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Mammal Review

REVIEW

Chemical Communication in Bears (Ursidae)

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ABSTRACT

Introduction: Chemical signals play a fundamental role in the communication systems of varied taxa. For solitary and wide–ranging mammals, the utility of olfactory communication is clear, enhancing fitness by enabling animals to navigate their social landscape without the costs associated with tracking an individual for visual, acoustic, or physical/competitive assessment.

Aims: Thus, the generally solitary lifestyle of bears (Ursidae) likely shaped the evolution of olfaction as a major method of communication. Historically, chemical communication has been generally understudied across bear species, in part due to the logistical constraints of their lifestyle. However, recent studies are beginning to reveal the role of chemical communication in the social lives of bears.

Methods: We employed a hybrid strategy in relevant literature searches, including sensitive searches through Web of Science, Scopus and Google Scholar databases, and reference lists of retrieved papers to identify additional, potentially relevant records. Our search yielded 72 papers fitting eligibility criteria.

Results and Discussion: Here we provide a review of the knowledge on chemical signalling in bears to highlight inter– and intraspecific similarities and differences and identify social function in the Ursidae. We discuss how species' anatomy and physiology may have shaped chemical signalling strategies among bears and develop three hypotheses: ursids communicate chemically (1) for mate location, attraction and assessment, (2) for competition when accessing mates, and (3) to reduce risk and defend resources. Chemical communication in giant pandas (*Ailuropoda melanoleuca*) and brown bears (*Ursus arctos*) has been studied quite extensively, and general function in seasonal and reproductive contexts has been described in polar bears (*U. maritimus*). However, little information exists on chemosensory ability in Andean bears (*Tremarctos ornatus*) and American black bears (*U. americanus*) and is widely lacking for sloth bears (*Melursus ursinus*), sun bears (*Helarctos malayanus*), and Asiatic black bears (*U. thibetanus*).

1 | Introduction

Chemical signals play a fundamental role in the communication systems of many taxa. The function of chemical signals varies widely, from species and kin recognition, facilitation of territoriality, and the coordination of movements, to the indication of the quality of foods, mates, or competitors (Müller-Schwarze 2006; Wyatt 2014). The wide array of body secretions, deposition behaviours, and strategies selected reflects the influences of environmental constraints and species

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ecology on the evolution of chemosignalling (Alberts 1992; Nie, Swaisgood, Zhang, Hu, et al. 2012). Whereas animals often use multiple modalities to convey important information to conspecifics (Munoz and Blumstein 2012), the long range and persistence of chemical signals suggests they play a unique role in conveying information in the absence of direct encounters. For solitary mammals, the utility of chemical communication likely enhances fitness by enabling animals to navigate their social landscape without expending the additional energy needed to track an individual for visual or acoustic assessment (Müller-Schwarze 2006) or risk aggressive interactions.

Bears (Ursidae) consist of five genera and eight species that occur throughout Eurasia and North America, and the Andes Mountains in South America (Servheen et al. 1999; Garshelis 2009). Bears are generally considered to be non-territorial and solitary species (Steyaert, Endrestøl, et al. 2012). However, associations during or outside the mating season also occur, including aggregations at concentrated food sources, for example, spawning salmon (*Oncorhynchus* spp.) (Schwartz et al. 2003; Steyaert, Endrestøl, et al. 2012; Heeres et al. 2024) or whale carcasses (Selva et al. 2019), and non-feeding aggregations for familiarity and social interactions, dictated by ecological conditions (Derocher and Stirling 1990; Clapham and Kitchin 2016). The solitary lifestyle of bears probably played a major role in the evolution of olfaction as a major method of communication and locating food, resulting in an excellent sense of smell (Nowak 2005; Togunov et al. 2017; Sergiel and Van Horn 2019), including the ability to collect conclusive information on, for example, the reproductive status of conspecifics without direct association (scent–scaping; Morehouse et al. 2021) and to employ cross–wind olfactory searching (Togunov et al. 2017). Like many other solitary mammals, chemical communication in ursids remains generally understudied. However, existing evidence suggests that its primary function is intraspecific communication across a range of behavioural contexts.

Here, we review the current scientific literature on chemical communication in bears to clarify its social function within the Ursidae. We outline fundamental concepts related to signalling competitive ability, as well as mate search and selection. We then explore how environmental and social constraints, in combination with anatomical and physiological characteristics of each species, may have shaped the evolution of both shared and divergent chemical signalling behaviours across bear taxa.

2 | Methods

To summarise the body of knowledge on chemical communication and its social function in ursids, we employed a hybrid search strategy (Wohlin et al. 2022). We searched the Web of Science, Scopus, and Google Scholar databases from their inceptions until March 2025, using the keywords 'bear', 'scent', 'marking', and 'chemical communication' combined into a single search string. We also screened reference lists and citations of the identified publications (backward and forward snowballing, respectively) and applied *ad hoc* search (Sukhera 2022; Wohlin et al. 2022), when general information related to scent sources and marking behaviour in other taxa was needed. Records were then selected for inclusion into a narrative review according to the following criteria: (i) the publication must describe relevant details of mode of chemical communication in ursid species; (ii) the publication was a peer–reviewed article or book chapter in an edited scientific volume; and (iii) the publication was in English.

3 | Summary of Literature Search Outcome

Our search strategy yielded a total of 438 records, which encompassed 396 publications from the search string, 29 through snowballed searches, and 13 from *ad–hoc* searches. Following screening and application of the inclusion criteria, 72 publications were included in the review. Table 1 summarises differences in body rubbing behaviour, substrate marking, scent sources, and chemosensory ability among the eight bear species from the reviewed publications, with key references. To provide additional interpretation, we also created an additional schematic Figure 1 linking scent sources to discrimination ability.

4 | Chemosensory Ability

Bears possess at least two distinct, but complementary, olfactory systems, structurally similar to other mammals (Wysocki 1979), that is, the main olfactory epithelium and the accessory olfactory system (i.e., vomeronasal organ). However, detailed histological studies of the vomeronasal organ sensory epithelium have been conducted only in brown bears (*Ursus arctos*) (Tomiyasu et al. 2017). The presence of incisive papillae in the roof of the mouth (Swaisgood et al. 1999) and response to pheromones (Wilson et al. 2020) strongly indicates a vomeronasal organ also in giant pandas (*Ailuropoda melanoleuca*). This, combined with the generally conserved nature of olfactory systems in mammals (Ache and Young 2005) provides strong indirect support for a functional vomeronasal organ in bears. At the molecular level, however, comparative studies have demonstrated that main olfactory epithelium receptor gene sequences are well–conserved, whereas vomeronasal organ receptors are associated with a wide range of genes, suggesting a more dynamic evolution and a potentially more important role within species (Grus and Zhang 2008). Very little is known about the number of olfactory receptor genes in bears, although polar bears (*Ursus maritimus*) have enlarged olfactory turbinals (Green et al. 2012). Whereas the surface area of olfactory turbinals often is used as a proxy for olfactory capability, recent research suggests that it does not necessarily correlate with the number of olfactory receptor genes, indicating a complex relationship between anatomical structures and genetic potential for olfaction (Martinez et al. 2023). Further studies are needed to explore the similarities and differences across ursid species in this area.

