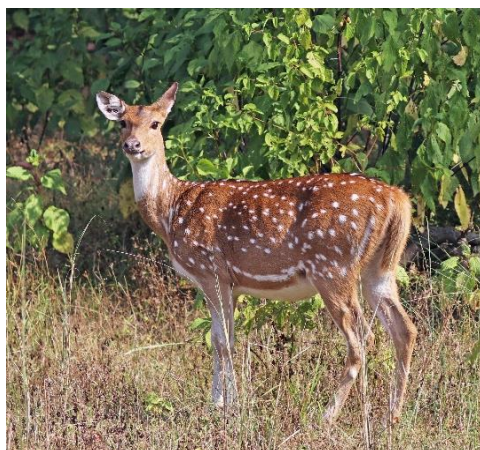


Axis Deer Impacts in Maui County

Strategies for mitigation & long-term management



Swette Center for Sustainable Food Systems, Arizona State University

February 2024

This publication is a Capstone Report by the Master of Science in Sustainable Food Systems and Graduate Certificate in Food Policy and Sustainability Leadership cohort of 2022.

Suggested Citation: Swette Center for Sustainable Food Systems. *Axis Deer Impacts in Maui County*. February, 2024. (Swette Center, 2024)

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This research project is dedicated to the communities impacted by the Maui wildfires. Our heartfelt condolences go out to all of those who lost their loved ones.

Pupukahi I Holomua: Unite to Move Forward.

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Executive Summary

The Maui County Department of Agriculture is working to control the overpopulation of axis deer in Maui County while also finding ways to utilize the deer as a sustainable food source to combat food insecurity. The department was established in 2022 to create healthy ecosystems, diversify agricultural practices, and formulate new opportunities to participate in local agriculture (Lyte, 2019). Given the high costs of living paired with the fact that over half of households in Maui County are below the ALICE (Asset-Limited, Income-Constrained, Employed) threshold, addressing food insecurity is critical (Hawai'i Health Matters, 2022).

This study was conducted to identify probable axis deer population levels, assess laws and regulations, quantify monetary damage caused by the deer, and identify economically viable solutions. It focused on the impacts of axis deer on five main topic areas: environment, agriculture, food security, public health, and culture.

Although population estimates vary, the most current estimate found is from 2021, indicating 145,000 to 167,000 deer across all of Maui County, consisting of the islands of Maui (60-70,000), Moloka'i (60,000), and Lāna'i (25-37,000) (Auweloa, personal communication, 2023). Regardless of the estimate used, the population of axis deer in Maui County is unsustainable, and economic and environmental damages likely far exceed current estimates.

Insufficient population data creates challenges in assessing the impacts and developing effective management strategies. Regardless, findings suggest that the economic impact from the axis deer overpopulation on agricultural crops could be from a \$50 - \$275 loss per deer or \$80 - \$20,000 loss per crop acre depending on the crop grown. Clearly, the economic loss is significant.

The laws and regulations surrounding slaughter, hunting, controlling, and selling axis deer meat are complex and often contradictory. A more thorough analysis of the rules and regulations should be undertaken with the guidance of the USDA and FDA. Considering more fluid policies regarding food security, climate change, and invasive species may create opportunities for innovation and reduce barriers to entry for hunters, social entrepreneurs, and other market actors.

Introduction

In 1868, King Kamehameha V accepted the first axis deer as a gift from India and located them on the island of Moloka'i to be a sustainable food source for the Hawaiian people (Hess et al., 2021). In 1920, they were introduced to Lana'i and in 1959, several axis deer were brought to the island of Maui (Hess 2008, Hess et al., 2021). Deer and other



ungulate populations thrive in Hawai'i as they have no natural predators, and with the capability to breed year-round, the axis deer population is on an exponential growth trajectory (Hess et al., 2021). Today, therefore, these invasive animals are causing significant damage to the environment and economy of Maui County (Hess, 2008). While their grazing habits cause extensive damage to native biodiversity, agricultural lands, residential areas, and local waters, axis deer also pose a significant risk to human health and safety.

Current estimates place the axis deer populations across Maui Nui (the islands of Maui, Lāna'i and Moloka'i) at over 145,000 and up to 167,000 (Auweloa, personal communication, July 13, 2023).

Current estimates place the axis deer populations across Maui Nui at **over 145,000 and up to 167,000**

Economic losses due to axis deer are affecting many local businesses and residents. A 2016 University of Hawai'i Economic Research Organization (UHRO) study concluded that axis deer had a \$2.1 million yearly economic impact on Maui (Burnett et al., 2016). Since then, the deer population has multiplied five times (Heaton, 2023). In conjunction with recent droughts, the deer population has begun to creep further into residential and agricultural areas, creating a situation in which even more economic damage is expected.

Unfortunately, the political and cultural landscape make it difficult to implement solutions to manage the population in an economically and socially beneficial way. A multi-

faceted approach must be utilized to sustainably mitigate the damage caused by the axis deer population while benefiting the local population.

