The emerging need to manage scavenged wildlife resources

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Abstract

Scavenged wildlife products are a unique variety of common pool wildlife resources 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 products from the animals that produce them complicates efforts to link their harvest to future resource availability, resulting in a lack of active management. However, 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, collected by "shed hunters" from wild herds for both personal and commercial use. In the Greater Yellowstone Ecosystem (GYE), home to the largest migratory cervid populations in the lower 48 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 and uncovered a diverse array of recreational and commercial values for antler collection. Our results show that resource users are experiencing externalities from increased congestion and indicate strong overall support for active management, though participants differed in their preferred approaches. For the first time, we explore the social dynamics and management preferences of scavenged resource user groups and highlight important complexities related to management. Notably, we emphasize the importance of the separability of the resource from the animal, a key characteristic of scavenged resources, when considering management approaches. Specifically, approaches like seasons designed to reduce overlap of resource use and wildlife during key periods could support recreational opportunities while reducing disturbances to wildlife.

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 products that are obtained without killing an animal or removing it from its habitat

Scavenged Wild Products

There is a notable lack of vocabulary in the field to describe non-lethal animal products. We introduce the term "scavenged wildlife resources" to describe the physical materials that animals grow or create, rely on, and eventually discard - including scales, skins, shells, feathers, antlers, nests, droppings, and other by-products of the animal's natural life processes. There are very few examples of scavenged wildlife products and their conservation import in the academic literature. 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, anecdotal 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 by Native Americans in the United States (USFWS 2009). Studies of scavenged wildlife products are rare, but their harvest requires pulses of human activity within wildlife habitats, potentially disrupting animal behavior, introducing stress, and reducing survival rates (Thorburn 2014, Edwards 2016, Hopping et al. 2018). Demand for this subset of wildlife products appears to be increasing, subject to the same drivers as global demand for wildlife products (Andersson et al. 2021, Mozer and Prost 2023) as the wildlife trade moves online, building novel connections between buyers and sellers and creating new markets for niche animal products (Di Minin et al. 2018, Nijman et al. 2022).

Scavenged Wild Products as Common-Pool Resources

Most wildlife resources exhibit the characteristics of Common-Pool Resources (CPRs) and are subject to the so-called "tragedy of the commons" (Hardin 1968, Ostrom 1990). Managing CPRs can be challenging due to difficulties in defining users, restricting access, and developing context-specific institutional arrangements tailored to the resource (Ostrom 2010, Moore and Rodger 2010). Wildlife adds complexity due to cross-jurisdictional mobility and competing management objectives (e.g., harvest vs. non-use values)(Skonhoft 1999). 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 are subject to the same dilemmas, in addition to an additional distinctive trait: they are physically separated from the animals that produce them. Specifically, scavenging can negatively impact the population of the wildlife species, reducing its population and potentially the scavenged products in the future. Moreover, user congestion in collecting the scavenged resource across space and time can diminish both its commercial value and the recreational experience of collecting it in multiple dimensions. For instance, it 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). However, the unique decoupling between the scavenged product and the animal has the potential to mask its nature as a common pool resource and therefore the potential benefits of regulation.

Traditionally, management of wildlife CPRs relies on a combination of approaches including command-and-control regulation, taxes and tradable permits, input regulations (e.g. licenses and seasons), and output regulations (e.g. quotas, size and type restrictions) (Heaps and Helliwell 1985, Sterner and Coria 2012, Teitelbaum et al. 2018). Two key attributes that are often considered when selecting a management approach are whether values are (i) use or non-use (Duffus and Dearden 1990, Fryxell et al. 2014), and (ii) recreational or commercial (Cooke and Cowx 2006, Chauhan 2022). However, scavenged products often defy traditional categorization into these binaries. Moreover, there is a lack of foundational knowledge about user groups and their behavior, including whether participants would even accept regulation (Ostrom 2000). As a result, these traditional management principles remain largely untested in the context of scavenged wildlife products.

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).

Historically, antler collection likely did not create a CPR dilemma in the GYE due to its small and geographically dispersed participant base. However, shed hunting has become increasingly popular over the last years and antler prices have increased, drawing 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 the death of male animals (Edwards 2016, Zuckerman et al. 2020). However, research linking shed hunting to animal movement is limited, and thresholds for harmful human activity remain unclear (Bates et al. 2021).