Volatile chemical components detected by the main olfactory epithelium allow for the detection of scents from a distance, whereas odour perception by the vomeronasal organ requires direct physical contact with the odour source and is therefore likely responsible for the detection of nonvolatiles (Halpern and Martinez-Marcos 2003). The vomeronasal organ is primarily

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TABLE 1 | Overview of the primary similarities and differences among bear species in terms of scent marking behaviour (tree and pedal marking), scent sources, and chemosensory ability (behavioural observations or chemical investigations) from reviewed articles. In all species, urine and faeces are likely the sources of chemical information.

Species	Tree marking	Pedal marking	Scent sources	Chemosensory ability	Key references
Giant panda	Rubbing	Foot scrape	AGS	ID, Sex, RC, Age, Kin	Swaisgood et al. (2004); Nie, Swaisgood, Zhang, Hu, et al. (2012)
Brown bear	Rubbing	Stomping	AGS + PAG + BAG + BSG	ID?, Sex, RC, Age, Kin?	Rosell et al. (2011); Clapham et al. (2012); Jojola et al. (2012); Sergiel et al. (2017); Tomiyasu, Kondoh, et al. (2018); Tomiyasu, Yanagawa, et al. (2018)
Polar bear	No	Passive	AGS? + PAG	Sex, RC, Kin?	Owen et al. (2015)
American black bear	Rubbing	Stomping	?	Kin?	Henderson et al. (2015); Taylor et al. (2015)
Andean bear	Rubbing	Stomping	AGS?	RC?	Filipczyková et al. (2016); López-Velasco et al. (2026)
Asiatic black bear	Rubbing	Stomping	AGS?	?	Ogawa et al. (2020)
Sun bear	Rubbing	?	AGS?	?	Tee et al. (2020)
Sloth bear	Rubbing	Stomping	PAG + AGS	?	Laurie and Seidensticker (1977); Khadpekar et al. (2021); Swaminathan et al. (2017)

Abbreviations: ?, Unknown or insufficient information available; AGS, Anal gland secretion (preliminary personal observations on polar bears, Asiatic black bears and sun bears; see text) or anogentital gland secretion (giant pandas); BAG, Back skin apocrine gland; BSG, Back skin sebaceous glands; ID, Individual identity; PAG, Pedal apocrine glands; RC, Reproductive; Rubbing, Body rubbing on trees and occasionally on other objects such as power poles, bridge pilings, and rocks.

thought to process compounds that provide information regarding the sex and reproductive status of signalers (i.e., Leinders-Zufall et al. 2000). For example, when giant pandas, and brown bears, encounter scent marks, they sniff, lick, and exhibit a brief flehmen (i.e., curling of the upper lip, exposure of the teeth and inhalation), thereby transferring chemical stimuli to the vomeronasal organ in the roof of the mouth (Swaisgood et al. 1999; Clapham et al. 2012). Flehmen has been also observed in male polar bears investigating conspecific scents (Owen et al. 2015) and in American black bears (*Ursus americanus*) during anogenital and excremental investigations (Gonzales et al. 2013). Although the main olfactory epithelium and the vomeronasal organ have traditionally been considered separate systems, more recent research suggests that the two systems are integrated and sometimes detect the same chemical cues (Keller et al. 2009).

5 | Sources of Scent

The substances used for chemical communication in mammals can originate from different cutaneous scent glands (e.g., sebaceous glands, apocrine, and eccrine sweat glands) as well as urine and faeces (Johnston and Barco–Trillo 2009). Sebaceous glands are evenly distributed over the body and are typically associated with hair follicles. They produce secretions that are rich in lipids, have an oily texture, and are excreted via body movement and rubbing of the skin (Tomiyasu, Kondoh, et al. 2018; Tomiyasu, Yanagawa, et al. 2018), as the glands cannot contract (Flood 1985). Apocrine sweat glands are also primarily observed in hairy skin, near sebaceous glands, and eccrine sweat glands secrete directly to the skin surface via pores. They tend to be confined to specific regions, for example, friction surfaces of footpads in carnivores or of hands, feet, and tails in primates (Sergiel et al. 2017). These basic gland types occur in more complex structures (e.g., anal sacs in carnivores; Gittleman 1996). Many, if not all, mammalian chemosignals are the product of metabolites produced by microbial–host interactions (Carthey et al. 2018). In giant pandas, anogenital gland secretions are produced by a community of fermentative bacteria and show evidence of specialised metabolic pathways responsible for chemosignal synthesis (Zhou et al. 2021).

In mammals, the production of glandular secretions is controlled primarily by reproductive hormones (Müller-Schwarze 2006; Johnston and Barco–Trillo 2009). In males, androgens (e.g., testosterone) influence secretions from sebaceous and apocrine glands (Schulz et al. 2006). In male brown bears, enlarged glands located in the skin on the back show both seasonal and testosterone-dependent development (Tomiyasu, Kondoh, et al. 2018; Tomiyasu, Yanagawa, et al. 2018; Tomiyasu et al. 2025). Ultrastructural analyses further demonstrate that these glands undergo seasonal changes in their secretory mechanisms (Tomiyasu et al. 2021). In general, females in mammals with a distinct breeding season show increased levels of oestrogen–dependent scent deposition around the time of mating, whereas females in species with no distinct breeding season show limited cyclicity (Holst and Eichmann 1998).

Among the Ursidae, only giant pandas possess specialised scent glands in the anogenital region (Swaisgood et al. 1999). Anogenital gland secretions, at least in giant pandas, are rich

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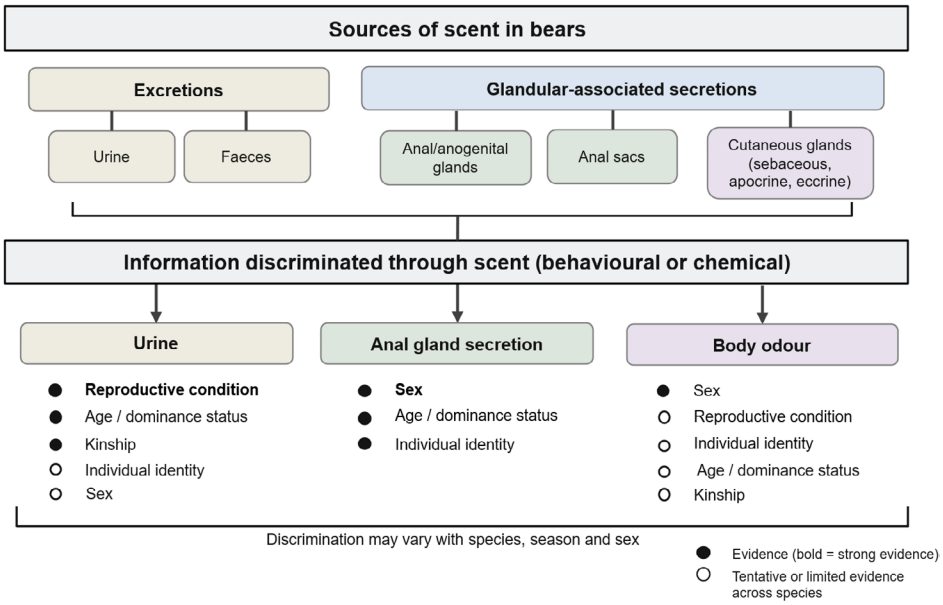


FIGURE 1 | Schematic of scent sources with behavioural and/or chemical discrimination in the bears.

in lipids (Zhou et al. 2021), making them less volatile, long–lasting signals, and therefore well suited to signalling home range occupancy (Swaisgood, Lindburg, White, Zhang, and Xiaoping 2004). Brown bears have anal sacs that are not truly glandular in structure, but serve as a repository for glandular secretions from the anal region (Rosell et al. 2011). Observations indicate that polar bears, sun bears (*Helarctos malayanus*), Andean bears (*Tremarctos ornatus*), and Asiatic black bears (*U. thibetanus*) also have anal sacs (J. Aars, R. von Horn, R. Pizzi, pers. comm.). However, it is not definitively known if bear species possessing anal sacs deposit gland secretions during defecation only or also independently of it, as observed in other carnivores, for example, wolves (*Canis lupus*) (Asa et al. 1985), and spotted hyenas (*Crocuta crocuta*) (Hofer et al. 2001).