In 2022, Maui County established its own Department of Agriculture. In trying to find a way to keep the original intent of the axis deer as a local food source while also trying to mitigate the damage caused by their overpopulation, in 2023 the Maui County Department of Agriculture asked the Swette Center for Sustainable Food Systems to quantify the damage caused by the overpopulation of axis deer and to identify economically viable options to utilize axis deer to combat food insecurity.

Therefore, this study aimed to identify probable axis deer population levels, assess laws, regulations, and costs of processing, quantify monetary damage to the environment, agriculture, and private business, and identify economically viable solutions. Through interviews and secondary data collection, our ASU research team endeavored to answer these questions:

Research Questions:

What are the quantifiable impacts of the axis deer overpopulation in Maui County? What culturally and economically appropriate solutions are available to the Maui County Department of Agriculture (MDOA) to sustainably and effectively control the axis deer population?

Through careful consideration, our team focused on four main aspects of mitigating damages and utilizing the axis deer population as a sustainable food source:

- a) Population estimates and carrying capacity of axis deer
- b) Environmental, agricultural and private damages caused by axis deer
- c) Laws and regulations surrounding the issue
- d) Current and potential solutions

Background

In November 2020, the citizens of Maui County overwhelmingly voted to establish a county-level Department of Agriculture, the first of its kind in Hawai'i. The Maui County Department of Agriculture (MDOA) aims to solve the growing issue of food insecurity by creating healthy ecosystems, diversifying agricultural practices, and formulating new opportunities to participate in local agriculture (Lyte, 2021). In 2021, an agriculture advisory group was established to make recommendations and guide how the newly minted department should focus its efforts through collaboration with community members and stakeholders (Maui County, 2023). The mission statement for the department is to “support the development and continued management of a sustainable regional agricultural system for Maui County to promote resident and ecosystem health and well-being and create a thriving circular agro-economic system that can be a model for the rest of the world” (Maui County, 2023).

In July 2022, when the Department began official operations, there was recognition by officials that axis deer were a significant barrier to achieving the department's goals and responsibilities. With this in mind, they began researching how to effectively manage the deer population while utilizing the deer as a tool to combat food insecurity.

Food Security in Maui County

“ALICE stands for ‘Asset Limited, Income Constrained, Employed’” and represents households with income above the federal poverty level but below the basic cost of living. The ALICE threshold represents the average income required to afford the basic necessities for living” (Hawai'i Health, 2023). A 2022 study found that 52% of Maui County households are below the ALICE threshold, with 47% of households “just getting by” or “finding it difficult to get by” (Aloha United Way, 2022).

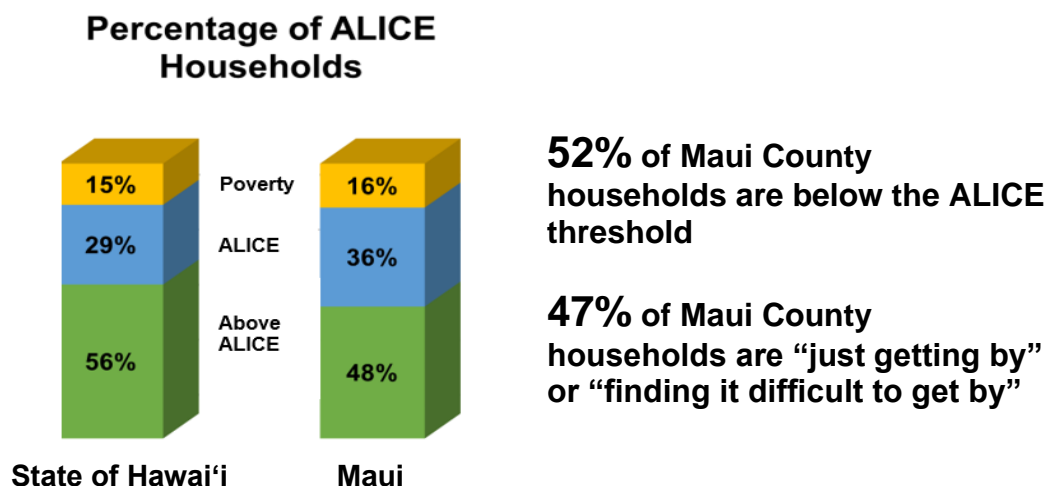


Figure 1: Percentage of ALICE households, Maui County. Source: Aloha United Way, 2022.

According to the 2020 United States Department of Agriculture (USDA) Thrifty Food Plan, **the cost to feed a family of four in Hawai'i for one month was approximately \$1,275, which is 90% higher than the national average** (Hawai'i Appleseed Center for Law & Economic Justice, 2022).