Antlers as a Potential CPR Dilemma

Social media platforms are credited with amplifying the appeal of shed hunting and attracting participants from outside of the area (Streep 2022). Congestion appears to be affecting multiple aspects of the user experience, including increasing the difficulty of finding antlers and reducing opportunities for solitude in nature. Moreover, the perception that visiting shed hunters are exploiting a local resource for profit sets up conflicts between Wyoming residents and non-residents. A flurry of media activity has drawn attention to the issue and emphasizes 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 amongst 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).

Despite a lack of formal knowledge about the shed hunting industry and its impact on wildlife, interviews with wildlife managers reveal that sustainably managing shed hunting is a regional priority (Maher et al. 2023). In 2008, wildlife managers instituted winter closures in key wildlife habitat to reduce shed hunting pressure on wintering animals (WGFD 2015). In March 2023, Wyoming took further action and passed Bill HB0276, designating antlers and horns shed on public land as state property effective 2024 and introducing two new restrictions: (1) a 7-day head start collecting antlers for Wyoming residents and (2) requiring non-residents to purchase a $21.50 conservation stamp. This approach distinguished residents and non-residents as separate user groups, temporarily restricting non-residents' access during the early collection period.

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. We examine management preferences and approaches for a scavenged wildlife resource and offer an initial exploration of management approaches for this resource type.

Methods

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 herds tend to occupy summer habitat in the higher elevation areas at the GYE's core, usually public land, then migrate to lower elevations during the winter to access optimal forage, often on private land (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.

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 is typically preferred (Wu et al. 2013). Antlers with unique features, like large size or 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 2020).

Antler Management Policy

The collection of shed antlers occupies a regulatory gray area and is not covered under wildlife protection laws, such as the Lacey Act, which restrict commercial use (Organ et al. 2012). No-take laws prohibit removing antlers from National Park Service units, but collecting and selling antlers is legal on other public lands and on private land with permission from the landowner. In 2008, Wyoming became the first state to regulate antler collection on public lands through Statute 23-1-302(a), establishing the Antler Regulation Area (ARA) and banning collection west of the Continental Divide from Jan. 1 to Apr. 30 (Figure 1). These regulations have unintentionally created shed hunting "openers," where large groups gather near trailheads and feedgrounds when closures lift, resulting in race-like competition for antlers. For example, Jackson, Wyoming is home to a famous May 1st opener that attracts up to 1,000 vehicles.

Study Design

We collected data from the year before and after Wyoming's new laws took effect, within and outside the Antler Regulation Area (ARA) (Figure 1). We focused on three geographic hubs in the GYE frequented by shed hunters: Cody, Jackson, and Pinedale (Figure 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 Lower 48's largest antler concentration.

Survey

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 (Figure 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. Logic filters ensured participants saw question blocks only if their responses met specific criteria. 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 Demographics section collected respondent background and recruitment details. In 2024 (Year 2), we added questions about how new laws affected participants' behavior.

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 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 (Figure 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 $1,000, with individual prizes up to $250, distributed via a separate Google form linked to the survey's final page. 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." In-person recruitment was more challenging in 2024 due to smaller shed hunting openers following new legislation.

Analysis

We analyzed data in R using the QualtRics package, creating 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, with non-responses (NAs) never exceeding 10% for non-text questions.

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 align with wildlife CPR management paradigms and help explore potential differences in resource use and management preferences based on key user traits (Duffus and Dearden 1990, Cooke and Cowx 2006, Chauhan 2022). "Profit-motivated" participants as 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 because Wyoming's legislation explicitly excludes non-residents as a user group. Residency was identified based on home address.

Numerical Variables

We calculated summary statistics (mean, median, SD) for numerical variables (Table 1 and 2, Appendix B) and tested for normality using the Shapiro-Wilk test (Yap and Sim 2011) and for equal variance with Levene's test using the {stats} package in R with significance threshold of P=0.05. We compared central tendencies for numerical variables within our two sets of user groups. None of our numerical variables met normality assumptions, and so we used the Wilcoxon rank-sum test (Mann-Whitney U) to assess the null hypothesis that the two groups come from populations with the same distribution. We report the location difference estimate for the median (Sainani 2012) and 95% confidence intervals for the location difference estimate following Bauer (Bauer 1972). All statistical tests were performed in R with a significance threshold of P=.05.