It has long been assumed that both brown bears and polar bears have pedal scent glands (Schaffer 1940). Histological examinations of skin sections from polar bears (Owen et al. 2015) and brown bears (Sergiel et al. 2017) did not show specialised scent glands per se, but rather relatively large and profuse apocrine glands on the interdigital skin, compared to skin at other regions of the body (Owen et al. 2015; Sergiel et al. 2017) (Figure 2). Interdigital skin in sloth bears (*Melursus ursinus*), however, contains very few prominent apocrine glands, compared to polar and brown bears (Patil et al. 2016). Whereas apocrine gland secretions function as chemosignals, it is unknown whether their secretions serve this function alone. Apocrine secretions may form a functional unit with sebaceous glands or provide complex signals in tandem with urine or other body odours (Sergiel et al. 2017). To our knowledge, the presence or absence of such modified glands in other bear species has not been verified.

Urine and faeces are used for communication in many mammals (Eisenberg and Kleiman 1972) and are less energetically expensive than glandular secretions (Müller-Schwarze 2006). A wide variety of metabolic events contribute to urinary chemical constituents (Flood 1985). Volatile compounds carried in faeces are assumed to be derived primarily from the liver, due to its metabolic importance (Flood 1985). An animal's chemical profile is formulated by all possible extractable molecules (Wyatt 2010), therefore, excreta are a likely source of chemical information in all mammals. In bears, complex volatile compounds in urine and potential pheromones have been studied in giant pandas (Dehnhard et al. 2006; Wilson et al. 2018, 2020), with groups of volatile substances increasing seasonally along with increases in oestrogens (Dehnhard et al. 2006). Civetone and decanoic acid, when used in choice bioassays, elicited both behavioural and physiological responses in male giant pandas, indicating that these compounds may serve as pheromone candidates for the species (Wilson et al. 2020). In contrast to anogenital gland secretions, urine is a relatively short–lived signal in giant pandas, conveying information more closely tied to motivational and physiological states (Swaisgood, Lindburg, White, Zhang, and Zho 2004).

Some mammals have modified, specialised scent hairs, called osmetrichia, to retain chemical signal compounds (Müller-Schwarze et al. 1977; Müller-Schwarze 2006). In red deer (*Cervus elaphus*) these hairs are narrower (have smaller diameter) than regular hair and have a different cuticular scale pattern (de la Peña et al. 2021). Such scent hairs were not found in a preliminary microscopic analysis in brown bears (A. Zedrosser, F. Rosell, J. Swenson, pers. comm.). However, hair specialisation can also occur at submicron and ultrastructural level, not detectable by visual and light microscopy inspection alone (de la Peña et al. 2021). Both male and female brown bears have long hair around the penis or vulva (Kilham and Gray 2002; Zhang 2009). Following urination, these hairs become moistened with urine and can be rubbed along vegetation as they walk (Zhang 2009) or against substrate, as observed in male American black bears (Taylor et al. 2015). Polar bear paws are densely haired (Orndorf et al. 2022), however, it remains unknown whether these hairs include modified scent hairs, despite considerable attention to the optical and chemical properties of polar bear fur (e.g., for the development of nanotechnologies; Wang et al. 2022). Across the scent sources described in bears, chemical signals appear to be

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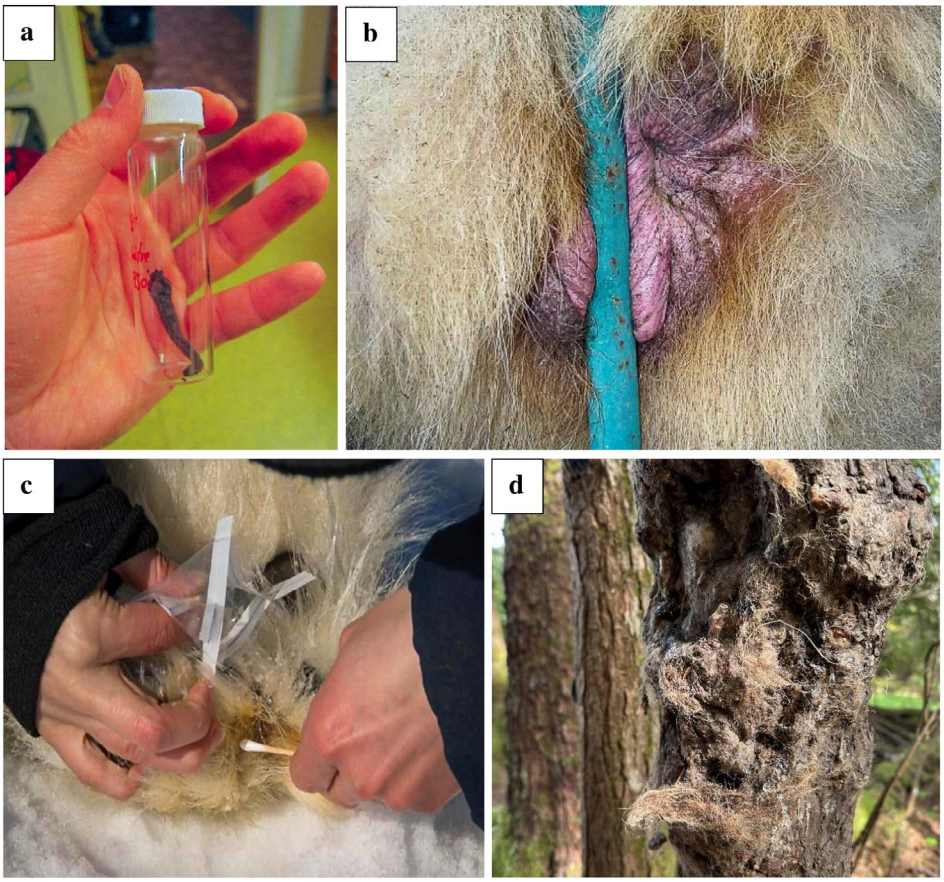


FIGURE 2 | Sources of bear scent: (a) anal gland secretion from an adult male brown bear, (b) anogenital gland secretion from a giant panda, (c) pedal apocrine glands from a polar bear and (d) hair and non-visible glandular secretions from a brown bear (Photos by (a) Frank Rosell, (b) Ron Swaisgood, (c) USGS in Alaska and (d) Melanie Clapham).

derived predominantly from conventional exocrine secretions and excretory products, with relatively little evidence for specialised scent organs. Anogenital glands of giant pandas represent an exception, whereas in other ursids the potential scent sources largely reflect regional specialisation or accumulation of otherwise general bodily secretions.

