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The emerging need to manage scavenged wildlife resources

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ABSTRACT

Scavenged wildlife resources are a unique type of common pool wildlife resource that are collected without killing or capturing the animal, and their collection is understudied and potentially underregulated relative to their conservation significance. The separability of these resources from the living population of animals that produce them can complicate efforts to link collection to future resource availability and develop management strategies. Furthermore, these resources are gaining popularity as online markets cater to a growing global demand for niche animal products. A notable example is naturally shed antlers from wild herds collected by "shed hunters" for both personal and commercial use. In the Greater Yellowstone Ecosystem (GYE), home to the largest migratory cervid populations in the continental United States, shed hunting's growing popularity has created a potential common-pool resource dilemma. We surveyed shed hunters before and after a key policy change in Wyoming. Our results reveal diverse recreational and commercial values for antler collection. We also show that resource users are experiencing externalities from increased congestion and indicate strong overall support for active management, though participants differ in their preferred approaches. Exploration of the social dynamics reveals multiple types of scavenged resource user groups giving rise to a complex management environment. In considering future management in the GYE shed hunting context, we emphasize the importance of the separability of the resource from the animal. Specifically, approaches like seasons designed to reduce overlap of resource use and wildlife during key periods can support recreational opportunities while reducing disturbances to wildlife.

1. Introduction

Globally, wildlife hold significant use and non-use values, and people exploit wildlife in diverse ways, influencing their persistence on the landscape (Duffus and Dearden, 1990; Roth and Merz, 2013; Pascual et al., 2023). Historically, research on the exploitation of wildlife has focused on optimizing harvest (Williams, 1996; Heffelfinger et al., 2013; Gren et al., 2018), curtailing illegal trade (Zimmerman, 2003; Van Uhm, 2016; Wu et al., 2025), and more recently on wildlife viewing and tourism (Moore and Rodger, 2010; Shannon et al., 2017). The prevailing perspective still prioritizes consumptive and lethal practices because of its clear impacts (Wiedenfeld et al., 2021), which may obscure the scope and impacts of wildlife resources that are obtained without killing an animal or removing it from its habitat.

1.1. Scavenged wildlife resources

There is a notable lack of terminology in the field to describe animal resources that are scavenged or collected rather than hunted or harvested. We propose the term "scavenged wildlife resources" to describe renewable natural resource materials that animals grow or create, rely on, and eventually discard during their life cycle, which humans collect. The defining feature of scavenged wildlife resources is that their collection does not require killing the source animal; instead, the resource becomes physically separated from the animal on its own or after natural death and can be collected by humans. Because they are an ancillary or derivative product associated with a more traditional renewable natural resource, there can be additional complexities associated with managing scavenged resources. Examples include antlers, feathers, nests, droppings, shells, and shed skin—as well as body parts from naturally deceased animals, such as skulls and ivory.

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There are limited examples of scavenged wildlife resources and their conservation import in scientific literature and even fewer examples where management options are considered. One example is the collection of edible Swiftlet nests - among the world's most expensive wildlife products - which has led to a significant decline in both nest yields and Swiftlet populations (Sankaran, 2001). Other examples include caterpillar fungus in the Himalayas (Hopping et al., 2018), sea shells (Hamidu et al., 2023), and wild honey (Oldroyd and Nanork, 2009). Though the majority of these resources appear to be collected without active management, there are notable exceptions to this, such as the collection of eagle feathers or of dead-heads (the skulls of naturally-deceased animals) in the United States (USFW, 2009) and of caterpillar fungus in the Himalayas (Zhang et al., 2024). Other examples, such as rhinoceros horn and elephant ivory, are well-studied and tightly regulated in the context of preventing poaching-related mortalities (Holden and Lockyer, 2021) but have not received attention when they are "scavenged" after the animal died naturally.

Overall, this resource type is highly heterogeneous, encompassing terrestrial and marine sources and spanning many types of animal body parts and animal-made materials. Additional variability relates to the number of scavenged materials individual animals are capable of providing across life stages and the extent to which the animal population is subject to hunting or harvesting for the animal's meat and not the scavenged resource. Scavenged resources can also vary in the extent to which scavenging leads to human activity within wildlife habitats that disrupts animal behavior, potentially introducing stress, and reducing the survival rate of the population (Thorburn, 2014; Edwards, 2016; Hopping et al., 2018).

Although they receive little attention in the scientific literature, demand for this subset of wildlife resources appears to be increasing. The same factors that have increased global demand for wildlife products (Andersson et al., 2021; Mozer and Prost, 2023), such as the shift to online trade, new connections between buyers and sellers, and the growth of niche markets for animal products (Di Minin et al., 2018; Nijman et al., 2022), likely also influence demand for scavenged resources.

1.2. Scavenged wildlife resources as common-pool resources

Most wildlife resources exhibit the characteristics of Common-Pool Resources (CPRs) and can be subject to the so-called "tragedy of the commons" without active management (Hardin, 1968; Ostrom, 1990). Managing CPRs can be challenging due to difficulties in defining users, restricting access, and developing context-specific institutional arrangements (Ostrom, 2010; Moore and Rodger, 2010). Wildlife are a type of renewable natural resource with additional management complexity due to potential cross-jurisdictional mobility and competing management objectives (e.g., harvest vs. non-use values) (Skonhoft, 1999; Lunstrum and Havice, 2025). Common pool wildlife resources are often subject to externalities, where actions of one participant can impact the value other participants derive from the resource, but are not considered in the decision-making of the participant (Verhoef, 1999; Clark, 2010). One common externality is a stock, or 'dynamic', externality, where extraction reduces the future availability of the resource for participants in future periods (Verhoef, 1999, Clark, 2010). A second type of externality relates to congestion, where the presence of additional users reduces the benefits or increases the costs for resource users (Brown, 1974; Verhoef, 1999; Phaneuf et al., 2009). Externalities are context-specific, and those associated with scavenged resource outcomes are likely diverse and could include the potential for negative impacts of scavenging on other resources and habitats.

Scavenged wildlife resources share these properties of CPRs and could, in theory, be subject to similar dilemmas. Specifically, scavenging can negatively impact wildlife species populations via increased human disturbances that affect wildlife behavior, health, and reproduction, as well as future resource availability (Sankaran, 2001; Hopping et al., 2018). Empirical studies demonstrating this link between scavenging and species' populations are difficult to implement, contributing to this resource type's limited representation in wildlife conservation literature. Nonetheless, a substantial body of research on the effects of human presence—particularly through recreation and tourism— on wildlife supports the theoretical connection between intensive scavenging activity and population impacts (Green and Higginbottom, 2000, Sato et al., 2013, Shannon et al., 2017). Second, user congestion in collecting the scavenged resource across space and time is possible and, if it occurs, can diminish individual profit and the recreational experience of collecting it in multiple dimensions. For instance, congestion can reduce resource availability, heighten competition and conflict, and disrupt the solitude and connection with nature that some users seek (Brown, 1974; Phaneuf et al., 2009; Lin, 2024). Importantly, the unique decoupling between the collection of the scavenged resource and a live animal can make CPR management more challenging by obscuring the link between resource and animal and creating ambiguity around whether the resource is regulated as part of the living animal and/or as a separate material. This can lead to the need to manage both the hunting or harvest of the animal and collection of the scavenged resource.