Categorical and Binary Variables

Our survey included categorical question formats such as multiple-choice, binary responses, and Likert-type items. Summary statistics for all questions are reported in Appendix B. We compared categorical response distributions between groups using the Chi-squared Test of Independence and tested the null hypothesis that there is no difference in how the participant groups answered that question. To identify specific associations contributing 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 (Bewick et al. 2004). Residuals with an absolute value greater than 1.96 ($p < 0.05$) were considered significant, indicating a deviation from expected counts (Bewick et al. 2004). We report the absolute value of the significant standardized residual (SR) and its level of significance using thresholds based on the standard normal distribution: $|r|>1.96$ ($p<0.05$), $|r|>2.58$ ($p<0.01$), and $|r|>3.29$ ($p<0.001$). For 2x2 contingency tables (e.g. binary data), we used one-sided Fisher's

Exact Tests 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 (Fernández-Cásseres and Russi-Pulgar 2023).

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 overrepresented individuals who prefer competitive environments. Shed hunters' protectiveness of their activity could further skew results, as our academic positionality may have attracted participants more trusting of science and 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, heavy snowfall delayed elk movement off feedgrounds, and winter closures were extended in parts of Wyoming, Idaho, and Montana. This allowed shed hunters to attend both the May 1st and May 15th openers, potentially increasing attendance and influencing behavior. In contrast, 2024 experienced a milder winter, with earlier feedground closures or no use at all near Pinedale.

Results

Overview of User Group Characteristics and Activities

We received 402 surveys, of which 318 (79.1%) met quality standards. 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. An exhaustive report of the survey results for each question by group are available in Appendix B. Respondents were predominantly male (81.7%) and white (96.7%), reflecting demographic trends in Intermountain West hunting communities (US Census Bureau 2021, USFW 2023). 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). There is an activity peak for shed hunting 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%).

Motivations and Values for Shed Hunting

Our results highlight diverse motivations for shed hunting, which participants valued for both the recreational experience and 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 (Figure 1). Notably, earning money ranked lowest and was most divisive, 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, indicating overlapping drivers of participation.

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 $400 (Tables 1 & 2) in their last season, demonstrating financial commitment to the activity. Profit-motivated hunters were more likely to skip work ($p = 0.003$, 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 (e.g., more outings; Table 1).

Antler collection provides a chance to profit from a common pool wildlife resource, and 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<0.001), 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.

Evidence of Congestion Externalities

Our results reinforce the idea that shed hunters are experiencing considerable congestion externalities (Figure 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%) of the participants reported encountering more shed hunters in the field since COVID, and 53.3% found it harder to locate antlers (Figure 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 to avoid competition, and 35.04% reduced their activities or stopped entirely. 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 11.8% strongly agreed, 29.7% somewhat agreed, 25.2% were neutral, 21.6% somewhat disagreed, and 11.8% strongly disagreed. Reported infractions included violating winter closures, trespassing, collecting in "No take" areas like National Parks, and stockpiling antlers outside of the seasons to collect on opening day. The 41.5% who at least "somewhat agreed" suggest eroding trust in the community. 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 give the impression that increasing competition may have fostered a minority of rule violators, undermining management efforts and creating conflicts amongst 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% used shed hunting-related social media. Non-residents (47.0%) were more likely to use social media more than Wyoming residents (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.

Management Preferences and Effect of Existing Regulations

Scavenged wildlife products are largely unregulated, and so we explored participants' management preferences. 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=0.316), but Wyoming residents favored stricter regulation than non-residents (SR=2.11, P<.05), potentially because they benefit from current policies.

In 2024, new legislation gave Wyoming residents a 7-day head start, barring non-residents from openers, and required non-residents to purchase a $21.50 conservation stamp. Wyoming residents were largely in support of the legislation (86.5% in support, 8.0%, unsure, and 5.5% opposed) in contrast to non-residents, who 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).