6 | Scent Deposition

As with other mammals (Wyatt 2014), bears deposit scent into the environment through a range of scent marking behaviours and strategies that have evolved to facilitate this method of communication (Figure 3). These include mostly direct transfer via contact with the substrate (e.g., tree rubbing or pedal marking; Clapham et al. 2012; Sergiel et al. 2017), involving different body regions and scent sources. As a result, scent marks vary in their mode of placement, spatial distribution, and persistence, reflecting the diversity of deposition strategies employed by bears.

6.1 | Tree Marking

Bears rub their bodies against objects in their environment to deposit secretions and excretions, mostly rubbing against trees, but also power poles, bridge pilings, buildings, and rocks (Rogers 1987; Puchkovskiy 2009; Karamanlidis et al. 2010; Sato et al. 2014; Seryodkin 2014) (Table 1). Here, we focus on scent marking via tree rubbing. Brown and American black bears rub trees with their back, flanks, chest, head, neck, and shoulders (Tschanz et al. 1970; Laurie and Seidensticker 1977; Müller-Schwarze 1983; Clapham et al. 2014; Taylor et al. 2015; Charlton et al. 2020; Morehouse et al. 2021). They also rub urine–soaked fur against marking trees (Brown and Macdonald 1985). Giant pandas mark with an anogenital rub and with urine (Kleiman 1983; Schaller et al. 1985). Adult male brown bears display a complex and repetitive sequence of rubbing behaviour, utilising various postures, particularly bipedal back rubbing (Clapham et al. 2014). Similarly, giant pandas display a complex body rubbing behaviour (rolling in and rubbing scent into the head and shoulder region with their paws), using conspecific anogenital gland secretions and urine, as well as other strong–smelling stimuli (Charlton et al. 2020; Swaisgood et al. 2000). Male giant pandas also employ an elevated marking posture, using a handstand to position scent marks high on tree trunks. Captive studies show that pandas invest more time investigating odours placed at elevated positions, and subadult males especially avoid areas treated with adult male urine designed to mimic such high-level scent marks (White et al. 2002). The use of elevated marking postures could function to convey competitive

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FIGURE 3 | Bear scent deposition and investigation methods: (a) tree rubbing by an adult brown bear, (b) stomping and urination by an adult male brown bear, (c) anogenital gland secretion marking by a giant panda and (d) and a polar bear sniffing a pedal gland mark (Photos by (a, b) Melanie Clapham, (c) Zhang Zejun and (d) Joanne Simerson).

ability through height of the mark (White et al. 2002) or to increase the detectability and longevity of the scent mark (Nie, Swaisgood, Zhang, Hu, et al. 2012). Sloth bears, American black bears, Asiatic black bears, Andean bears and sun bears have also been observed to rub trees using both upright bipedal and quadrupedal postures (Joshi et al. 1999; Laurie and Seidensticker 1977; Garcia-Rangel 2012; Taylor et al. 2015; Filipczyková et al. 2016; Tee et al. 2020; Ogawa et al. 2020) (Table 1). Male Andean bears use established trails across their habitat and investigate and rub trees as means of communication (Filipczyková et al. 2016), although a more recent study documented that females and subadults rub trees, but at a lower rate than males (López-Velasco et al. 2026). Polar bears do not appear to actively deposit scent on objects. Instead, it appears that they passively mark their environment as they walk and can discriminate between the sex and reproductive status of conspecifics through pedal scent (Owen et al. 2015).

The available evidence points to several recurring features of tree rubbing across ursids: the deposition of scent from multiple body regions, the use of different marking postures, and frequent association with repeatedly used marking locations (over-marking). In some species, scent is also positioned at different heights on marking objects, suggesting that the deposition characteristics of a mark may form part of the signal. However, the apparent absence of active object marking in polar bears indicates that scent-deposition strategies may vary among species. Whether such variation is associated with ecological or habitat differences remains an open question.

6.2 | Pedal Marking

Pedal marking is a form of substrate–based scent deposition in bears, whereby secretions from apocrine and sebaceous glands in the interdigital, metacarpal, and metatarsal skin, and from eccrine glands in the footpads, are deposited onto the substrate both passively while walking (Owen et al. 2015) (Table 1) and actively through stomping, in which bears twist or press their paws into the ground (Clapham et al. 2014; Sergiel et al. 2017). This mode of scent deposition may allow signals to be distributed over large areas and may provide receivers with information associated with recent presence and movement patterns. It has been documented in brown bears (Sergiel et al. 2017; Revilla et al. 2021), American black bears (Taylor et al. 2015), and sloth bears (Swaminathan et al. 2017). Pedal marking often occurs alongside tree rubbing (Clapham et al. 2014; Taylor et al. 2015), forming repeatedly used marking locations visited by multiple individuals (Revilla et al. 2021). Pedal marking is not well studied in giant pandas, but foot–scraping behaviour is commonly observed in association with scent deposition and investigation (Swaisgood et al. 2000). Evidence in other bear species remains limited; however, experimental and observational studies in polar bears indicate responsiveness to conspecific scent cues, including pedal deposits (Owen et al. 2015). In sloth bears, few prominent apocrine sweat glands around hair follicles or on their interdigital skin have been recorded (Patil et al. 2016). For other ursid species, direct evidence is currently lacking, underscoring the need for comparative research on the distribution, expression,

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and functional significance of pedal scent deposition across the family Ursidae.

6.3 | Faecal Marking

Faeces have an important scent marking function in many carnivores (Macdonald 1980; Robinson and Delibes 1988; Barja et al. 2004), but it is uncertain whether faeces have this role in bears. Pandas and brown bears do not show much attention towards faeces from conspecifics (White et al. 2003; Clapham pers. obs.), but both species typically defecate near their resting sites, which concentrates faeces (Steyaert, Hütter, et al. 2012; Steyaert et al. 2019; Kang et al. 2017). This may be due to site use intensity rather than intentional marking (Kang et al. 2017; Wang et al. 2023). In the absence of evidence that bears deliberately place faeces at specific locations or respond to conspecific faeces, we do not consider this pattern sufficient to classify concentrated defecation as faecal marking. Nevertheless, the repeated accumulation of faeces at resting sites may increase the potential for olfactory information to be available to subsequent visitors. This should be investigated further.

6.4 | Anal Gland Secretion/Anogenital Gland Secretion Marking

Except giant pandas (see below), evidence for the role of anal gland- or anogenital gland secretions in bear communication remains indirect. Brown bears have sex–specific differences in secretion composition (Rosell et al. 2011), suggesting that these secretions may encode biologically relevant information. Brown bears are frequently observed sniffing the ground and sitting at the base of rub trees during marking events, which could facilitate the deposition of anal gland secretions (Clapham et al. 2014). However, despite these suggestive chemical and behavioural observations, direct evidence demonstrating conspecific responses to anal gland secretions is currently lacking. Thus, its functional role in communication remains unresolved.