2020 Thrifty Food Plan Cost for a Family of Four

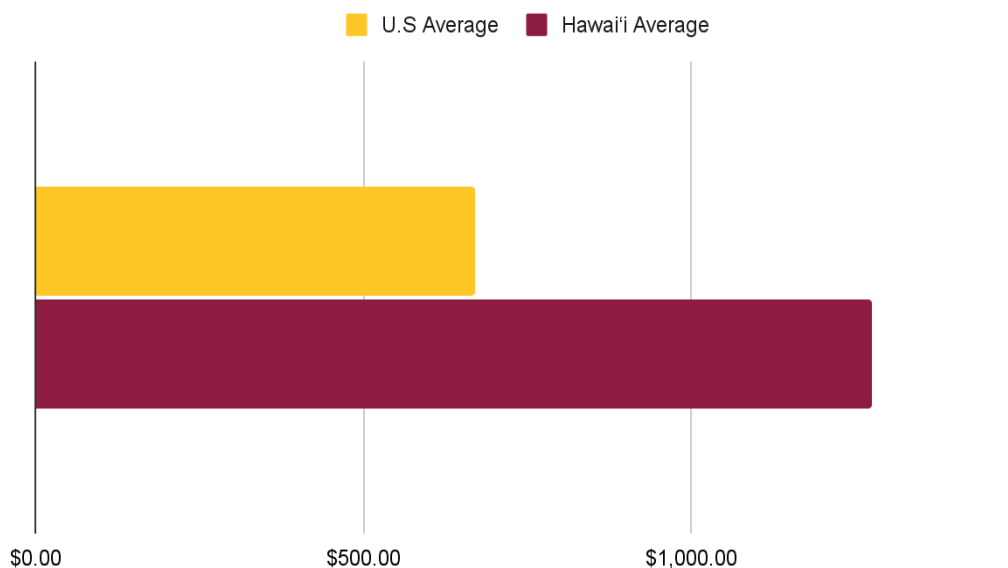


Figure 2: Monthly composite cost for a budget food plan for a family of four, Hawai'i vs. the U.S. average. Source: Authors utilizing data from Hawai'i Appleseed Center for Law & Economic Justice, 2022

In addition to high costs, Hawai'i is located over 2,500 miles from the US continent and imports an estimated 88% of its food (Loke & Leung, 2013), making it highly vulnerable to supply chain shortages and shipping disruptions (State of Hawai'i, 2012). Lack of housing, transportation, and time, with many family members who work multiple jobs to make a living, are the top barriers to food access (Hawai'i Department of Health & Meter, 2018).

While official USDA estimates indicate that 9% of Hawai'i households suffer from food insecurity (USDA, 2023b), some organizations believe it is higher. Feeding America estimates that 11% of households in Maui County are food insecure (Feeding America, 2021). According to a food insecurity data brief published by the University of Hawai'i, food insecurity rates for adults in Maui County are as high as 26%, with percentages for Native Hawaiians (27%) and other Pacific Islanders (44%) at rates double that of Caucasian residents (15%) across Hawai'i (University of Hawai'i et al., 2018).

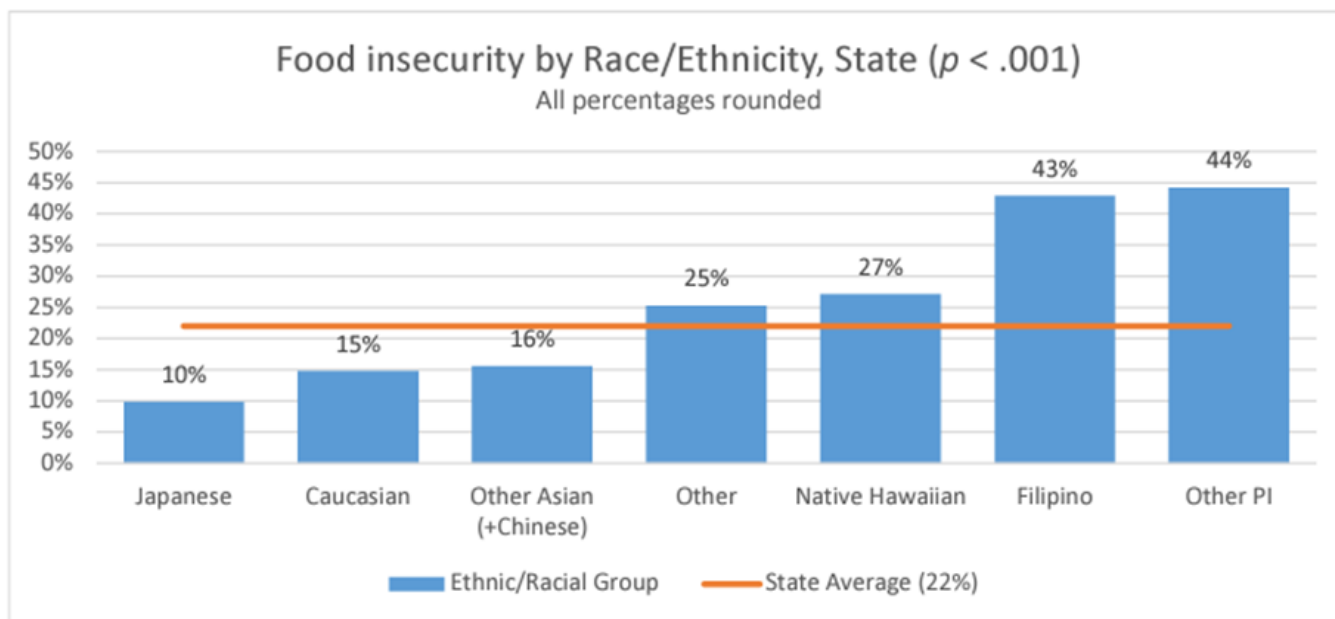


Figure 3: Food insecurity by race/ethnicity, State. Source: University of Hawai'i et al., 2018

Number of Supplemental Nutrition Assistance Program (SNAP) enrollees is another important measure of food insecurity. 12% of residents participated in the Supplemental Nutrition Assistance Program in 2020, but not all eligible households were enrolled (FRED Economic Data, 2022). The Hawai'i Department of Health reported that the economic impacts of COVID-19 increased SNAP enrollment by 55% (Hawai'i Department of Health, 2023).