We evaluated how the new legislation impacted participation and found that the legislation influenced participation rates as well as participants' frequency, geographic range, and enthusiasm for shed hunting (Figure 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 their search areas. The exclusion of non-residents from openers may have increased resident participation, leaving the net impact on total activity uncertain without more information on the population. 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 (Figure 4).

We asked participants about their level of support for five policy approaches using a Likert scale: an antler tax, a shed hunting license, resident advantages (in place), seasonal closures (in place), and stricter enforcement of existing policies (e.g. winter habitat closures)(Figure 5). Stricter enforcement was most popular, 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, but it is possible non-residents would support these tools to a greater degree if implemented in their own localities.

Discussion

Despite being characterized by their separability from their animal providers, scavenged wildlife resources are still subject to CPR dilemmas and multiple types of externalities from overuse. In the case of shed antler collection, we uncover strong potential for stock (e.g. dynamic) externalities, when resource collection negatively impacts wildlife's provision of the resources to future users, and congestion externalities, where additional users increase costs or decrease benefits of scavenging to others. Shed antler collection is a key example of how growing global demand for niche wildlife products can reshape local conditions and generate externalities, even when a product is scavenged instead of hunted. Here, we explore emergent principles for managing scavenged wildlife resources and discuss how different strategies may align with the distinct characteristics of resources and user groups.

Understanding User Groups

Information on user groups is scarce for historically unregulated, open-access resources, such as shed antlers collected on public land. We suggest scavenged 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. Our findings highlight diverse and overlapping values for antler collection, with participants appreciating 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.

Ecological Considerations of Scavenged Resources

Effective management of scavenged resources is hindered by limited understanding of how resource collection affects wildlife, but we propose that several specific resource attributes can influence species survival and future resource availability. First, when resource collection overlaps with wildlife in

space and time, it increases the risk of harm. However, if collection of the scavenged product can be separated from wildlife use of that habitat, conservation impacts can be minimized through more active management. For example, migratory and wide-ranging species, such as the GYE's cervid herds, have high separability and may be better able to avoid the negative impacts of scavenged resource collection compared to species that remain in fixed, year-round ranges and cannot avoid human presence (low separability). Second, the risk of harm to wildlife is higher if other individuals and species depend on the discarded resource for reproduction, shelter, or nourishment. For example, a nest or honeycomb may still be in use when collected, and discarded antlers are used by other cervids and rodents for nutrients like calcium and phosphorus (Woodbury 1940, Dryden 2016). Collecting discarded feathers, converesly, may pose little harm to the derivative animal.

Third, species vary in their tolerance for disturbance by humans (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. For example, in Wyoming, managers implemented shed hunting seasons using evidence from studies on the effects of winter recreation on herds. Finally, trade-offs and synergies may occur between different uses for the same wildlife resources, making it challenging to accommodate multiple interests when priorities conflict. For example, there is a direct tradeoff between shed antler collection and hunting because a hunted animal cannot provide antlers in future years. This trade-off diminishes as the animal ages. Interestingly, our findings show that 90% of shed hunters also hunt big game, suggesting these activities can be complementary. Shed hunting may even enhance hunting success by helping participants learn about landscapes and animal movements. Given this overlap, existing wildlife management tools, such as game surveys, could be adapted to support both hunting and shed collection more effectively.

Towards Management Principles for Scavenged Resources

We explore how traditional management tools for wildlife CPRs could be adapted for scavenged resources. For unregulated resources, the first question is whether user groups desire management (Ostrom 2000). In our case, evidence from the survey indicated that congestion was substantially detracting from users' experiences, and users were in support of active management. Below, we discuss common natural resource management policies and their applicability to shed hunting and scavenged resources more broadly (Sterner and Coria 2012, Gren et al. 2018).

Input Regulations

Input regulations restrict how a resource is exploited, including limits on equipment, method-of-take, participants, and spatial or temporal dimensions of participation (Sterner and Coria 2012). For scavenged resources, input restrictions may serve as the most direct management strategy because conservation externalities are tied to the input (e.g. human presence) and not the take of the resource due to its separability. Seasonal restrictions, like those used in Wyoming, could be an effective way of limiting stock externalities for resources with high separability between the product 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, for example, 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, like Jackson's shed hunting opener (Streep 2022). Seasonal approaches are less likely to be effective for species without distinct seasonal habitats.

