% of all Inuit garments have been identified by hair microscopy, DNA analysis, or both (i.e., approximately 93% of the garments were still only identified macroscopically).

Regarding ruminants, Western and Central Inuit preferred caribou for clothing. The geographical division in the database is evident: 64% of the garments came from caribou among Western and Central Inuit; among Eastern Inuit, only 8%. However, these figures do not indicate whether SkinBase ascertained if clothing was made entirely or partially from caribou skins.

As for Phocidae, the species identifications we performed revealed that sealskin was the dominant clothing material among Eastern Inuit. The database confirms the difference: 40% of Western and Central Inuit's clothing came from Phocidae, compared to 85% of Eastern Inuit's clothing. The calculation does not include specific seal species, as the methods only identified a few seal species. Considering that the Inuit generally preferred sealskin for waterproof footwear (Issenman, 1997), the distribution is unclear.

Our analyses further reveal that the identification of domestic dog agrees with the registered garments' geographical distribution. However, the sample amount is too large within the empirical material. Of all registered clothing at the NMD, fur from domestic dog covers 0.5% of the total number of garments. In this project, we identified samples from 10 garments with domestic dog fur. The large number reveals the uncertainty of the macroscopical identification, long known to be significant. Besides Inughuit and Iivit, most skins of domestic dog used for trimming came from Alaska. Wolf is found in one Central

TABLE 3. b) Empirical material: species identification in 39 garments from Eastern Inuit (TROUSERS) – *continued*:

Gender	Inuit group	Suit	Accession	Identification number	Sample	Macro identification	TLM identification	DNA identification
Female	Inughuit Eastern Inuit	NGF1	L.4354	31857_a	Trousers front, fur	Arctic fox[5]	*V. lagopus*[5]	DNA failed
Female	Inughuit Eastern Inuit	NGF2						
Female	Inughuit Eastern Inuit	NGF2	L.9555	33010_a	Trousers front, fur	Arctic fox[5]	*V. lagopus*[5]	*V. lagopus*[5]
Male	Inughuit Eastern Inuit	NGM1	L.9550	20420_a	Waist band, fur	Seal[3]	*P. vitulina*?[3]	DNA failed
Male	Inughuit Eastern Inuit	NGM2	L.2098	31589_a	Trousers front, fur	Polar bear[5]	*U. maritimus*[5]	DNA failed
Male	Inughuit Eastern Inuit	NGM2						
Female	Kalaallit Eastern Inuit	WGF1	L.7818b	67905_a	Trousers leg trimming, de-haired	Seal[4]	(No hair)	DNA failed
Female	Kalaallit Eastern Inuit	WGF2	Ld.32b	31316_a	Trousers front, fur	Seal[3]	*P. hispida*[3]	*P. hispida*[3]
Female	Kalaallit Eastern Inuit	WGF3	Lc.187b	30493_a	Trousers front, fur	Caribou/reindeer[1]	*R. tarandus*[1]	Analysis not performed
Female	Kalaallit Eastern Inuit	WGF4	L18.140e	33443_a	Trousers front, fur	Harbour seal[3]	*P. vitulina*[3]	DNA failed
Male	Kalaallit Eastern Inuit	WGM1	Ld.31b	31313_a	Trousers back, fur	Seal[3]	Phocidae[3]	Phocidae[3]
Female	Iivit Eastern Inuit	EGF1	L.5072	32169_a	Trousers front, fur	Seal[3]	*P. hispida*[3]	DNA failed
Female	Iivit Eastern Inuit	EGF2	Ld.133.9	31432_a	Trousers front, fur	Un-specified species	*P. hispida*[3]	Phocidae[3]
Male	Iivit Eastern Inuit	EGM1	Ld.162	117711_a	Trousers front, fur	Seal[3]	*P. groenlandicus*[3]	DNA failed
Male	Iivit Eastern Inuit	EGM2	L.5013	32109_a	Trousers leg, fur	Polar bear[5]	*U. maritimus*[5]	DNA failed

[1] Ruminant (with fur)
[2] Ruminant (de-haired skin or sinew thread)
[3] Phocidae (with fur)
[4] Phocidae (de-haired skin or gut skin)
[5] Carnivore (with fur)

Inuit garment outside the empirical material. Sampling from Arctic fox matches the registered geographical distribution: 0.4% of the registered clothing contains Arctic fox, mostly found among Inughuit and used for entire garments and trimmings.

Specimens from polar bear, sampled from Inughuit and Iivit garments, are consistent with the registered geographical distribution: 8% of all the NMD's Inuit garments contain polar bear, used for trimmings and entire garments. Of these, approximately 84% are from Inughuit and Iivit. The rest are primarily from the Western Inuit and used for decoration and trimming.