Genital rubbing, a behaviour likely associated with anal gland- or anogenital gland secretions deposition, has been documented only rarely in bears, but may play a role in the communication of reproduction–related cues. In sloth bears, observations of captive females indicate that genital rubbing occurs predominantly during the breeding season and closely coincides with behavioural indicators of oestrus, as assessed by changes in vulval visibility (Khadpekar et al. 2021). The occurrence of this behaviour in captivity was positively associated with female age and with the presence of adult males in close physical proximity, whereas the presence of other females had no apparent effect (Khadpekar et al. 2021). These findings highlight a largely understudied component of chemical communication in bears.

6.5 | Dynamics of Marking

Several studies have documented a peak in marking behaviour during the mating season in brown bears (Craighead et al. 1995; Green and Mattson 2003; Karamanlidis et al. 2007; Tattoni et al. 2015) and American black bears (Harger 1974; Burst and Pelton 1983; Rogers 1987; Taylor et al. 2015). Andean bears in some regions have a peak in marking behaviour in the dry season, but it is unknown if Andean bears have a distinct mating season (López-Velasco et al. 2026). Genetic analyses of hair samples and behavioural observations indicate that adult male brown bears rub more than other age–sex classes during the mating season (Karamanlidis et al. 2010; Kendall et al. 2009, 2019; Stetz et al. 2010), although rubbing behaviour may occur at lower levels outside the breeding period (Clapham et al. 2012, 2014). The same has been found for Andean bears, based on behavioural observations (Filipczyková et al. 2016; López-Velasco et al. 2026). Female polar bears show elevated investigation of conspecific pedal scent during the mating season (Owen et al. 2015). In giant pandas, males scent-mark trees year–round, whereas female marking is largely confined to the mating season (Nie, Swaisgood, Zhang, Hu, et al. 2012) and females investigate scent signals of adult male conspecifics more during the mating season (White et al. 2004). Within this period, females further increase their scent–marking rate when in oestrus (Swaisgood et al. 2000) and males preferentially investigate the odour of oestrous females (Swaisgood et al. 2002). Similarly, genital rubbing in captive sloth bear females is largely confined to the breeding season and associated with oestrus, varying with age and male proximity (Khadpekar et al. 2021).

Overall, the available evidence indicates that scent marking and scent investigation are frequently modulated by reproductive context, with sex- and reproductive status-specific patterns emerging across several ursid species. Although the available evidence is uneven among taxa, this recurring association suggests that reproductive activity can be an important driver of the temporal dynamics of chemical communication in bears.

6.6 | Scent Site Selection to Maximise Signal Detection

The production and deployment of scent signals can be energetically costly, thus selecting strategies that minimise costs by maximising the likelihood of signal detection (Alberts 1992). This could be accomplished by bears marking substrate that increases scent range or persistence. For example, giant pandas selectively urinate and mark with anogenital gland secretions on trees with deep, furrowed bark, which could facilitate signal persistence (Zhou et al. 2019). They also urine-mark on larger trees, perhaps to create a larger odour field (Nie, Swaisgood, Zhang, Hu, et al. 2012; Zhou et al. 2019). Rough surfaces may extend signal life by reducing loss of odours to rainfall. Unlike brown bears (Clapham et al. 2013), Andean bears have been found to select leaning trees for marking (Filipczyková et al. 2024), akin to big cats (Smith et al. 1989). Selection of leaning trees may protect scent marks from rainfall and enhance detectability when overhanging trails (Filipczyková et al. 2024). Giant pandas, American black, Andean, and brown bears mark close to trails where conspecifics are more likely to encounter their signals (Burst and Pelton 1983; Green and Mattson 2003; Nie, Swaisgood, Zhang, Hu, et al. 2012; Puchkovskiy et al. 2012; Clapham et al. 2013; Kleiner et al. 2018; Bowersock et al. 2022; López-Velasco et al. 2026), and marking appears biased towards

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larger trees (Green and Mattson 2003). However, Kleiner et al. (2018) reported that Andean bears selected smaller rub trees closer to waterholes, and Filipczyková et al. (2024) did not find size to be an important predictor of Andean bear use for marking. Other properties of a tree, including resin content and the capacity to retain scent or the aromaticity of resin or bark, may also influence their suitability as marking substrates (Schaller et al. 1985; Nie, Swaisgood, Zhang, Hu, et al. 2012; Clapham et al. 2013; González-Bernardo et al. 2021; Filipczyková et al. 2024). In brown bears, the preferential use of resin-rich coniferous species, particularly fir (*Abies* spp., Puchkovskiy 2009), has been suggested to enhance odour adhesion and prolong signal persistence (Clapham et al. 2013; Sato et al. 2014). By comparison, González-Bernardo et al. (2021) observed that brown bears primarily selected birch (*Betula* spp.) trees for rubbing, with selection influenced by tree characteristics rather than by proximity to areas of high conspecific density. Site selection may be further explained by the use of locally rare tree species or conspicuous objects to mark that enhance detection (Clapham et al. 2013). Giant pandas select marking sites with a more open microhabitat, which would facilitate detection by conspecifics (Wang et al. 2023).

Across species, marking sites are frequently associated with travel routes or other locations where encounters with conspecifics are likely. Substrate characteristics, such as tree size, bark structure, orientation, resin content, and local microhabitat, may further affect signal persistence or detectability. However, the specific characteristics associated with marking site selection appear to vary among species and habitats, suggesting that local environmental conditions may shape how bears optimise scent signal deployment. Importantly, most studies have inferred the potential effects of marking site characteristics on scent persistence or detection rather than measuring these processes directly, highlighting an important opportunity for experimental research on the relationship between site selection and chemical signal transmission.

7 | Scent Assessment

Analysis of the chemical composition of scent can provide insight into the information encoded in chemical signals. Complementary behavioural discrimination experiments can reveal how scents are perceived and distinguished by receivers and may indicate motivational states. Below, we summarise the current evidence of scent discrimination abilities in bears.

7.1 | Sex and Reproductive Condition

As finding mates and assessing potential rivals are central to reproductive fitness in many species, the ability to discriminate the sex of conspecifics is widespread, particularly among species with direct mating interactions (Johnston and Barco–Trillo 2009). Consistent with this, several studies have demonstrated sex–specific chemical profiles in giant panda anogenital gland secretions (Hagey and Macdonald 2003; Yuan et al. 2004; Liu et al. 2006; Zhang et al. 2008). In adults, Zhang et al. (2008) identified three putative female pheromones (5–methylhydantoin, indole, and erucic acid) and two putative male pheromones (squalene and hydroquinone). In contrast, Yuan et al. (2004) did not detect sex–specific compounds but reported differences in the relative abundances of several compounds shared by both sexes. In brown bears, Rosell et al. (2011) found that the adult anal gland secretions likely encode information about sex. Behavioural studies demonstrated sex–specific chemosensory responses to conspecific scent in giant pandas (Swaisgood et al. 2000; White et al. 2004; Owen et al. 2016), brown bears (Tschanz et al. 1970; Jojola et al. 2012), and polar bears (Owen et al. 2015).