Licenses, permits, and conservation fees have the potential to help resolve CPR dilemmas with scavenged wildlife resources in addition to generating revenue, collecting user data, and being relatively uncontroversial when priced appropriately (Scrogin et al. 2000, Von Saltza and Kittinger 2022). Requiring permits for all shed hunters could provide additional funds and data but may face resistance from residents and increase administrative demands. Specific user groups can also be targeted directly, but such instruments require an understanding of the user population and work best when based on clear, enforceable criteria. In Wyoming, the 7-day ban on non-resident shed hunting disallowed participation in 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). Furthermore, when participation is already density-dependent (e.g. competition disincentivizes participation), excluding one group may not reduce total activity. This could well have been the case in WY where non-resident restrictions may have encouraged resident participation. As a result, the primary effect of Wyoming's new legislation may have been to redistribute the benefits of shed hunting from non-residents to residents, rather than to reduce total participation.

Lastly, restricting the use of certain technologies and aids can help minimize conservation impacts by specifically targeting the most disruptive activities for wildlife. In the case of shed hunting, restrictions could be applied to technologies such as snowmobiles, UTVs/ATVs, drones, and similar tools. However, this introduces another layer of abstraction between resource use and wildlife conservation, making it less transparent and harder to evaluate.

Output Regulations

Output regulations limit the amount or type of resource that can be extracted and include quotas, individual bag limits, catch-and-release, and size and type restrictions (Sterner and Coria 2012). For scavenged resources, output regulations may be less direct than input restrictions in reducing congestion and human presence. However, output restrictions could be effective in limiting the impacts of scavenging for materials that are ecologically important (Sterner and Coria 2012, Fryxell et al. 2014). For example, quotas on edible Swiftlet nest collection minimize total reproductive impact directly (Sankaran 2001).

The suitability of specific output instruments depends on participants' values for the resource. For scavenged resources that are heavily commercial in nature, quotas and bag limits may be successful in curtailing collecting because they limit the resource's profitability. For recreational resources where the experience of scavenging is valued more highly relative to the material itself, quotas or bag limits may have a less direct effect on participation since limiting collection may not diminish enjoyment proportionally. In the case of shed hunting, bag limits could actually backfire by encouraging participants to spend more time searching for higher-quality items, ultimately increasing human presence in wildlife habitat (Poos et al. 2010). Similarly, size and type restrictions may promote selective harvesting for any

scavenged resources with high variability in quality, in addition to being difficult to enforce. Output restrictions could therefore work best with scavenged resources where the material is valued more relative to the experience, has low variability in quality, and whose removal can cause ecological harm.

Taxes & Tradable Permits

Taxes have the potential to curb overharvest of scavenged resources by reducing the resource's profitability and generate 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). Thus, taxing open-access and informally traded resources, such as antlers, is 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 and artisanal items is more feasible but would affect only a small fraction of antlers, disproportionately burdening artisans and low-income sellers without ensuring reduced shed hunting pressure. Furthermore, antler taxes are less popular than other approaches, with 29% support. One alternative that has been used to fund wildlife management since the 1930s 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). However, shed hunting requires no specialized equipment, and the majority of our participants did not purchase equipment specifically for shed hunting, making the argument for complementarity between equipment and wildlife weak (Walls 2022).

Direct Regulation

Command-and-control, or direct regulation, mandates specific behaviors or outcomes through laws, standards, and enforcement mechanisms (Smith 2001). Scavenged resources often lack sufficient data, and managers could consider bans or moratoriums until more information is available. Such direct measures are appealing for their simplicity but require enforcement and may face resistance from user groups. Alternatively, direct regulation could target commercial use of a resource specifically. In the case of shed hunting, banning antler sales may have ambiguous effects because users have overlapping recreational and commercial values for the product and antlers' commercial viability appears to both encourage and discourage participation, depending on the users' values. However, reducing commercial incentives could help deter exploitation by a minority of financially-motivated "bad actors" who detract from the experience for others.