Wolverine, confirmed by DNA analyses, was sampled from a Siberian Inuit parka. The species is registered sparsely in Arctic North America. In total, approximately 1% of the complete Inuit collection contains wolverine, which is used as trimmings.

Because of the limited Western Inuit skin clothing in the NMD collection, we only identified a few species (i.e., species of Phocidae, domestic dog, and wolverine). However, the Western Inuit also used skin from a wide variety of fur-bearing mammals, for example, bighorn sheep (*Ovis canadensis*), ground squirrel, marten (genus Martes), and beaver (*Castor canadensis*) (Chaussonnet, 1988; Oakes and Riewe, 2007).

Geographical Distribution of Species Used in Clothing

Based on the species identification results (see Tables 3a and 3b), Figure 5 shows the geographical distribution of the most widely used mammal skins for Inuit clothing. The figure provides additional information about the origin of the garments and whether the skin of an animal species is used for the entire garment, or just for the edging of the garment (e.g., Western Inuit mostly used wolverine fur as trimmings for caribou clothing). While Inuit in Central Arctic Canada trimmed caribou garments with fur, de-haired caribou, or Phocidae skin, Inuit on the Labrador Peninsula also trimmed caribou garments with fur from Canidae. In Greenland, besides Phocidae and caribou skin for whole garments, Inughuit used fur from Arctic fox, domestic dog, and polar bear for complete garments and trimmings. Kalaallit trimmed garments with Phocidae and caribou skin (with and without fur) and fur skin from domestic dog. In East Greenland, Iivit trimmed Phocidae skin garments with domestic dog and polar bear fur and made whole garments from the latter.

TABLE 3. b) Empirical material: species identification in 39 garments from Eastern Inuit (FOOTWEAR) – *continued*:

Gender	Inuit group	Suit	Accession	Identification number	Sample	Macro identification	TLM identification	DNA identification
Female	Inughuit Eastern Inuit	NGF1	L.9271	32950_a	Leg trimming, fur	Polar bear[5]	*U. maritimus*[5]	Ursinae[5]
Female	Inughuit Eastern Inuit	NGF2						
Female	Inughuit Eastern Inuit	NGF2	L.9556	33011_a	Leg, de-haired	Seal[4]	(No hair)	Phocidae[4]
Male	Inughuit Eastern Inuit	NGM1	L.9551	33006_a	Leg trimming, de-haired	Seal[4]	(No hair)	*E. barbatus*[4]
Male	Inughuit Eastern Inuit	NGM2	L.2104	31595_a	Leg trimming, de-haired	Seal[4]	(No hair)	DNA failed
Male	Inughuit Eastern Inuit	NGM2						
Female	Kalaallit Eastern Inuit	WGF1	L.7818c	67906_a	Leg trimming, fur	Seal[4]	Phocidae4	DNA failed
Female	Kalaallit Eastern Inuit	WGF2	Ld.32c	31317_a	Leg, de-haired	Seal[4]	(No hair)	Phocidae[4]
Female	Kalaallit Eastern Inuit	WGF3	Lc.187d	30495_a	Leg trimming, de-haired	Seal[4]	(No hair)	DNA failed
Female	Kalaallit Eastern Inuit	WGF4	L18.140g	33444_a	Leg trimming, fur	Dog[5]	*B. taurus*[1]	DNA failed
Male	Kalaallit Eastern Inuit	WGM1	Ld.31c	31317_a	Leg, de-haired	Seal[4]	(No hair)	DNA failed
Female	Iivit Eastern Inuit	EGF1	L.5082	32179_a	Leg trimming, fur	Un-specified species	*C. lupus familiaris*[5]	Canidae[5]
Female	Iivit Eastern Inuit	EGF2	L.1545.2	31535_a	Leg trimming, fur	Polar bear[5]	*U. maritimus*[5]	Ursinae[5]
Male	Iivit Eastern Inuit	EGM1	Ld.66c	20246_a	Leg, de-haired	Seal[4]	(No hair)	DNA failed
Male	Iivit Eastern Inuit	EGM2	L.5024	32120_a	Leg, fur	Seal[3]	*P. hispida*[3]	*P. hispida*[3]

[1] Ruminant (with fur)
[2] Ruminant (de-haired skin or sinew thread)
[3] *Phocidae* (with fur)
[4] *Phocidae* (de-haired skin or gut skin)
[5] Carnivore (with fur)