During the mating season, captive female polar bears were more motivated to investigate conspecific pedal scent, and males were able to distinguish between the reproductive condition of females in behavioural bioassays, with responses indicating heightened discrimination in the breeding season compared to the nonbreeding season (Owen et al. 2015). Likewise, male (but not female) giant pandas discriminate between oestrous and nonoestrous female urine, showing preferential investigation and flehmen responses (Swaisgood et al. 2000, 2002; Hong et al. 2007). Playback experiments suggest that exposure to calls by females in oestrus is associated with increased scent–marking, but not vocalisations, in both male and female giant pandas, indicating potential interactions between auditory and chemical signalling (Xu et al. 2012). In brown bears (Dehnhard et al. 2005) and Andean bears (Dehnhard et al. 2006), the chemical composition of urine varies with reproductive condition. Chemical cues therefore appear to provide information relevant to different stages of reproductive assessment, from identifying the sex of a conspecific to distinguishing reproductive condition, with responses shaped by the timing and context of reproduction.

7.2 | Age and Dominance

As reproductive hormones largely regulate glandular secretions, chemical constituents also vary with age (Müller-Schwarze 2006). Age is usually correlated with body size and fighting ability, and fights between bears can result in serious or lethal injuries, particularly for subordinate individuals (Craighead et al. 1995; Derocher et al. 2010). Consequently, the ability to assess a potential opponent's fighting ability without direct interaction would be advantageous, allowing individuals to adjust their behaviour through challenge or deferral (Gosling and McKay 1990). Age has also been shown to be a strong determinant of reproductive success in several bear populations (Zedrosser et al. 2007; Costello et al. 2009; Richardson et al. 2020), suggesting a selective benefit to signalling age–related qualities via scent.

In giant pandas, anogenital gland secretions encode age–related information (Yuan et al. 2004; Liu et al. 2006), and individuals of all age–sex classes can discriminate between adult and subadult male urinary and anogenital gland secretions odours, as well as female urinary odours (White et al. 2003). Scent–marking behaviour further reflects age; juvenile male giant pandas either do not scent mark until sexual maturity (Tian et al. 2007) or mark at substantially lower frequencies than adults (Swaisgood pers. comm.). Comparable age–related differences occur in brown bears, with subadults exhibiting simpler motor patterns

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of scent marking than adults (Clapham et al. 2014). In captivity, young brown bears avoid rubbing sites used by unfamiliar adult males (Tschanz et al. 1970), and in the wild subadults scent mark at a lower frequency during the breeding season (Clapham et al. 2014). Time investment in scent marking, as a proxy for effort, was also lower for subadults during the nonbreeding season (Clapham et al. 2014). Scent mark posture also confers information about age and dominance. In giant pandas, only adult males adopt the handstand posture to deposit urine (Swaisgood et al. 2000). Pandas are more likely to avoid areas where other pandas have handstand–marked, and subadult males showed the strongest avoidance, consistent with the risk incurred in direct interactions with a dominant adult male. Collectively, this indicates that juvenile bears behave differently at marking sites to adults and may even emit a different chemical message to adults, as seen in Asian elephants (*Elephas maximus*) (Rasmussen et al. 2002; Clapham et al. 2012).

7.3 | Individuality

The complexity of the chemical composition of secretions/excretions and the number of odour sources that produce scent gives the potential for each individual of a species to have its own olfactory 'fingerprint' (Müller-Schwarze 2006). At present, giant pandas are the only bears for which scent signalling individuality has been demonstrated through both chemical and behavioural analyses, with the chemical composition of anogenital gland secretions being individual–specific (Yuan et al. 2004; Zhang et al. 2008). Both male and female giant pandas could discriminate individual odour cues from male anogenital gland secretions, but not female urine, indicating that scent individuality may depend on the source of the odour (Swaisgood et al. 1999).

The ability to recognise individual conspecifics is thought to be most advantageous in species with complex social interactions, facilitating the recognition of long–term partners and the establishment of dominance hierarchies (e.g., spotted hyena: Burgener et al. 2009). However, individual recognition would also benefit nonsocial species in decision making related to mate choice and competition. Individual recognition should be an important factor in dominance communication for bears, particularly for species that aggregate at productive food resources (e.g., brown bears, American black bears: Craighead et al. 1995; Taylor et al. 2015) or form mating aggregations (e.g., giant pandas: Nie, Swaisgood, Zhang, Liu, and Wei 2012). Social awareness of individuals would help to reduce risk, particularly for more vulnerable subordinate bears (Swenson et al. 2001). It may also be important for initiating non-agonistic interactions, such as social play (polar bears: Latour 1981, brown bears: Clapham and Kitchin 2016). Similarly, individuality could be required for certain reproductive strategies, such as those displaying individual mate preferences (giant pandas: Martin-Wintle et al. 2015). It has been suggested that male brown bears possibly recognise females with whom they have previously mated (Bellemain et al. 2006), thereby reducing the risk that males kill their own offspring during sexually selected infanticide. The role of chemical communication in sexually selected infanticide deserves further investigations in bears in general.

Chemical analyses of brown bear scent secretions indicate that individual identity is encoded in chemical profiles through variation in the presence and relative abundance of compounds, rather than through unique, individual–specific substances (Mazzatenta et al. 2023; Clapham et al. 2023). As some compounds may occur consistently within samples from a given individual and be absent in others, there is not enough evidence to reliably distinguish each bear by a fixed set of markers. This pattern reflects the typical complexity of mammalian scent signals, in which individual odours arise from distinctive combinations and concentrations of shared compounds rather than from single, diagnostic chemicals (Soso et al. 2014). Similar investigations are needed for the remaining bear species, to supplement those conducted for giant pandas and brown bears.

7.4 | Kinship

As bears are primarily solitary, the ability to recognise kin through odour would reduce the likelihood of inbreeding or escalated aggression among spatially proximate relatives. Evidence for olfactory–mediated kin recognition has been documented in ursids, particularly in giant pandas. Kinship information is present in the urine of adult males during the mating season, but not in females or subadults (Liu et al. 2008). Similarly, Hagey and Macdonald (2003) observed that two closely related adult male giant pandas shared highly similar anogenital gland secretion profiles. In contrast, Zhang et al. (2008) found no correlation between anogenital gland secretions compositional similarity and genetic distance, highlighting variability in the strength or expression of olfactory kin signals.

Maternal–offspring recognition also appears to rely on olfactory cues. Female giant pandas have been shown to distinguish their own dependent offspring from unrelated cubs, and cubs are able to recognise their mother's odour (Swaisgood, Lindburg, White, Zhang, and Xiaoping 2004). This recognition may persist for months or years beyond the period of maternal dependency, although it remains unclear whether it is mediated by phenotype matching or familiarity through olfactory memory (Gilad et al. 2016). Kin recognition may further influence male reproductive strategies in sexually selected infanticide by enabling males to recognise cubs they have sired (Bellemain et al. 2006; Clapham et al. 2012).

Evidence from ecological and chemical ecology studies suggests that kin recognition is also possible for other bear species beyond giant pandas (e.g., American black bear: Rogers 1987, brown bears: Støen et al. 2005, polar bear: Zeyl et al. 2009), but dedicated studies are still needed to determine whether scent cues mediate kin recognition per se.