Food security, particularly among native Hawaiian and other Pacific Islander groups is a growing issue of concern in the islands. Utilizing axis deer as a sustainable food source is one potential solution to creating affordable local food options for Maui County and beyond.

Methodology

This research was conducted by five graduate student researchers under the tutelage of Research Specialists Carly Wyman and Kū'ike'okalani Kamakea-Ōhelo and the supervision of Professor Kathleen Merrigan at the Swette Center for Sustainable Food Systems of Arizona State University. The research process included an initial exploration of the research topic and questions, a literature review, and stakeholder interviews. An interpretation of the findings followed.

This study was reviewed by the Arizona State University Institutional Review Board (IRB) and was deemed exempt pursuant to Federal Regulations 45CFR46 (2)(i) tests, surveys or observation. The IRB number is STUDY00018142.

Research Design

The research method employed was qualitative, using semi-structured interviews as a primary data collection method. Secondary data that was referenced by the interviewees as well as that found through desk research were also evaluated for inclusion in the study. The qualitative approach allowed the researchers to understand the challenges and opportunities through the lenses of various stakeholders, including farmers, extension agents, and the Maui Department of Agriculture. The study targeted 25 to 30 participants for interviews, with the respective heads of a given institution representing the views of constituent groups. However, this research method was abandoned mid-way through the project out of respect for residents and officials dealing with the aftermath of the wildfires that destroyed Lahaina and parts of Kula, Maui in August, 2023. Ultimately, the team completed a total of 6 interviews. A table of interviewees is detailed below.

The duration of the interviews ranged from 30-60 minutes via Zoom and were recorded with the consent of the interviewees. Interviews began with general questions followed by custom questions depending on the category of stakeholders under review (see Appendix A). Areas of discussion included but were not limited to:

- The economic, social, and environmental impact of the axis deer on Maui
- Meat processing capacity on the Island
- The potential for alternative population control mechanisms
- The viability of the current operating business model of Maui Nui Venison for sustainability

Table 1: Interview Participants

Interview Participants
Amber Starr-Cook, Kamehameha Schools
Carolyn Auwelo, USDA - Natural Resource Conservation Service
Glen Teves, University of Hawai'i
Jacob Muise, Maui Nui Venison
Kaipo Kekona, Hawai'i Farmers Union United
Kyle Caires, University of Hawai'i

Population, Growth, & Removal of Axis Deer

Before exploring potential solutions for managing the axis deer population, it is important to have an understanding of the most current population estimates and growth rates. Relying on prior unpublished estimates of the axis deer population on the island of Maui by the State of Hawai'i Division of Forestry and Wildlife (DOFAW), the Maui Invasive Species Committee (MISC), and several other researchers, Hess and Judge (2021) modeled scenarios of future population growth rates based on removal rates. By using unpublished aerial survey estimates by Gieder, they determined the total population in a 1,100 sq. km. (684 sq. mile) range to be at least 10,000 deer, with a total carrying capacity of 22,000 for that area, based on an estimated median population of 20 deer / sq. km. (12 deer / sq. mile). The range they chose is roughly equivalent to the area of the island of Maui, which sits at about 1183 sq. km. or 735 square miles (County of Maui, 2015).

Table 2: Estimated population density and carrying capacity per square mile and per 684 sq. miles of axis deer in Maui County. Source: Authors, utilizing data from Hess and Judge (2021).

	Current Est. Population Density	Est. Carrying Capacity (based on median population of 12 deer / sq. mile)	Est. Current Population as a % of Carrying Capacity
Per sq. mile	12 deer (20 / sq. km.)	32 deer	37.5%
Per sq. 684 miles	10,000 deer (10,000 / 1,100 sq. km.)	22,000 deer	45.45%

To calculate the population growth rate, Hess and Judge included several factors, such as females being sexually mature between 6-10 months of age, a 235-day gestation period, a 3:2 ratio of females to males, and a 10-year lifespan. The population growth rate was found to be at a baseline of $0.208 \pm .001$. In other words, **the population will grow at around 20% annually without management.** Further findings suggested that a 10% removal rate would result in a $0.103 \pm .001$ growth rate, halving the annual population growth. Removing 30% of the deer population at a 3:2 female-to-male ratio would result in a $-0.130 \pm .0004$ growth rate, or a reduction in population of around 13%. If the removal rate ratio were to increase to 4:1, female to male, the resulting growth

rate would be $-0.223 \pm .004$, or a reduction of 22%, indicating that the removal of more females would reduce the population more quickly (Hess and Judge, 2021). Hess and Judge conclude that “[e]ffectively reducing axis deer will most likely require an annual removal of approximately 20–30% of the population and with a greater proportion of females to increase the population decline. Selective removal of males may not only be inefficient, but also counterproductive to population reduction goals” (Hess and Judge, 2021, p.561).