Traditionally, management of wildlife CPRs relies on a combination of approaches including market-based approaches where hunting or harvest incurs a tax or requires a tradable permit, input regulations that restrict how a resource is exploited (e.g. access requirements such as licenses or permits that limit who can participate, equipment and technology restrictions such as engine size or gear allowed, and spatial limits or seasons that dictate where and when hunting or harvest can occur), and output regulations (e.g. extraction limits and size and type restrictions on the harvested or hunted animal) (Heaps and Helliwell, 1985; Sterner and Coria, 2012). These approaches are sometimes used individually but can also be used in combination. In the context of scavenged resources, in addition to exploration and classification of the resources themselves, there is a lack of foundational knowledge about user groups and their behavior, including whether participants would even accept regulation (Ostrom, 2000; Cox et al., 2010). As a result, these traditional management approaches remain largely untested in the context of scavenged wildlife resources.

1.3. Evidence from shed antler collection in the Greater Yellowstone Ecosystem

Naturally shed antlers exemplify the challenges and significance of managing scavenged wildlife resources. Antlers, bony appendages grown primarily by male cervids for mate competition and sometimes defense, are shed in winter and early spring after the rut (McCarthy et al., 1998). Human societies have collected antlers, an activity coined "shed hunting," for thousands of years, using them for tools, decoration, art, and medicine (Osborne, 2017; Langley and Wisher, 2019). In the Greater Yellowstone Ecosystem (GYE), four wide-ranging cervid species—elk (*Cervus canadensis*), moose (*Alces alces*), mule deer (*Odocoileus hemionus*), and, to a lesser extent, white-tailed deer (*Odocoileus virginianus*)—shed their antlers seasonally (Kauffman et al., 2020; Middleton et al., 2020). Shed hunters collect cast antlers for both commercial and recreational purposes, fueling a niche regional economy while also providing a popular outdoor activity during the hunting off-season (WGFD, 2015).

1.3.1. Antler collection as a potential CPR dilemma

Shed hunting in the GYE has become increasingly popular over the last decade and drawn new participants (Streep, 2022). Intense antler collection may harm wildlife by causing stress and avoidance behaviors during late winter and early spring, critical periods for survival, leading to stock externalities if this results in death or reduced reproductive capacity (Edwards, 2016; Zuckerman et al., 2020). However, research linking shed hunting to wildlife persistence is limited, and thresholds for harmful human activity remain unclear (Bates et al., 2021).

Congestion also appears to be affecting multiple aspects of the shed hunting user experience, including increasing the difficulty of finding antlers and reducing opportunities for solitude in nature (Streep, 2022). Moreover, the perception that visiting shed hunters are exploiting a local resource for profit sets up conflicts with locals shed hunters. Media activity has drawn attention to the commercial aspects of the activity, depicting shed hunters as male, opportunistic, and profit-driven and using terms such as "gold rush," and "black market" to describe the lucrative and sometimes illicit nature of antler collection (Hughes, 2018; Streep, 2022; Koshmrl, 2024; Peterson, 2024; Owens, 2024). There has been a rise in the documentation of antler-related crimes (Peterson, 2024; Schmitt, 2024), which poses significant challenges for law enforcement and generates distrust among shed hunters (Koshmrl, 2024). These dynamics mirror a broader national trend of migration to rural areas with high recreational appeal, which has contributed to increased congestion externalities on public lands, particularly in the post-COVID-19 era (Dimke et al., 2021; Lin, 2024).

1.3.2. *Management of antler collection in the GYE*

Although scavenged wildlife resources are largely unregulated, regulations in the GYE are evolving, offering a unique opportunity to explore participants' management preferences. Interviews with wildlife managers reveal that managing shed hunting is a regional priority but that implementing a management approach is complicated (Maher et al., 2023). The collection of shed antlers occupies a jurisdictional gray area (Lunstrum and Havice, 2025) and is not covered under wildlife protection laws, such as the Lacey Act, which restricts commercial use. Currently, shed antler management is shaped by a combination of federal and state-level policies. Federal no-take laws prohibit the collection of any wildlife resources, including antlers, from National Park Service (NPS) units, but it is legal to collect and sell antlers found on public land or on private land with landowner permission. Recently, Western states have begun to implement additional policies on public lands by using a combination of spatial restrictions, seasons, and access requirements, with regulations varying based on state residency. In 2008, Wyoming became the first state to formally regulate antler collection through Statute 23-1-302(a), which established the Antler Regulation Area (ARA) and banned collection west of the Continental Divide from Jan. 1 to Apr. 30 (Fig. 1). This statute spatially and seasonally restricted access to collection sites with the goal of reducing shed hunting pressure on wintering animals (WGFD, 2015). In 2023, Wyoming expanded its regulatory framework by passing Bill HB0276, which designates shed antlers and horns on public land as state property beginning in 2024. The law introduced two additional provisions: (1) a 7-day head start for Wyoming residents and (2) the inclusion of shed antler collection among the activities requiring non-residents to purchase a $21.50 conservation stamp before entering the field. Wyoming's policy distinguishes between residents and non-residents and regulates when, where, and who can collect but does not limit how many antlers are collected and how antlers may be used or sold.

Despite pioneering efforts to regulate this atypical wildlife resource, limited information is available about user characteristics, resource attributes, and management preferences. We aim to inform the development of management approaches for scavenged resources by exploring four research questions as they apply to shed hunting: (1) What are the defining traits of the user groups engaged with scavenged wildlife resources? (2) What are the motivations and values for collecting wildlife products and what role does commercial interest play? (3) Are users experiencing congestion externalities and if so, how are they adapting their behavior? (4) Which management strategies are best aligned with user groups and resource attributes? We conducted a survey of shed hunting participation in the GYE in 2023 and 2024, before and after Wyoming's new legislation was passed. The survey allows us to examine user groups, their experiences, and their management preferences.