7.5 | Age of Scent Marks

Information on the age of scent marks can be important for both senders and receivers. Senders depositing fresh marks can signal recent presence or current reproductive status, whereas receivers assessing scent age determine whether scent marks remain biologically relevant. In competitive contexts (e.g., intrasexual conflict) the ability to assess scent recency

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provides important information for mediating risk. For most bear species, the persistence and detectability of scent marks under natural conditions have not been directly quantified. Evaluation of giant panda anogenital gland secretions collected in the wild revealed no sign of loss or degradation of the chemical constituents for at least 2 weeks (Zhou et al. 2019). Similarly, studies in captive giant pandas have demonstrated that anogenital scent samples remain detectable for extended periods, with individuals responding to scents that were at least 120 days old, and adults, but not subadults, were able to discriminate between odours aged 0 to 5 days (Swaisgood, Lindburg, White, Zhang, and Xiaoping 2004).

Field studies of brown bears provide indirect evidence that scent marks may retain informational value far beyond the moment of deposition. Long–term marking sites, such as rub trees and pedal marking areas, are repeatedly visited, sniffed, and remarked by multiple individuals across seasons, suggesting that accumulated scent cues remain relevant to receivers over time (Sergiel et al. 2017; Revilla et al. 2021). The persistence of these cues is likely influenced by the chemical compositions of secretions, as well as environmental conditions such as temperature, humidity, ultraviolet exposure, and substrate, which collectively affect chemical degradation and volatilisation (Martín and Lopez 2013; Zhou et al. 2019; Revilla et al. 2021).

Information about a scent mark's age may be particularly important in a reproductive context. For males, the ability to distinguish recent from older female scent marks could inform decisions whether continued searching or courtship is worthwhile. In giant pandas, for example, one–week old scent from an oestrous female informs the male that the female has most likely ovulated, rendering further pursuit unprofitable (Swaisgood, Lindburg, White, Zhang, and Xiaoping 2004). This is especially important for species that are spontaneous ovulators, for example, the giant panda (Owen et al. 2016). Because ovulation timing is not mediated by the presence of a male (Swaisgood et al. 2000; Owen et al. 2016), male pandas might be more likely to miss the fertile period if their assessments of its timing are inaccurate. Although such temporal discrimination has not been experimentally demonstrated in free–ranging brown bears and other ursid species, apart from examples given above, studies showing individual, sex– and age–specific chemical signatures in their secretions (Sergiel et al. 2017; Clapham et al. 2023) indicate ursid scent marks contain complex information that could, in principle, be interpreted in a temporal framework.

8 | Discussion

Considering evidence from both captive experiments and field studies, three hypotheses concerning the function of observed chemosensory ability and behaviour are relevant for bears: (1) ursids communicate chemically to the opposite sex for mate location, attraction and assessment, (2) ursids communicate chemically to the same sex for competition to access mates, and (3) ursids communicate chemically for risk reduction and resource defence.

8.1 | Locating, Attracting and Assessing Mates

Without appropriate communication and courtship, mating will not take place (Swaisgood et al. 2000; Swaisgood, Lindburg, White, Zhang, and Xiaoping 2004; Zhang et al. 2014). Thus, there is evidence to suggest that the different bear species, especially giant pandas (Swaisgood et al. 2000, 2002; Swaisgood, Lindburg, White, Zhang, and Xiaoping 2004; Hong et al. 2007; Nie, Swaisgood, Zhang, Hu, et al. 2012), but also polar bears (Stirling and Derocher 1990), use scent signals to locate and attract mates, and assess female reproductive status. For example, both male and female giant pandas emit more sexually motivated vocalisations when exposed to odours of the opposite sex, and males vocalise even more in response to odours of oestrous than non-oestrous females, suggesting that these odours play a role in priming sexual motivation in advance of face–to–face encounters (Swaisgood et al. 2000). Also, adult male polar bears recognise the path of a lone adult female (most likely in oestrus) instantly and follow her until he catches up to her or is distracted by another female (Stirling and Derocher 1990). Although evidence on other bear species is limited compared to that of giant pandas and polar bears, the concentration of chemical communication just prior to and during the mating season indicates a similar function (brown bears: Clapham et al. (2012), American black bears: Taylor et al. (2015), and Andean bears: Filipczyková et al. (2016)).

Reproductive condition of female giant pandas, polar bears, brown bears, and Andean bears can be discriminated behaviourally and/or chemically through various odours (Dehnhard et al. 2006; Owen et al. 2015). It is therefore likely that male bears have evolved strategies to utilise these cues to increase mating opportunity. Indeed, both male polar bears and giant pandas are able to discriminate between the reproductive condition of females based on scent, and preference is shown for oestrus females (Swaisgood et al. 2000, 2002; Owen et al. 2015). That such scent discrimination ability and preference is lacking during the nonbreeding season, indicates seasonal motivation of effort (White et al. 2004; Owen et al. 2015) and changes in chemical composition (Dehnhard et al. 2006), placing emphasis on a reproductive function. It is possible that female bears in other species also signal oestrus by increasing their rate of urination and/or scent marking, as do pandas (McGeehan et al. 2002; Swaisgood et al. 2002).

Self–advertisement behaviour in bears has been linked to reproductive context and mating opportunities (Lamb et al. 2017). For example, the increase in self–advertisement behaviour by female pandas when approaching oestrus (Lindburg et al. 2001; McGeehan et al. 2002; Nie, Swaisgood, Zhang, Hu, et al. 2012) reflects a pattern consistent with selection for enhanced signalling during their extremely short fertile period (Kleiman 1983). For species other than giant pandas, the lower female effort in more direct modes of scent marking, such as tree marking, indicates more reliance on more indirect methods of chemical communication, such as through faeces (Clapham et al. 2012). Polar bears, sloth bears, and brown bears utilise pedal scent to leave a continuous olfactory trail (and most likely also Andean bears and giant pandas). The pedal scent for polar bears documents the presence and reproductive status of females (Owen

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et al. 2015), which may also be the case for other bear species. Although evidence is limited, behaviours such as foot–scraping, pedal marking (stomping), and urination may increase as female bears come into oestrus, and male interest in these odours may increase as ovulation approaches, although overt marking-related behaviours have not been documented in polar bears. Further investigation into pedal scents and the chemical constituents of female urine across seasons is required to gain a comprehensive understanding of self–advertisement by female bears.

Male bears may use scent marking as a method to attempt to influence female mate choice. There is abundant evidence that females of many species use scent to evaluate the relative quality of potential mates (Gosling and Roberts 2001; Fisher et al. 2003; Roberts and Gosling 2004). Giant pandas engage in active mate choice and opportunities to exercise free mate choice are associated with greater fitness (Martin-Wintle et al. 2015). Wild brown bears that scent mark more frequently and at more sites have a higher number of offspring and mates, indicating a fitness advantage (Morehouse et al. 2021). Although it is unknown whether scent marks function through direct (i.e., mate attraction), indirect (i.e., dominance/competitor signalling (see below)), or non-mutually exclusive mechanisms, these findings suggest a key relationship between chemical communication and reproduction in brown bears (Morehouse et al. 2021).

Thus, ursid chemical communication appears to function not simply as a means of locating potential mates, but as part of a broader reproductive signalling system in which scent production and assessment can facilitate mate encounter, indicate female reproductive condition, and influence subsequent mating interactions and success.