Table 3: *Estimated Population Growth Rates as Determined by Removal Rates*
 Source: *Table by authors utilizing data from Hess and Judge, 2021*

	No Removal	10% Removal	30% Removal
No Removal	20.8% Growth Rate	N/A	N/A
3:2 Female to Male Removal	N/A	10.3% Growth Rate	13% Reduction Rate
4:1 Female to Male Removal	N/A	N/A	22.3% Reduction Rate

There are two important caveats to consider when reviewing these population estimates. First, there is uncertainty about the justification of the estimates of axis deer on Maui. In a January 2022 survey done by Maui Nui Venison in conjunction with Maui County, a total of 46,473 deer on the western slopes of Haleakalā were recorded using forward-looking infrared technology, with a total estimate of 60,000 deer inhabiting Maui. This number is six times the estimate used by Hess and Judge. However, whether the estimate is correct or not, this does not necessarily affect the outcomes of the population growth rate after applying different removal rate values. If the estimate of 60,000 deer is correct, using Hess and Judge’s population growth rate of $0.208 \pm .001$ would have increased that number to 72,480 deer within one year (by January 2023) with no removal.

Second, there is uncertainty about the population density. A caution recognized by Hess and Judge is that axis deer have been found to inhabit lands at a much higher rate than the suggested 20 deer/km² (12 deer / sq. mile) that they use in the study. Populations reached up to 200 deer/km² (120 deer / sq. mile) in Nepal, suggesting that **carrying**

capacity could be as much as ten times more than reported by Hess and Judge (Hess and Judge, 2021).

Unfortunately, no further county-wide population research has been done, indicating additional research is needed to assess the most accurate numbers of axis deer on specific islands within Maui County. Until further research is completed, the most current estimate that can be identified is from 2021, indicating 145,000 to 167,000 deer across all of Maui County, including the islands of Maui (60-70,000), Moloka'i (60,000), and Lāna'i (25-37,000) (Auweloa, personal communication, 2023). Regardless, it appears that population levels are still far off from the carrying capacity, indicating that without management, continued exponential growth of the population is probable.

Deer Impacts

Environmental Impacts

Three islands in Maui County contain axis deer (all the islands in the county except Kaho'olawe, which is uninhabited) (Auweloa, personal communication, July 13, 2023). Hawai'i's dry forests are environmentally degrading, and this is occurring at a more accelerated rate than its rainforests (Dixon, 2011). This is due to the compounded impacts brought on by the overpopulation of ungulates such as pigs, goats, sheep, cattle, and deer, as well as drought, and lack of natural resource management. While all the aforementioned species contribute to environmental degradation, axis deer pose a unique threat due to their proliferation. Axis deer prefer lowland dry forest habitat; in Maui this habitat has already been reduced by more than 90% since the introduction of the deer to the island (Anderson, 2003).