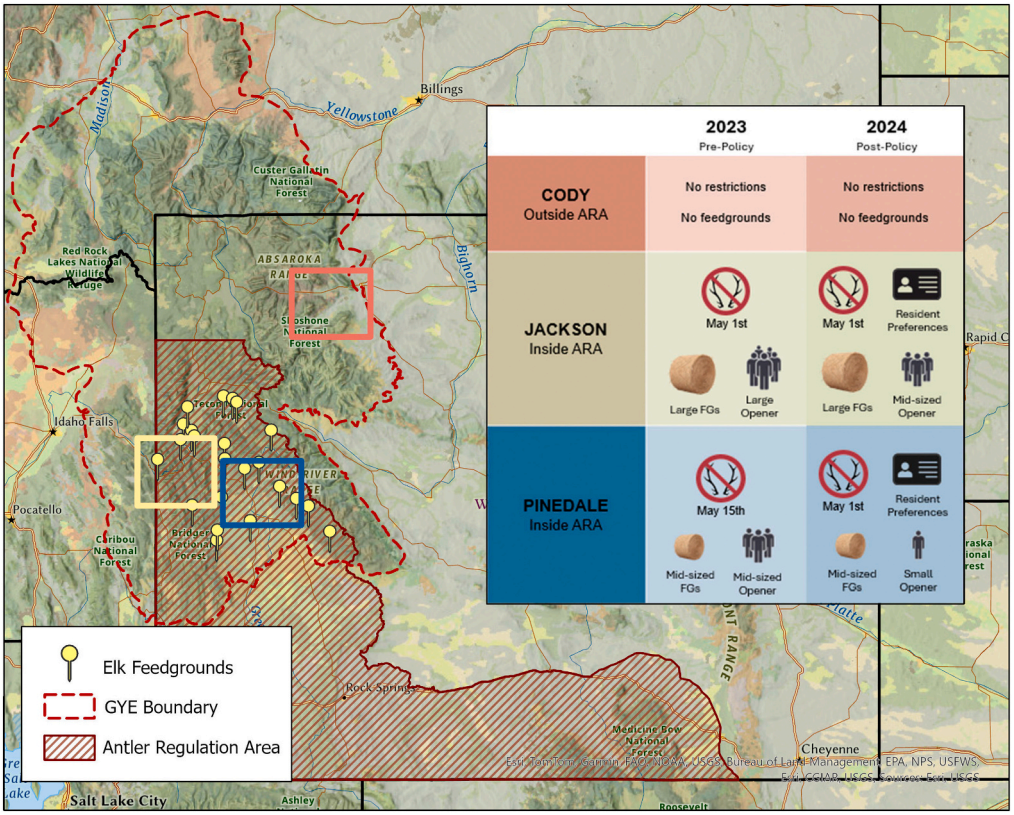

Fig. 1. Overview of shed hunting sites and study design.

2. Methods

2.1. Study area

The Greater Yellowstone Ecosystem (GYE), the world's largest intact temperate ecosystem (~80,000 km^2), spans a complex matrix of public and private lands managed by various agencies and thousands of landowners (Middleton et al., 2022). Far-ranging, migratory cervids regularly cross administrative boundaries (Gigliotti et al., 2022), and their management is considered a conservation priority due to their economic, ecological, and cultural value to society (Secretary of the Interior, 2018; Maher et al., 2023). Elk are the dominant herbivore in the system and migrate from summer habitat in the higher elevation areas at the GYE's core to lower elevation winter habitat (Proffitt et al., 2010; Barker et al., 2019). In Western Wyoming, 22 government-run feedgrounds provide resource subsidies to elk throughout the winter (Smith, 2001), and shed antlers are often concentrated in herds' winter habitat and around feedgrounds. The implementation of shed hunting seasons to Wyoming's ARA has created shed hunting "openers," where large groups gather near trailheads and feedgrounds as closures lift, resulting in race-like competition for antlers. Jackson, Wyoming is home to a famous May 1st opener that attracts up to 1000 vehicles.

Antler collection supports a niche economy in the region, and antler products from the GYE are sold domestically and internationally (Robbins, 1997) and crafted into items such as knife handles, jewelry, chandeliers, furniture, and increasingly into pet chews—a market valued at $69 billion in 2018 (Hughes, 2018). Additionally, they are used in Traditional Chinese Medicine, although live velvet, the soft, vascularized tissue that covers a growing antler, from farmed animals is typically preferred (Wu et al., 2013). Antlers with unique features and matching sets can sell for thousands of dollars. The average price per pound of antlers sold at Jackson, Wyoming's Annual Elk Fest Auction, a proxy for national prices, rose from $8.12/lb. in 2010 to $23.55/lb. in 2024 (Antler Auction Totals on the National Elk Refuge, 2020).

2.2. Study design

We collected survey data from the year before and after Wyoming's new laws took effect in 2024, within and outside the Antler Regulation Area (ARA) (Fig. 1). We focused on three geographic hubs in the GYE frequented by shed hunters: Cody, Jackson, and Pinedale (Fig. 1). These hubs represent the region's shed hunting policies, are near public lands with high cervid densities, and offer reliable opportunities to encounter shed hunters. The Cody hub, outside the ARA, has no feedgrounds and features dispersed antler collection. Jackson and Pinedale, within the ARA, experience intense activity during season "openers" near feedgrounds. Jackson, home to the National Elk Refuge (NER) and up to 11,000 wintering elk, hosts the largest antler concentration in the contiguous United States.

2.3. Survey

2.3.1. Overview

We surveyed shed hunters in the Greater Yellowstone Ecosystem (GYE), targeting participants aged 18 or older who collect or have collected shed antlers within the GYE boundary (Fig. 1). To address privacy concerns (Bonnie et al., 2020), we ensured full anonymity. We drafted and piloted a survey with wildlife managers and shed hunters and received Institutional Review Board approval from UC Berkeley's Office for Protection of Human Subjects. The survey (Appendix A) included three sections: (1) Activities, (2) Perceptions and Policies, and (3) Demographics and featured multiple-choice, drop-down, "select all that apply," Likert-scale items (Robinson, 2014), and text entry questions. The Activities section examined participants' values, motivations, commercial involvement, and use of antler-related social media. The Perceptions section addressed views on shed hunting trends, illegal collection, and current or proposed management. The management approaches (taxes, licenses, and seasons) explored in the survey were identified in conjunction with managers as those currently implemented or considered to have a high potential for implementation. Other management considerations (residency and enforcement) were also included based on manager input. In 2024 (Year 2), we added questions about how new laws affected participants' behavior. The Demographics section collected respondent background and recruitment details.

2.3.2. Implementation

We used Qualtrics to implement our survey and recruited participants through convenience sampling via in-person and online methods (Wardropper et al., 2021). Probability-based sampling was infeasible due to a lack of knowledge about the user population and its characteristics. While convenience sampling likely increased our sample size, it limits the generalizability of findings to the broader shed hunting population. We recruited participants using flyers with QR codes placed at local businesses (e.g., gas stations, restaurants, retailers), public access points and trailheads near Wyoming's 22 feedgrounds (Fig. 1), and shed hunting events. Permission to post flyers was obtained from business owners or public authorities. Online recruitment included digital flyers on Twitter and Instagram profiles under "GYE Antler Study," partner organization listservs, and shed hunting influencers promoting the survey. To incentivize participation, we offered outdoor retailer gift cards totaling $1000, with individual prizes up to $250. Online recruitment, including listservs and social media, accounted for 46.2 % of participants, while in-person efforts at trailheads, businesses, and events brought in 36.0 %. Word of mouth contributed 14.2 %, and 6.9 % selected "Other."

2.4. Analysis

We analyzed all survey data in R. Using the QualtRics package, we first created a workflow where completed surveys were downloaded via an application programming interface (API) and processed through data checks and cleaning. We flagged responses with reCAPTCHA scores >0.5 (likely bots) for manual review and filtered responses that failed a trap question. Since questions were optional, sample sizes (n) reflect the number of respondents per question.

2.4.1. User group criteria

We classified respondents in terms of two binary criteria representing their motivations and residency: (1) whether they were primarily recreation- or profit-motivated and (2) whether they were Wyoming residents or non-residents. These groupings enable exploration of resource use and management preferences based on key user traits (Duffus and Dearden, 1990; Cooke and Cowx, 2006; Chauhan, 2022). "Profit-motivated" participants were those who answered "Yes" to "Have you ever sold shed antlers for profit?" OR entered a percentage greater than 0 for "What % of sheds found in your last season did you sell?" AND answered "Neutral", "Agree," or "Strongly Agree" to the statement "I shed hunt for the chance to earn money." This classification combined self-reported motives with actual behavior. We differentiated between residents and non-residents, who experience Wyoming's statute differently and may approach management from differing standpoints as local versus non-local users. Residency was identified based on home address.