Ultimately, the success of management tools will depend on user group buy-in and enforceability (Ostrom 1990). Our findings show that shed hunters generally support existing mechanisms such as seasons and local preferences, but the most frequently cited need was for increased enforcement, which is a known challenge for Wyoming's already strained game wardens (Koshmrl 2024, Peterson 2024). As Wyoming's shed hunting laws enter their second year, their long-term effectiveness remains uncertain if enforcement limitations lead to a resurgence of illegal practices and erode user trust. Looking forward, expanding licenses or fee-based permits to Wyoming residents could generate revenue for enforcement and improve population data but would require overcoming administrative burdens and limited constituent support.

Caveats & Future Directions

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. Convenience sampling generated responses but limited our ability to assess how representative the sample is. Despite this, we found a diverse range of values associated with shed hunting, with users motivated by overlapping commercial and recreational interests. Importantly, we identified a clear consensus that users are experiencing congestion externalities from excessive scavenging and that more active management is desired. 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 that reflects the diverse traits of scavenged resources and user groups. For example, there is a need to establish causal links between resource collection and wildlife persistence (e.g. identify stock externalities), potentially by using quasi-experimental approaches with wildlife movement data. Second, understanding user groups' values and motivations is critical when selecting regulatory mechanisms, and population-level studies on user groups and valuation approaches, such as recreation demand models, can fill this gap. Third, testing transferable management principles through case studies can provide actionable insights on what tools work best with different resource attributes and user traits. Finally, research should contextualize scavenged products within the global wildlife trade and link supply and demand trends to forecast future resource use.

Looking ahead, 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 atypical wildlife resources.

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Tables

Table 1: Summary Statistics for Wyoming Residents vs. Non-residents

	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 (1**13**)	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(**1,678.09**	237.5 (**950**)	1,272.28 (**2,661.78**)	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 < 0.05
** p < 0.01
*** p < 0.001

Table 2: Summary Statistics for Recreation- vs. Profit-motivated

	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)**	1,053.97 **(1,222.44)**	300 **(750)**	2,218.56 **(1,406.78)**	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 < 0.05
** p < 0.01
*** p < 0.001