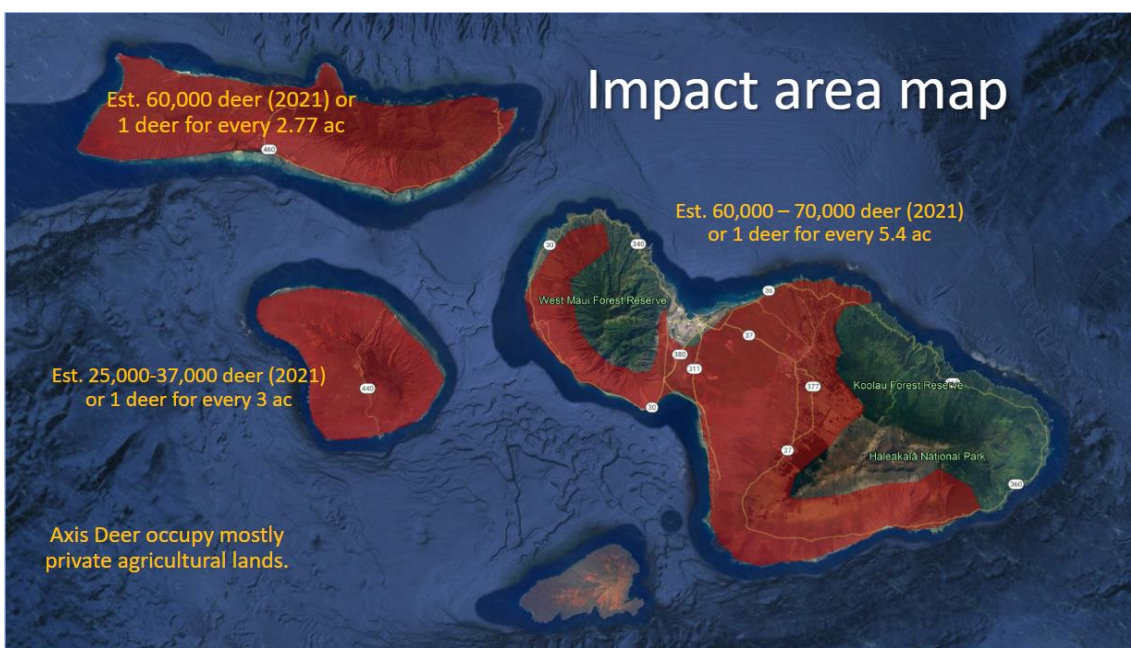


Figure 4: Axis deer impact area map for Maui County. Map created with a 2021 estimate of 60,000-70,000 deer for Maui Island and a total of 145,000-167,000 county-wide. Source: State Rangeland Management Specialist Carolyn Auweloa, personal communication, July 13, 2023.

Hawai'i is known for its high endemism levels in its native animals and plants due to its extreme isolation and climatic conditions. Over 10,000 species can only be found on this archipelago (Department of Land and Natural Resources, 2010). Of the 1,023 native plant species in Hawai'i, 89% are endemic to the islands (Anderson, 2003). The top two threats to these native floras are invasive ungulates and invasive plants

(Anderson, 2003, Department of Land and Natural Resources, 2010). Because Hawai'i's native floras evolved without any herbivore predators, they do not have defenses such as thorns or toxins to deter axis deer (Anderson, 2003). Additionally, deer are efficient grazers as their spatulate first incisors allow them to graze closer to the ground than cattle (Elliot, 1973, as cited in Anderson, 2003). Their impact can also be seen through foraging and the rubbing and polishing of their antlers on the bark of trees, which can cause significant damage. Figure 5 below displays ungulates rated as posing a high threat to the native ecosystems on all major Hawaiian islands.

Threat	Kauai	Waianae (Oahu)	Koolau (Oahu)	East Molokai	West Maui	East Maui	Kohala (Hawaii)	Mauna Kea (Hawaii)	Windward Mauna Loa	Kau/Kapapala (Hawaii)	Kona (West Hawaii)	Pohakuloa/Puuwaawaa
Ungulates	H	H	H	H	H	H	H	H	H	H	H	H
Weeds	H	VH	VH	H	H	H	H	H	VH	H	H	H
Fire	L	H	M	H	M	L	L	M	L	L	H	VH
Small Mammals	M	H	M	L	L	M	L	M	M	M	M	L
Pathogens	M	L	L	L	L	M	L	M	M	M	M	L
Development	L	M	M	L	L	L	L	L	H	L	H	L
Military Training	L	H	M	L	L	L	L	L	L	L	L	H
Recreational Use	L	L	L	L	L	L	L	L	L	L	L	L
Stream Diversion	L	NA	L	L	M	M	L	M	NA	NA	NA	NA
Overharvesting	L	L	L	L	L	L	L	L	L	L	L	L
Logging	L	L	L	L	L	L	L	M	L	L	H	L
Grazing	L	L	L	L	L	L	M	M	L	L	H	M
Overall rank:	M	H	H	M	M	M	M	H	H	M	H	H

VH=Very High Threat, H = High, M = Medium, L = Low, NA = Not Applicable, no perennial streams.

Figure 5: Threat Assessment Summary by Geographic Landscape. Source: Department of Land and Natural Resources, 2010.

Axis deer eat various plant parts such as leaves, stems, fruits, seeds, flowers, new shoots, and bark (Anderson, 2003). Their diets vary depending on the availability of food. Excluding agricultural crops, axis deer have been observed eating 68 species of plants, 30 of which are native and the majority of the rest being invasive weeds (Anderson, 2003). When pressure from this excessive grazing destroys the vulnerable native flora, in its place,

unpalatable or invasive plant species grow that can withstand heavy grazing (Ehlert and Menendez, 2022). Close to 100% of the forage base on the east end of Moloka'i has been observed as degraded due to overgrazing from axis deer, and only toxic plants such as lantana and verbesina remain (Auweloa, personal communication, July 13,

2023). These invasive plants are only edible to specialized insects and are inedible to livestock (Auweloa, personal communication, July 13, 2023). This destruction of forage then exposes topsoil to erosion.

When there is a shortage of wild vegetation, as the deer are currently experiencing, they encroach on agricultural lands and consume farmers' crops and spread further into deep valleys and remote ridges in search of food. In their search, they spread invasive species and trample ground bird and seabird nests and burrows (Nosowitz, 2021). A management plan to address the axis deer's effect on native species should therefore also consider the potential for various weed species to thrive once they are no longer suppressed by axis deer (Anderson, 2003).

In addition to pressure from overgrazing, Maui is facing severe drought which officials are deeming indefinite (State of Hawai'i, 2022). In May of 2023, while most of the State of Hawai'i posted higher than normal rainfall averages, the island of Maui posted below-average rainfall (National Weather Service, 2023). The leeward (western) sides of the Hawaiian Islands typically have larger variations in rainfall, and the 1970's, as well as 1990-2019, were particularly dry years (Frazier et al., 2022). Due to the population of axis deer being primarily on the western side of the island of Maui, this can cause greater issues. During extreme drought conditions, axis deer will eat the most palatable item available until it becomes scarce, then move on to other available plants. Water shortage slows wild vegetation growth, which, when combined with excessive deer grazing, creates the perfect conditions for soil erosion.