2.4.2. Statistical analysis

We analyzed survey responses using methods from Yap and Sim (2011) and Sainani (2012) for numerical data, constructing confidence intervals per Bauer (1972), and followed Bewick et al. (2004) and Fernández-Cásseres and Russi-Pulgar (2023) for categorical data. Given limited information about our total population, we compared the central tendencies (e.g. median) of numerical variables (Tables 1 and 2, Appendix B) and the response frequencies of categorical variables across

Table 1
Summary statistics for Wyoming residents vs. non-residents. Parentheses indicate "Non-resident" value.

	n Res (non-res)	Mean Res (non-res)	Median Res (non-res)	SD Res (non-res)	Difference estimation 95 % CIs (Positive difference means non-res estimator is higher)
# of outings	185 (113)	6.38, 11.67	4, 6	6.60 (14.44)	1.00** (0–3)
Time travelled	185 (113)	2.07 (3.87)	1 (3)	2.75 (3.87)	1.07*** (1–2)
Antlers (quantity)	179 (108)	19.60 (46.38)	9 (16.5)	27.79 (27.55)	5.00*** (2–10)
Antlers (pounds)	162 (98)	69.99 (134.05)	24 (40)	100.26 (225.50)	12**(5–25)
Money spent (USD)	76 (54)	690.32 (1678.09)	237.5 (950)	1272.28 (2661.78)	450*** (170–800)
Gross earnings (USD)	177 (108)	266.15 (503.44)	0 (0)	766.61 (2237.07)	0*** (0–0)
Net earnings (USD)	75 (51)	293.52 (−1031.29)	−100 (−600)	1422.96 (3984.75)	−500*** (−990 to −180)
% antlers sold	178 (112)	18.88 (19.66)	0 (0)	33.86 (32.41)	0 (0–0)

** $p < .01$.
*** $p < .001$.

Table 2
Summary statistics for recreation- vs. profit-motivated. Parentheses indicate "Profit-motivated" value.

	n Rec (prof)	Mean Rec (prof)	Median Rec (prof)	SD Rec (prof)	Difference estimation 95 % CIs (Positive difference means prof estimator is higher)
# of outings	209 (89)	7.83 (9.70)	6 (4)	10.11 (11.61)	1.00* (0–2)
Time travelled	209 (89)	2.75 (2.75)	2 (2)	0.93 (0.93)	0.00 (0–0)
Antlers (quantity)	204 (83)	25.93 (38.90)	9 (15)	43.43 (65.90)	5** (1–9)
Antlers (pounds)	181 (79)	72.49 (143.73)	20 (50)	115.40 (229.98)	25*** (10–40)
Money spent (USD)	94 (36)	1053.97 (1222.44)	300 (750)	2218.56 (1406.78)	300** (95–645)
Gross earnings (USD)	205 (80)	157.18 (865.71)	0 (0)	844.49 (2334.75)	0*** (0–0)
Net earnings (USD)	91 (35)	−933.62 (295.69)	−230 (−250)	2266.51 (3677.17)	145 (−180–750)
% antlers sold	206 (84)	7.54 (47.71)	0 (51.5)	22.17 (38.42)	47*** (27–54)

* $p < .05$.
** $p < .01$.
*** $p < .001$.

user group pairings (e.g., residents vs. non-residents; profit- vs. recreation-motivated). Since none of our numerical variables met normality assumptions required for parametric tests, we used the Wilcoxon rank-sum test (Mann-Whitney U) to test the null hypothesis that respondent groups came from populations with the same distribution. If rejected, we tested the alternative hypothesis that one group had a greater estimated median using R's wilcox.test() function with alternative = "greater" or "less" and conf.int = TRUE. In Tables 1 and 2, we report summary statistics and 95 % confidence intervals for each numerical variable and each user group. The "Difference Estimation" column gives the estimated difference in median between groups, in which a positive value indicating a higher median for the specified group. These non-parametric estimates help interpret how group characteristics relate to variation in behavior, effort, and economic outcomes.

For categorical questions (e.g., multiple-choice, yes/no, Likert-type), we used the Chi-squared Test of Independence to assess whether response distributions differed between groups. Each test evaluated the null hypothesis of no association between group membership and response category using R's chisq.test() on contingency tables. For example, to compare preferences for levels of regulation across motivation groups, we used chisq.test(regulation_table), where regulation table is a 2 × 4 matrix with rows representing participant and columns representing response categories (no regulation, less, same, more). To identify which categories of responses (e.g. more respondents choosing "no regulation" than expected) contributed to any significant results, we calculated standardized residuals (adjusted Pearson residuals) by dividing the difference between observed and expected counts by the standard error of the expected count. We report the absolute value of the significant standardized residual (SR) and its level of significance using thresholds based on the standard normal distribution: $|r| > 1.96$ ($p < .05$), $|r| > 2.58$ ($p < .01$), and $|r| > 3.29$ ($p < .001$). For binary (2 × 2) comparisons, we used one-sided Fisher's Exact Tests via R's fisher.test() to test the null hypothesis that there is no association between the two variables against the alternative that the proportion in one group is greater than in the other and report p values, the odds ratio (OR, e.g. how much more or less likely one outcome is), and 95 % confidence intervals for the OR. We use a significance threshold of $P = .05$ when discussing results.

2.4.3. Accuracy and reliability

Population-level data on shed hunting user groups is unavailable, as this activity has not been previously studied and largely occurs in an open-access setting. This limits the inferences we can draw, and summary statistics should be interpreted cautiously (Wardropper et al., 2021). Participation bias likely arose from our recruitment methods, which could favor certain shed hunter demographics. For example, using social media likely biased responses toward social media users, and recruiting at shed hunting "opener" events may have over-represented individuals who prefer competitive environments. Shed hunters' protectiveness of their activity could further skew results, as our academic positionality may have attracted participants more supportive of science-driven management. Finally, participants may have had higher stakes in the issue or been motivated by the cash prize. Despite these limitations, our diverse recruitment techniques likely helped minimize bias and reach a broader shed hunter population. Unusual weather conditions also impacted our study. In 2023, winter closures were extended in parts of Wyoming, Idaho, and Montana, which allowed shed hunters to attend both the May 1st and May 15th openers, potentially increasing attendance and influencing behavior.

3. Results

3.1. Overview of user group characteristics and activities

We received 402 surveys, of which 318 (79.1 %) met quality standards. Survey responses for each question by group are available in Appendix B. Among respondents, 28.3 % were "profit-motivated," and 71.7 % were "recreation-motivated." Wyoming residents comprised

62.9 % of participants, and non-residents made up 37.1 %. Surveys collected before policy changes accounted for 53.8 % of responses. The proportion of Wyoming residents increased in 2024 to 75.5 % from 52.1 %, likely due to non-resident restrictions. Respondents were predominantly male (81.7 %) and white (96.7 %), reflecting demographic trends in Intermountain West hunting communities (US Census Bureau. 2021; USFW, 2009). The median age was 37 (M = 39.2, SD = 13.8), and most participants had household incomes over $75,000 and a bachelor's degree or higher. Participants had a median of 15 years of shed hunting experience (M = 16.7, SD = 12.1), and most (89.3 %) were also big game hunters.