Registration and Identification Methods

After the species identification, we registered our results in NMD's object database to appear on the related website (Schmidt, 2016; http://skinddragter.natmus.dk/). Nevertheless, one question remains: how does one determine the species or family if results of the different identification methods differ or have failed? A successful DNA determination will prevail over hair TLM on a species level, especially regarding species of Phocidae and Canidae. In practice, the DNA result applies to the specific species determination. When DNA identifies the family level, and hair TLM identifies the species, the latter appears as the final result. However, as occurred in a few cases in our study, if the DNA analysis result contradicts the hair TLM (or the macroscopic identification), we must consider the risk of contamination or sample exchange (i.e., repeat the analysis). In the case of caribou, musk ox, and Phocidae fur, macroscopic identification is reliable. As mentioned above, there is a risk of misidentification regarding skins from the young seal, dog, wolf, Arctic fox, polar bear, and wolverine.

Appendix 1 shows our results in the far-right column. Currently, it is not possible to register the identification method in the NMD SkinBase database. An updated version of the database will include this option.

Possible Effect of the Fur Trade on Observed Species

In terms of identifying Canidae, especially the Arctic fox, the effect of the fur trade is possibly reflected in the sparse number of garments made of Arctic fox in Western and Central Inuit clothing. Also, the relatively low prevalence of this species among Inughuit may indicate the influence of the fur trade. Concerning wolf, the fur trade may have reduced the use of this species in Canadian Inuit clothing. Future identification of all Canidae skins in Inuit clothing would be valuable in determining the impact of the fur trade. A second possible focus for future research would be the general significance of using Canidae, especially domestic dog, which was widespread among Inuit in the Bering Strait region, Alaska, Labrador, and Greenland. Apart from wolverine and cattle, the apparent absence of exotic fur skins in Inuit clothing is a third theme that encourages further analyses, primarily trimming material.