Once the topsoil fully erodes, it is difficult to recover. Instead, the subsoil layer is exposed, but it is not a conducive medium for plant growth due to toxic levels of micronutrients and lack of structure (Auweloa, personal communication, July 13, 2023). The land slowly loses its ability to store water, as a lack of ground cover and healthy tree coverage slows rain penetration into the ground (Anderson, 2003) and excessive sedimentation and flooding are more likely to occur during extreme storm events. While in the past, sedimentation occurred due to both overgrazing from ruminants and land-use changes for livestock production and agriculture (Field, Cochran, Logan, et al., 2008), today it is primarily attributed to overgrazing by deer (Auweloa, personal communication, July 13, 2023).

Because of this loss of vegetation and exposed topsoil, in heavy rain events, excessive runoff flows into the ocean and near-shore reefs. The sedimentation from excessive runoff causes significant coral reef destruction and fatality, which ultimately impacts the availability of fish for local consumption (Jones, 2021). While these authors could not find data regarding economic loss due to sedimentation of coral reefs at the time of writing, coral reefs are widely recognized as critical to Hawai'i's economy and food

resources (Field et al., 2019). From 1994 to 2006, nearly one-quarter of all coral reefs in Maui were lost (Hawai'i Division of Aquatic Resources, 2014). Because coral reefs are a major ecosystem for fish, it can only be surmised that fish populations are also declining.

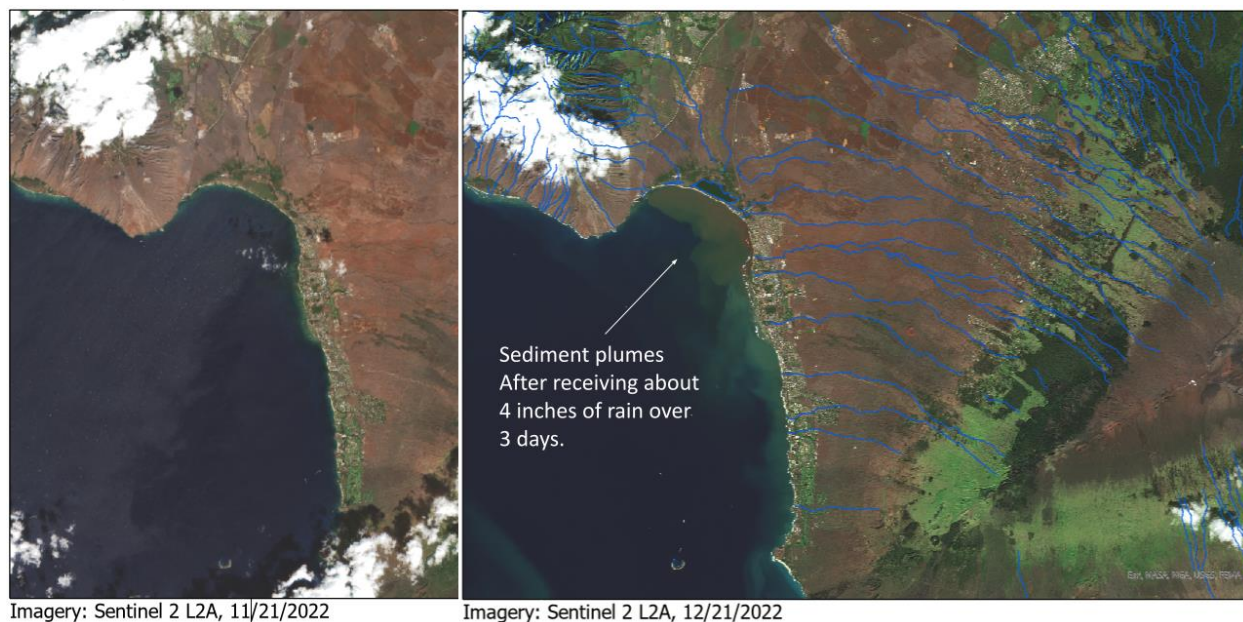


Figure 6: Satellite Images of Maui's leeward coast before and after receiving 4 inches of rain in 2022. Source: Auwelo, personal communication, July 13, 2023.

Soil erosion on Moloka'i has been well documented and in fact, a large mudflat now exists due to 100-plus years of soil runoff build-up. Severe sedimentation is progressing on the east end of the island where invasive ungulates including axis deer transformed the 'ōhi'a-hapu'u rainforest to a grassy scrubland (Hess, 2008). Silt runoff is entering and severely degrading the most extensive barrier reef ecosystem in the archipelago on the southern coast of the island (Hess, 2008). A solution considered is developing a sediment basin that would retain sediment by holding the flood water in a basin and allowing it to settle out before pouring out into the ocean (Auwelo, personal communication, July 13, 2023). However, to be useful in Moloka'i, the sediment basin must be large enough to support a 10,000-acre watershed, making it cost-prohibitive and unattainable.