Shed hunting has a strong regional appeal. Respondents were from 15 states and 72 counties, with most from Wyoming (59.1 %), Montana (13.5 %), and Idaho (12.6 %). Participants most commonly collected antlers on public land (US Forest Service, Bureau of Land Management, and State land) with an activity peak in May, with 94.5 % of participants active. Antlers are graded by condition, with "browns" (freshest and most desirable) comprising 65.3 % of finds, indicating most antlers are collected the same year they are dropped, effectively resetting collection annually. The most common uses for antler were décor (86.4 %), gifts (39.3 %), pet chews (32.8 %), artisanal products (27.0 %), and medicinal products (1.7 %).

3.2. Motivations and values for shed hunting

Our results highlight diverse motivations for shed hunting, which participants valued as a recreational experience and for material. Participants described shed hunting as a culturally and recreationally important activity around which they built community, honed their backcountry skills, and connected with nature. Top motives, ranked using a Likert scale, were: (i) enjoying nature, (ii) exercise, (iii) spending time with friends and family, (iv) raw antler material, and (v) earning money (Fig. 2). Notably, earning money ranked lowest, with 47.7 % of respondents "Strongly Disagreeing" with shed hunting for financial gain. Within our sample, we found no significant differences in motives between Wyoming residents and non-residents. The only significant difference in motives between profit- and recreation-motivated participants was that profit-motivated participants were more likely to value the antler material itself (SR = 3.96, $P < .001$), though "Earning money" was excluded from that analysis because it was used to define those user groups. These findings suggest financial motivation does not preclude valuing other aspects of shed hunting and overlapping drivers of participation (Fig. 2).

Participants dedicated substantial time, money, and effort to antler collection (Tables 1 and 2). 67.1 % of respondents took time off work to shed hunt, and participants spent a median of $400 (Tables 1 and 2) in their last season. Profit-motivated hunters were more likely to skip work ($p = .003$, OR = 2.26 (1.36, ∞)) and spent more on the activity ($P = .006$, Table 2), likely in anticipation of financial returns. Respondents reported collecting an average of 29.7 antlers (94.1 pounds) in their last season, and non-residents found more antlers than residents ($P < .001$, Table 1), likely due to greater effort expended (Table 1).

We explored the extent to which participants engaged in the commercial trade of antlers. Less than half (48.9 %) of participants had ever sold antlers, and 19.2 % of last season's total finds across participants were sold. Profit-motivated participants sold an average of 47.7 % of their finds (Table 2). In fact, few respondents profited from antler sales: the median difference between participants' spending and earnings was $300 (95 % CI: $180–$400, P < .001), indicating that, on average, participants spent more than they earned. Only 15.1 % reported a net profit, while the average loss was $592.14. There was no evidence to indicate that profit-motivated participants earned more money than recreation-motivated participants (Table 2), suggesting that our participants had similar financial outcomes regardless of motivation.

3.3. Evidence of congestion externalities

Our results reinforce the idea that shed hunters are experiencing considerable congestion externalities (Fig. 3). Nearly all participants (96.3 %) had observed an increase in shed hunting's popularity over the past decade, with 85.0 % noting a rise since COVID-19. Many (80.5 %) reported encountering more shed hunters in the field since COVID, and 53.3 % found it harder to locate antlers (Fig. 3). Almost all shed hunters (92.7 %) had adjusted their behavior to adapt to these trends: 64.2 % had changed locations to avoid congestion, 42.6 % were secretive about their activities, and 35.04 % reduced their activities. Declines in interest in the sport noted by 27 % of participants appear to be offset by increased interest from other participants (22 %).

We asked participants to what extent they agreed with the statement "Most shed hunters engage in illegal activities to obtain a competitive advantage," and found that 41.5 % agreed or strongly agreed, suggestive of eroding trust in the community. Reported infractions included violating seasonal closures, trespassing, collecting in "No take" NPS units, and stockpiling antlers outside of the seasons to collect on opening day. Additionally, 54.1 % had experienced or knew of conflicts over antlers, with recreation-motivated shed hunters less likely to report conflicts (49.5 %) than profit-motivated ones (65.2 %) ($P = .009$, OR = 0.526 (0–0.83)). Overall, these results imply that increasing competition may have fostered a minority of rule violators, creating conflicts among participants.

Social media has been credited with popularizing shed hunting by attracting new participants and creating markets for antler products (Hughes, 2018; Streep, 2022). However, none of our participants reported learning about shed hunting through social media, and only 35.2

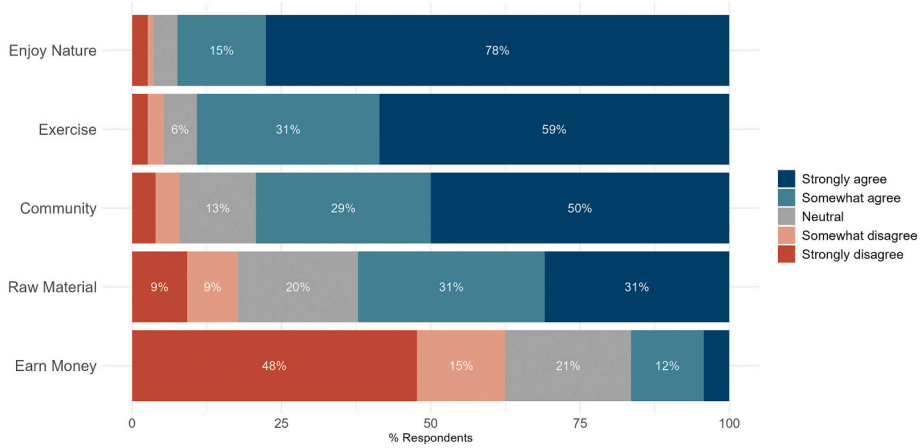

Fig. 2. Respondents' motivations for shed hunting.