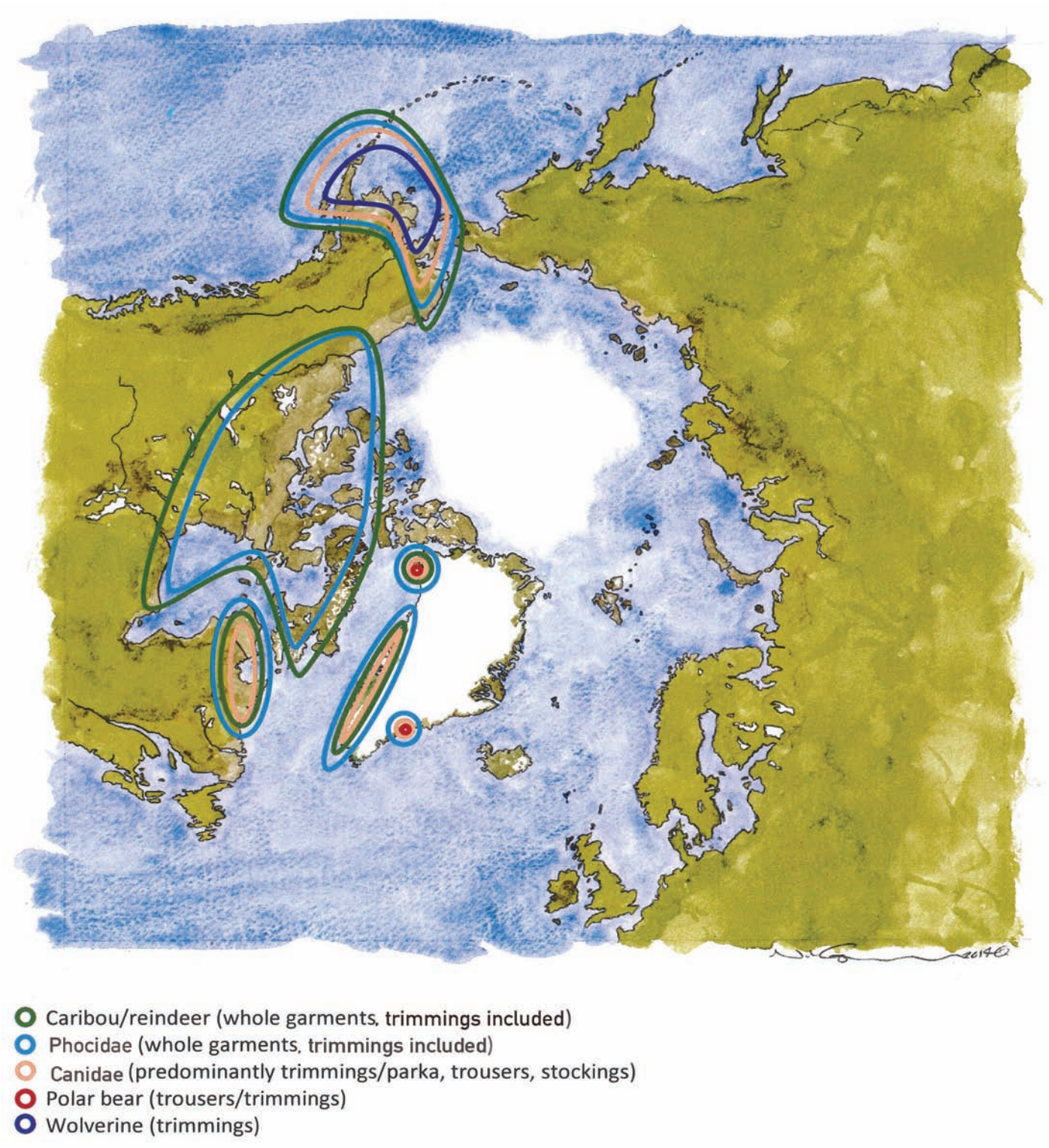

FIG. 5. Geographical distribution of dominant animal species used for clothing among Inuit (approximately 1830–1940) based on the collection of the National Museum of Denmark. Animal species are ranked according to their occurrence in the museum collection (i.e., the number of garments where the species appear). The most used species among Western and most Central Inuit was caribou. On the Labrador Peninsula and among Eastern Inuit in Greenland, garments made of Phocidae were mainly used.

Research to further connect garment materials with the fur trade, and greater attention to the presence of marketable fur on certain garments, even in small amounts in (e.g., trimmings, amulets or decoration), could help reveal provenance for as-yet undocumented garments.

The absence of certain species in Inuit traditional clothing also reflects that hides from large animals (e.g., musk ox, bearded seal, walrus, whale) were too coarse for clothing. Instead, they were suitable for sleeping skins, tents, boats, straps, for example.

CONCLUSION

This study revealed that hair TLM is a reliable method that can stand alone for species identification of the most common species used in historical Inuit fur clothing: caribou, musk ox, and Phocidae. We confirmed macroscopic speciation of different species of seal, for example, harp seal (*P. groenlandicus)*, ringed seal (*P. hispida),* and harbour seal (*P. vitulina),* by TLM. When macroscopic identification of Phocidae was impossible, biomolecular analysis (in this case, DNA analyses) was compulsory for species identification. TLM of hairs from wolverine and polar bear provided easy identification. However, macroscopically, fur from polar bear can be confused with young Phocidae and domestic dog, but not by TLM. Regarding macroscopical identification and TLM of Canidae, fur and hair characteristics from Arctic fox were separable from domestic dog and wolf. Still, the latter two were difficult to distinguish, both microscopically and macroscopically. Thus, we needed DNA analysis to distinguish between domestic dog and wolf.

The obvious advantages of hair microscopy are ease of analysis and low cost. The sustainable, mounted hair specimens we created will extend the necessary reference library. Regarding DNA analyses, the potential identification to species level is desirable, and the general rapid development of methods could lead to future, less expensive, biomolecular approaches. Still, DNA material is vulnerable to degradation and contamination, and sampling can be more destructive.

It is crucial to perform at least two of the analysis methods we examined, of which hair TLM should be one. Bearing in mind that contamination and poor conservation of DNA can be a problem, hair TLM and, if possible, macroscopic identification is essential for securing species identification. This study highlights the value of adding more analyses in species identification as a means of arriving at novel insight into material traditions across historical Inuit cultures.

Finally, the study highlights that animal skin and hide for clothing were used differently among Western, Central, and Eastern Inuit. The use depended on the native species available, tradition, and to a minor extent, the fur trade. The primary skins used as clothing material and trimmings indicate the geographic and cultural provenance. Western Inuit mainly used caribou skin, trimmed with domestic dog fur, wolf, wolverine, and fur from other predators. In contrast, Central Inuit used caribou and Phocidae as primary skin and trimming material. Among Inuit on the Labrador Peninsula and Eastern Inuit, Phocidae was most common as primary skin, and trimming with domestic dog skin was usual. In North and East Greenland, skin from Arctic fox and polar bear were commonly used as trimmings. Thus, we conclude that species identification of primary skin and trimming is an essential tool to estimate the origin of Inuit garments. In putting forward this assertation and through additional research, we hope to identify garments without initial data to recover cultural value.

Because of the limitations of the NMD's Western Inuit clothing collection, we will seek to enlarge the empirical data for future analyses by inviting other museums holding parallel garments to participate in our work. This larger dataset will hopefully strengthen and broaden the conclusions we have presented in this paper and offer richer insights into this aspect of Inuit culture.

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