Figures

Figure 1: Overview of Shed Hunting Sites and Study Design

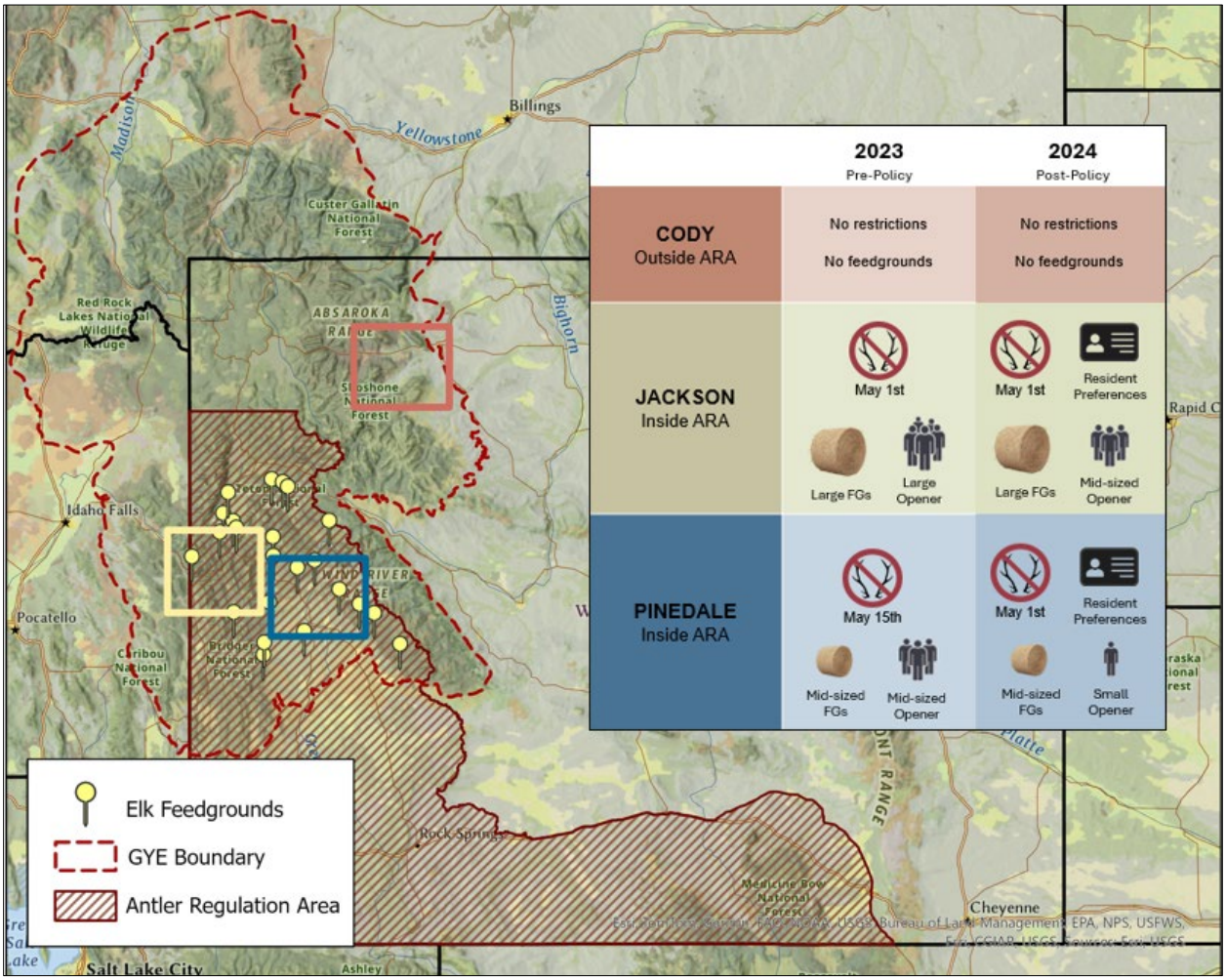

Figure 2: Respondents' motivations for shed hunting

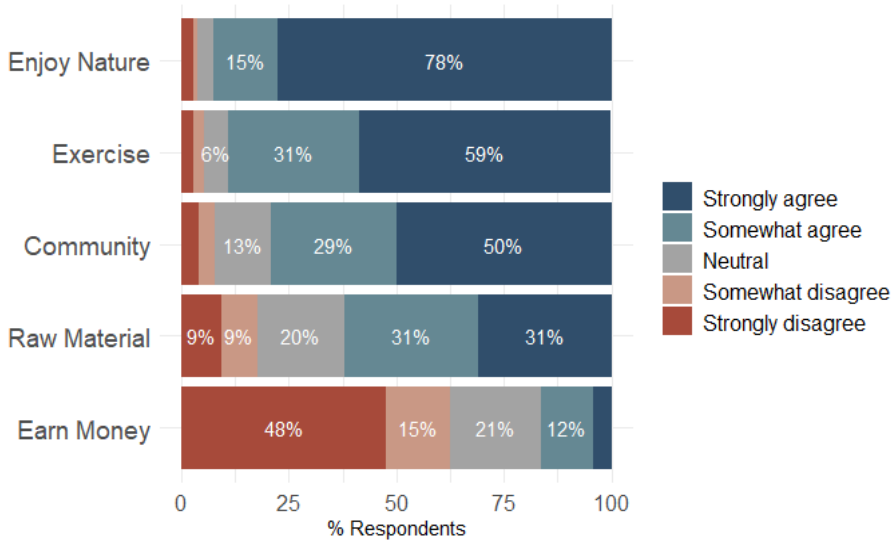

Figure 3: Trends in perceived shed hunting congestion