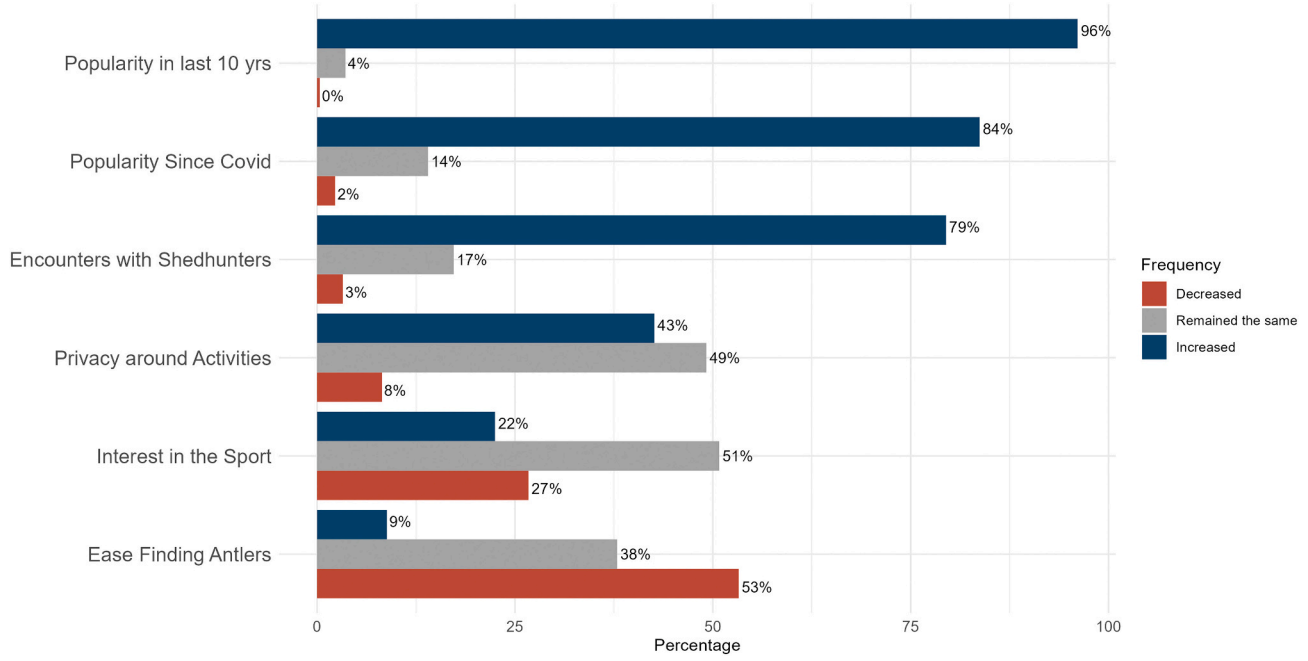

Fig. 3. Trends in perceived shed hunting congestion.

% used shed hunting-related social media. Non-residents (47.0 %) were more likely to use social media (27.9 %) ($P < .001$, OR = 2.28 (1.35–3.82)), suggesting it may influence non-residents to travel outside of their localities to shed hunt.

3.4. Management preferences and effect of existing regulations

Notably, nearly all respondents (91.5 %) supported some level of regulation. Relative to existing policies, 8.5 % wanted no regulation, 13.7 % favored less, 39.5 % supported current levels, and 38.2 % preferred more. Preferences did not differ between profit- and recreation-motivated participants ($X^2 = 3.534$, df = 3, $P = .316$), but Wyoming residents favored stricter regulation than non-residents (SR = 2.11, $P < .05$), potentially because they benefit from current policies.

Wyoming residents were largely in support of 2024 legislation giving residents a 7-day head start and requiring non-residents to purchase a conservation stamp to participate (86.5 % in support, 8.0 %, unsure, and 5.5 % opposed). In contrast, non-residents were largely opposed (27.1 % in support, 8.5 % unsure, 64.4 % opposed). Support did not differ between profit- and recreation-motivated participants ($X^2 = 0.032$, df = 2, $P = .984$).

The new legislation influenced participants' frequency, geographic range, and enthusiasm for shed hunting (Fig. 4). In 2024, 28.6 % of non-residents avoided Wyoming due to the laws, and 21.6 % of residents participated when they otherwise would not have. Notably, about a third of residents (36.5 %) and non-residents (33.3 %) expanded the geographic extent in which they operated, potentially bringing shed hunting into new wildlife habitat. The exclusion of non-residents from openers may have increased resident participation, leaving the net impact on total activity ambiguous. Active management of the resource had a positive impact on enjoyment for 45 % of WY residents, who benefited from the policy change, but reduced enthusiasm for the sport for 30 % non-residents (Fig. 4).

We asked participants about their level of support for three management approaches - an antler tax, a shed hunting license, and seasonal closures (in place) - and two aspects of current and potential policies – resident advantages (in place) and stricter enforcement of existing policies (e.g. winter habitat closures) (Fig. 5). Stricter enforcement was the

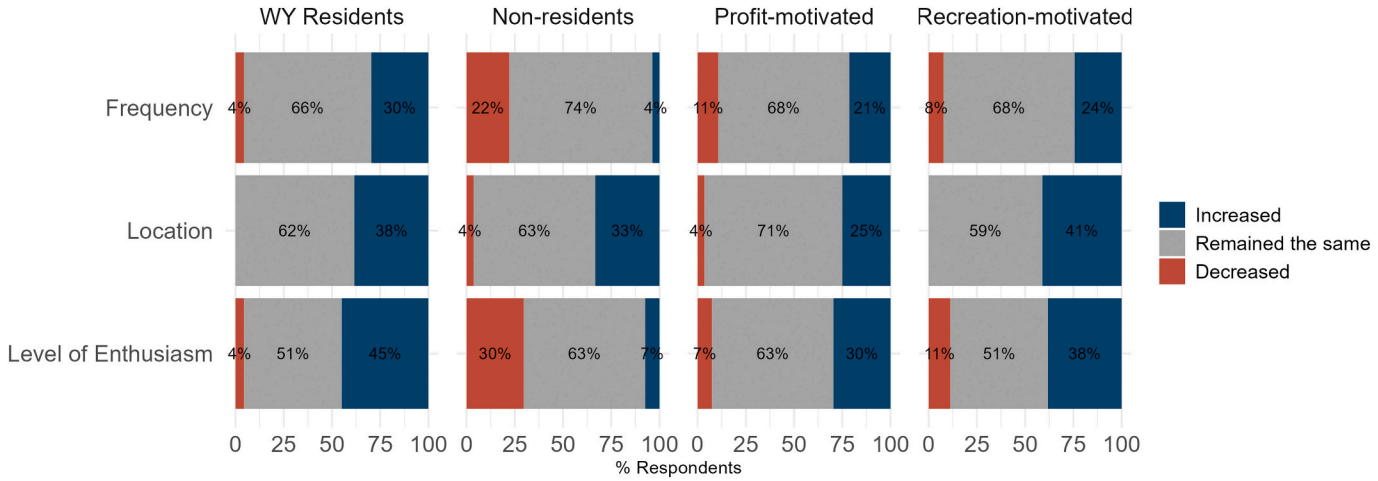

Fig. 4. Changes in participants' enthusiasm for, frequency, and extent of shed hunting activities after Wyoming's new policies.