8.2 | Male–Male Competition for Mates

The distribution of female scent in the environment, either through urine, substrate or tree marks and the seasonality of habitat use, can result in several male bears locating and attempting to monopolise a reproductive female simultaneously (Steyaert, Endrestøl, et al. 2012; Nie, Swaisgood, Zhang, Liu, and Wei 2012; Heeres 2025). In this situation, more dominant males displace subordinates, seemingly by a combination of size and aggressiveness (Craighead et al. 1995; Nie, Swaisgood, Zhang, Hu, et al. 2012). Here, there is a potential fitness benefit for dominant males to have previously displayed their competitive ability to subordinate males in an attempt to manipulate their behaviour (Roberts et al. 2001). Additionally, there would be a survival and potential fitness benefit to receivers if they evolved to use this prior knowledge of a potential opponent and react accordingly (Krebs and Dawkins 1984). Under this hypothesis, dominant individuals are selected to signal competitive ability and subordinates to use these cues to make adaptive decisions on whether to escalate an encounter or avoid encounters altogether. Evidence from brown bear scent marking studies in both North America and Europe suggest that the primary function of tree rubbing is to communicate dominance between males, displayed through higher marking frequency (Tschanz et al. 1970; Clapham et al. 2012, 2014; Tattoni et al. 2015), and reduced investigation of male scent by females (Clapham et al. 2012). Likewise, male American black bears generally scent mark at a higher frequency than females (Rogers 1987; Taylor et al. 2015). Whereas female scent marking behaviour is mainly concentrated around oestrus, male scent marking and chemosensory behaviour continues outside of the breeding season in polar bears, brown bears, and giant pandas (Nie, Swaisgood, Zhang, Hu, et al. 2012; Clapham et al. 2012, 2014; Owen et al. 2015; Tattoni et al. 2015). In captive giant pandas, only adult males adopt the handstand marking posture, and resident males are much more likely to use the handstand mark than 'trespassing' pandas (Swaisgood et al. 2000). In experimental presentation of male urine at different heights, pandas first spend more time investigating high marks, then avoid the area, indicating that the handstand serves as a competitive signal (White et al. 2002). When male pandas were presented with the odour of other males, they showed heightened interest in neighbouring oestrous females, indicating that male–male competition may facilitate sexual motivation (Bian et al. 2013). This suggests that scent marking plays a prominent role in the competitive lives of male bears and may be used to influence the behaviour of future potential opponents in a manner that reduces the costs to the individual of unnecessary escalated aggression.

8.3 | Risk Reduction and Resource Defence

Territorial large carnivores usually place scent marks at territory boundaries (e.g., Smith et al. 1989; Sillero-Zubiri and Macdonald 1998), providing an olfactory association between the resident and the defended area, and reducing the frequency of escalated agonistic encounters with intruders (Gosling 1981). Alternatively, less territorial species seem to cluster marks in locations frequently visited by conspecifics, for example, trees and trail intersections (Harmsen et al. 2010; Clapham et al. 2013).

Bears do not meet the strict criteria of territoriality (Steyaert et al. 2021). In giant pandas, females and subadults spend the majority of their time in relatively exclusive core areas, and there is some evidence that they are less tolerant of intruders in these areas (Schaller et al. 1985; Zhang et al. 2014). However, they are not known to deposit scents at home range boundaries, instead clustering marks at communal scent stations in areas (open habitat, ridges, trails) where other pandas are likely to encounter them (Wang et al. 2023). Brown bears generally are considered solitary and non-territorial (Steyaert, Endrestøl, et al. 2012). Males do not defend exclusive territories, but instead occupy large home ranges that may overlap with several other males and many females (Zedrosser et al. 2023; Heeres 2025). Their spatial behaviour is shaped by access to mates and food, rather than territorial defence (Zedrosser et al. 2023; Heeres 2025). Female adult brown bears form matrilineal assemblages (spatial clusters of related females), with home range overlap correlated with relatedness, likely based on kin recognition (Støen et al. 2005). Related females living in matrilineal assemblages have a very high home range overlap with neighbouring related females, compared to very little overlap of home ranges with neighbouring, but unrelated, females (Støen et al. 2005; Zedrosser et al. 2023). Likewise, in some populations, female American black bears display elements of territoriality in both their spatial movements and area defence behaviour, and scent

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marking is conducted by resident, rather than transient males (Rogers 1987). In contrast, polar bears occupying a drifting ice environment do not maintain home ranges in the traditional sense (Jodouin et al. 2025). However, individual polar bears exhibit interannual fidelity to geographic regions, consistently use core areas, and follow similar movement patterns between seasonally important habitats (Auger-Methe et al. 2016). The degree of philopatry is higher in females of the coastal ecotype (Brun et al. 2021). Together, this suggests that polar bears' communication system is not likely focused on defending or indicating residency in an area but may instead facilitate both risk avoidance among conspecifics (including while aggregating) and mate detection. Sloth bears display home range overlap and evidence of both social tolerance and hierarchy. Tree marking in this species has been attributed to communicating dominance relationships among individuals (Joshi et al. 1999).

Temporal patterns of scent marking behaviour vary among bear species and populations, and the spatial patterns and deposition behaviour may also vary temporally. Sloth bears, brown bears, and American black bears have been observed to scent mark trees beyond the breeding season (Joshi et al. 1999; Clapham et al. 2012; Bowersock et al. 2022), and Andean bears throughout the year (mating season from February to September (Pillco Huarcaya et al. 2024); López-Velasco et al. 2026), suggesting that chemical signals remain valuable to bears year-round, and function extends beyond communication for mating. The communication of dominance may function more broadly than male–male competition for mates, factoring ultimately in reducing risk through self-advertisement for both males and females. Reducing risk may be especially relevant within confined areas near concentrated food sources or other non-feeding aggregations, where potentially costly and injurious encounters with conspecifics are more likely. Communication to signal defence of a temporary resource, such as concentrated food, appears to be more applicable to bear ecology than signalling territorial ownership and may be conditional on species, age, sex and relatedness. These patterns likely reflect the dynamic function of chemical signalling within ursid social systems.

9 | Conclusions

Chemical signalling strategies appear to be quite similar across bear species, although this is based on limited data for some species. Most research has focused on scent deposition behaviour and the bears' ability to recognise sex, reproductive condition, and age through scent, although there are also indications that they can recognise individuals and kin. Results indicate a social function related to signalling competitive ability and finding and choosing mates. This similarity in function and the challenge of maintaining social relationships selects for similar patterns of marking behaviour. Chemical communication in giant pandas and brown bears has been studied quite extensively, and general function in seasonal and reproductive contexts has been described in polar bears. However, little evidence exists on the sources of scent and chemosensory ability for Andean bears and American black bears, and is widely lacking for sloth bears, sun bears, and Asiatic black bears.

Author Contributions

Frank Rosell: conceptualization, data curation, formal analysis, funding acquisition, methodology, writing – original draft, writing – review and editing, visualization, project administration. **Agnieszka Sergiel:** conceptualization, methodology, writing – review and editing. **Megan A. Owen:** writing – review and editing. **Helga V. Tinnesand:** writing – review and editing. **Ronald R. Swaisgood:** conceptualization, writing – review and editing. **Jon E. Swenson:** writing – review and editing. **Andreas Zedrosser:** writing – review and editing. **Melanie Clapham:** data curation, formal analysis, writing – review and editing.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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