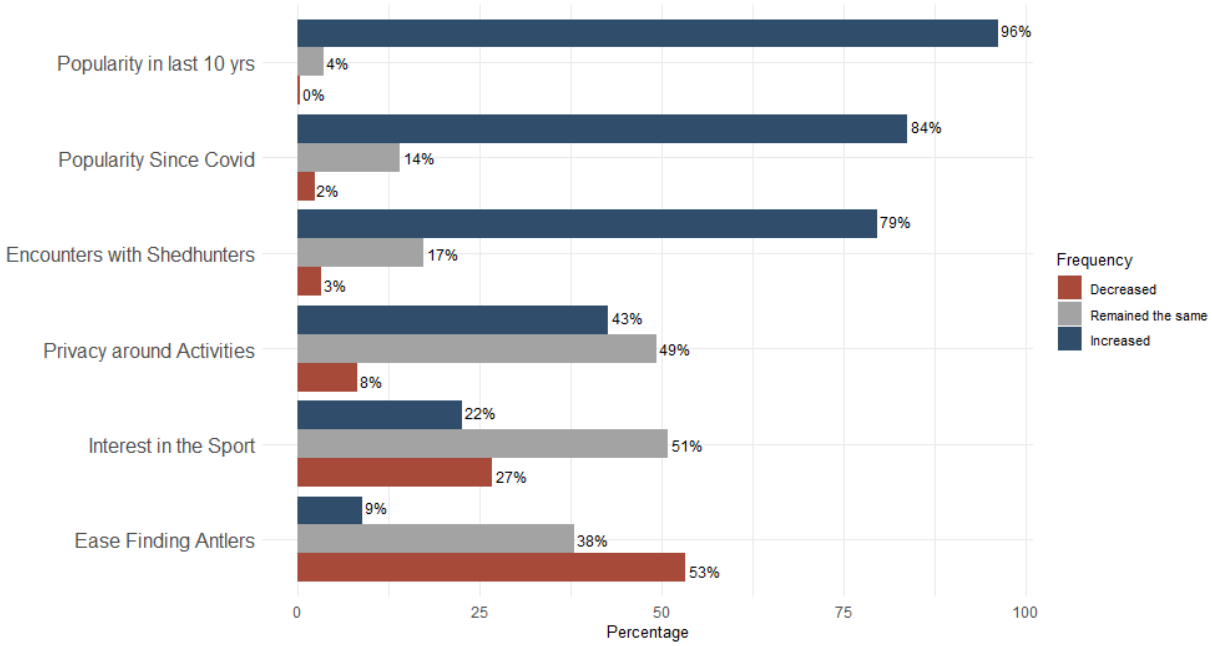

Figure 4: Changes in participants' enthusiasm for, frequency, and extent of shed hunting activities after Wyoming's new policies.

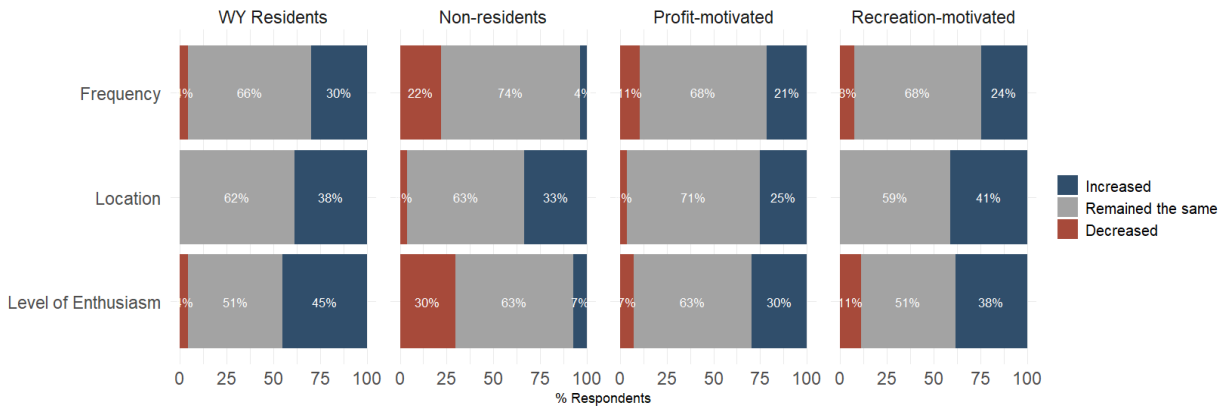

Figure 5: Management preferences of shed hunters operating in Wyoming