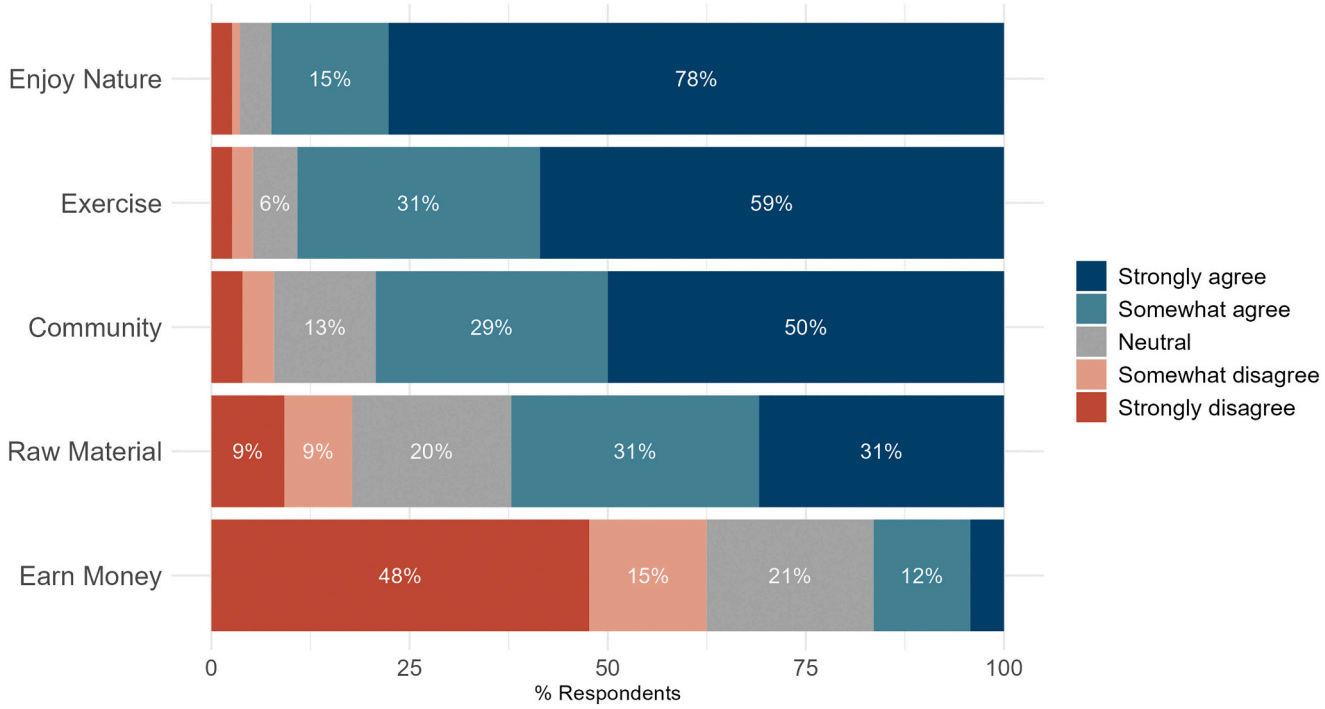

Fig. 5. Management preferences of shed hunters operating in Wyoming.

most popular of the provided approaches, with 74.3 % support, followed by resident advantages and seasonal closures, both of which are already in place. Interestingly, preferences did not differ between recreation- and profit-motivated groups for any policy. Wyoming residents favored resident advantages (SR = 4.56, $p < .001$) and licenses (SR = 3.7, $P < .01$) more than non-residents.

4. Discussion

Shed antler collection is a key example of how growing global demand for niche wildlife products can reshape local conditions and create CPR dilemmas, even when a product is scavenged instead of hunted. A main motivation for examining management in this context is the potential for stock (e.g. dynamic) externalities when resource collection negatively impacts wildlife's provision of the resources to future users (Zuckerman et al., 2020; Bates et al., 2021). Furthermore, in the case of shed antler collection, we uncover a clear congestion externality, where additional users increase costs or decrease benefits of scavenging to others. Here, we explore potential approaches to managing scavenged wildlife resources, with a focus on GYE shed hunting, and discuss how different strategies may align with the distinct characteristics of resources and user groups.

4.1. Understanding user motivations

Scavenged wildlife resource user groups can be characterized by their motives and values for participation and their level of commercial involvement, with consideration to their level of entitlement to the resource. Notably, because the same resource can form the basis for both hunting or harvesting and scavenging, understanding user motivations for scavenging may require a broader view of resource use. For example, trade-offs and synergies may occur between different uses for the same wildlife resources, making it challenging to accommodate multiple interests when priorities conflict. Our results show 90 % of shed hunters hunt big game, creating a nexus in management between the scavenged and hunted resource.

Our findings also highlight diverse and overlapping values for antler collection. Participants appreciated the antler material, social and community engagement, connection to nature, physical activity, and monetary value. Financial motivations did not preclude deriving enjoyment from the recreational aspects of shed hunting and most participants incurred net financial losses regardless of motivation. This suggests that antler sales could opportunistically offset costs for some participants rather than act as a major financial incentive. As a result, management targeting commercial activity in isolation may have an ambiguous effect on total participation, and therefore, congestion. In practice, Wyoming classified user groups by residency, asserting that local users had a greater entitlement to Wyoming's antlers. This rationale aligns with U.S. wildlife policies prioritizing in-state residents who pay taxes and bear coexistence costs, but it could be seen as less compelling for migratory species crossing jurisdictions.

4.2. Ecological considerations of scavenged wildlife resources

Several resource attributes can influence species survival and future resource availability. First, when resource collection overlaps spatially or temporally with wildlife use, the risk of harm increases. Separating these activities can reduce negative impacts—migratory species, for example, may avoid disturbance more easily than those in fixed ranges. Second, harm is greater when animals rely on the resource for reproduction, shelter, or nourishment. Nests, honeycombs, or antlers may still be used by wildlife, whereas collecting discarded feathers likely poses minimal risk (Woodbury, 1940; Dryden, 2016). Third, species vary in their tolerance for human disturbances (Samia et al., 2015). Research on wildlife tourism (Shannon et al., 2017), bird-watching (Aas et al., 2023), and recreation (Steven et al., 2011; Larson et al., 2016) provides insights into disturbance thresholds and can be used to predict the impacts of intensive scavenging.

Ecological considerations have emerged as an important factor in shed hunting management in the GYE. For instance, the potential presence of a stock externality, whereby shed hunting can negatively influence the population, was considered when Wyoming set shed hunting seasons. Furthermore, there is a potential direct tradeoff between shed antler collection and hunting, because a hunted animal

cannot provide antlers in future years. However, our finding that the hunting and scavenging user groups overlap suggests shed hunters may have an incentive to support management tools for shed hunting that result in lower ecological impact to the population and therefore have the potential to support both hunting and shed hunting opportunities in the future. Existing tools like game surveys could be adapted to support both uses.

4.3. Toward management principles for scavenged resources

There is considerable heterogeneity in how renewable natural resources are managed and in the characteristics of scavenged wildlife resources, suggesting a wide range of potential tools and strategies for management. Indeed, literature suggests that best practices when developing management tools for a CPR should take into account resource characteristics and the local context (Ostrom, 2000; Cox et al., 2010). Here, we discuss how three traditional management tools for wildlife CPRs and other renewable natural resources – seasons, licenses, and taxes – could be or are applied to shed hunting in the GYE and lessons for management of scavenged resources more generally. Importantly, these are only three management approaches among many that could be applicable to managing scavenged wildlife resources (Sterner and Coria, 2012; Gren et al., 2018), suggesting the need for further work to explore management in other contexts.

4.3.1. Managing antler collection in the GYE

For unregulated resources, the first question is whether user groups desire management (Ostrom, 2000). Our context presents a complication as one user group, residents, is legally entitled to create policy governing another user group (non-residents). Evidence from our survey indicates that congestion is substantially detracting from users' experiences, and there is support among both resident and non-resident users for active management of shed antler collection.

Two types of input regulations – seasons and access requirements – are currently in place and received support from survey participants. Seasonal restrictions, like those used in Wyoming, could be an effective way of limiting stock externalities for scavenged wildlife resources with high separability between the resource and derivative animal, allowing use while minimizing impacts. However, distinguishing resource collection from other recreational activities is difficult without apprehending individuals with illegally collected materials, creating enforcement challenges (Koshmrl, 2019, 2023). In Wyoming, wildlife managers implemented seasons that banned all human activity in critical winter habitat, but survey respondents believe that a notable proportion of other shed hunters violate these closures. Furthermore, seasons can also create competitive "openers," leading to conflicts among participants (Streep, 2022).

Access requirements like licenses, permits, and conservation fees and stamps have the potential to help resolve CPR dilemmas with scavenged wildlife resources by limiting participation, generating revenue for management, and collecting user data (Scrogin et al., 2000; Von Saltza and Kittinger, 2022). The appropriate instrument depends on the management goal: for example, a license is best used when the goal is to limit, control, or monitor participation, while a conservation stamp could serve as financial tool to generate funding for management (Cohen and Altman, 2021). In Wyoming, a shed hunting license could enable managers to monitor who is participating and set issuance limits, while permits could be used to restrict access to specific localities. While these access requirements offer benefits, they may also provoke pushback from residents and add administrative burdens.

Specific user groups can also be targeted directly by access requirements, provided there is an enforcement mechanism. Wyoming's 7-day resident head start effectively banned non-residents from high-congestion opening events and was enforceable via state IDs. However, it relied on the reasoning that local residents have a greater right to the resource and excluded groups (non-residents) that were not represented in decision-making (Ostrom, 1990; Cox et al., 2010). Furthermore, when participation is already density-dependent (e.g. competition disincentivizes participation), excluding one group may not reduce total activity. In Wyoming, non-resident restrictions may have encouraged greater resident participation, ultimately redistributing the benefits of shed hunting rather than reducing overall activity.

The third management approach we examined is taxes. Taxes can prevent the overharvest of renewable resources, including scavenged resources, by reducing their profitability, while also generating revenue for management (Heaps and Helliwell, 1985). Tax collection is most effective for commercial resources because it relies on well-defined property rights, structured markets, and controlled points of sale (Heaps and Helliwell, 1985). Taxing antlers would be challenging due to dispersed extraction, absence of centralized markets, and weak enforcement mechanisms. Only about 20 % of antlers from our respondents entered the commercial supply chain, the lower tiers of which are largely informal with transactions typically conducted in cash. Taxing final products like pet chews is more feasible but would affect only a small fraction of antlers without ensuring reduced shed hunting pressure. Furthermore, antler taxes are less popular than other approaches, with 29 % support. One alternative is taxes on private goods (e.g. sporting equipment) that are compliments to target public good (e.g. game animals) (Lueck and Parker, 2022; Walls, 2022), but the majority of our participants did not purchase equipment specifically for shed hunting.

4.3.2. Jurisdiction

Jurisdiction is a critical but often overlooked aspect of managing wildlife resources (Lunstrum and Havice, 2025). In the case of scavenged wildlife resources, two levels are particularly relevant: jurisdiction over the animal and over the land or water where the resource is collected. In the U.S., terrestrial wildlife are publicly owned but move freely across public and private lands (Nie et al., 2020). In Wyoming, if an elk sheds an antler on private land, it becomes private property. If it sheds on public land, it belongs to the state and may be legally collected without a permit, except in national parks where removal is prohibited entirely. If the antler is not naturally shed and remains attached to the skull, it is classified as a "dead head" and typically requires a permit to collect. The current set of laws creates a complex jurisdictional landscape in which the key legal distinction hinges on whether the antler was naturally shed and on what type of land.

There is also the potential for jurisdiction issues to create perverse incentives for collectors and challenges for enforcing regulations. The spatial mismatch between animal ownership and land tenure creates jurisdictional adjacency (Lunstrum and Havice, 2025), complicating enforcement and incentivizing problematic behaviors, such as hazing wildlife across boundaries to shift ownership outcomes. These challenges are compounded by difficulties in verifying where a resource originated or whether it was legally obtained. As with high-value wildlife products like rhino horn or ivory, a key management concern is distinguishing poached materials from those obtained through natural mortality (Holden and Lockyer, 2021). In the case of antlers, this distinction is more feasible due to ossification at the base, which clearly marks natural shedding. In future efforts to manage scavenged wildlife resources, it will be important to proactively craft legal frameworks that account for current jurisdictional authority and/or define jurisdictional authority in a way that supports successful management.

4.4. Conclusions and caveats

The success of management tools for scavenged resources will likely depend on user buy-in, enforceability, and jurisdictional clarity. While this discussion focuses on scavenged resource management, outcomes may also be shaped by broader wildlife policies, such as hunting regulations that influence the timing, location, and quality of available materials. Future work could explore management approaches that account

for this endogeneity. Our findings indicate that shed hunters generally support measures like seasons and local priority access, but the most common concern was weak enforcement, a persistent challenge for Wyoming's already overextended game wardens (Koshmrl, 2024; Peterson, 2024). As Wyoming's shed hunting laws enter their second year, their long-term success may be at risk if enforcement gaps allow illegal activity to resurface and undermine user trust. Expanding access requirements to residents could improve enforcement capacity and data collection, but would require navigating administrative challenges and limited public support.

There are important limitations to how our survey results should be interpreted. First, shed hunters, like many users of scavenged resources, are challenging to study due to the open access nature of the activity, and convenience sampling limits our ability to assess how representative the sample is. Despite this, we identified diverse values associated with shed hunting, a clear consensus that surveyed users experience congestion from excessive scavenging, and strong support among surveyed users for more active management. These findings lay the groundwork for recognizing and managing scavenged wildlife resources as an emerging category of wildlife CPRs.

Our case study represents just one type of scavenged resource, and further research is needed to identify the diverse traits of, understand the use and users of, and explore management options for this category of resource. One important area of study is identifying and quantifying any causal links between resource collection and wildlife health and persistence (e.g., the nature and strength of stock externalities). Future exploration of the management of scavenged resources would also benefit from population-level studies on current and potential user groups. By defining scavenged resources as a category of CPR, we also hope to catalyze research testing transferable management principles and insights into which tools work best with different resource attributes and user traits. Finally, research is also needed to contextualize scavenged products within the global wildlife trade and link supply and demand trends to forecast future resource use.

Developing transferable management principles for scavenged wildlife resources is increasingly urgent amidst the rapid expansion of the global wildlife trade fueled by online platforms. Insights from Wyoming's shed hunting industry underscore the many ways the public benefits from wildlife, broadening our understanding of its values and uses and suggesting that stakeholders could benefit from more active management of this category of wildlife resources.

CRediT authorship contribution statement

Samantha Maher: Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Tyler Kjorstad:** Writing – review & editing, Project administration, Methodology, Investigation, Conceptualization. **Kailin Kroetz:** Writing – review & editing, Supervision. **Van Butsic:** Writing – review & editing, Supervision, Conceptualization. **Arthur D. Middleton:** Writing – review & editing, Supervision, Resources, Conceptualization.

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Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used ChatGPT in to request suggestions for reducing word count. After using this tool/service, the author(s) reviewed and edited the content as needed and take (s) full responsibility for the content of the publication.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Samantha Maher reports financial support was provided by The National Geographic Society. Samantha Maher reports financial support was provided by The National Institute of Food and Agriculture (USDA). If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2025.111457.

Data availability

Data will be made available on request.

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