Agricultural Impacts

Maui's agricultural systems have seen a notable shift over time. Originally, indigenous practices were completely self-sufficient. However, this was followed by a period of monocropping in plantation settings, which coincided with the start of importing and exporting food to the islands. These factors have ultimately reshaped the community's

food system toward over-dependence on imported foods. Although the number of farms has increased in recent years, the average size of farms has decreased, indicating a growing trend towards smaller farms and diversified production (USDA- NASS, 2017). Still, the lack of scale, access to post-harvest and processing infrastructure, and high shipping and input costs create challenges for production and getting these products to market.

As outlined above, axis deer are highly versatile herbivores that consume diverse forage items. While their preferred food is grass, they can adapt to eat whatever is available based on the forage conditions. This adaptability poses a serious problem for Maui as their variability in forage consumption can significantly impact a wide range of not just native or invasive species, but agricultural production as well. According to the Hawai'i Department of Land and Natural Resources (DLNR), agricultural lands in Maui County are seeing the worst effects of the overpopulation of axis deer (DLNR, 2022).

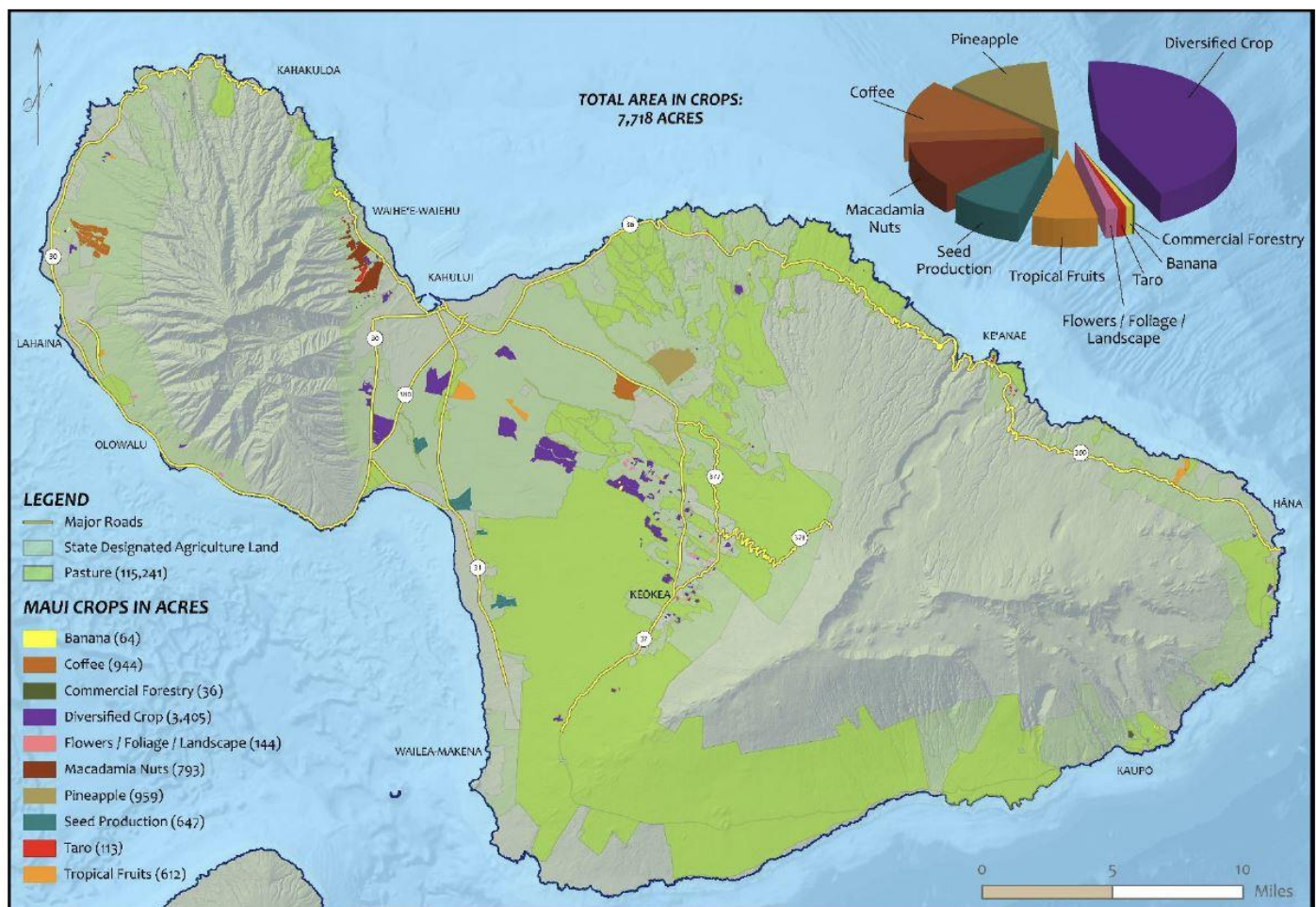


Figure 7: Maui Crops in Acres. Source: Hawai'i Department of Agriculture, 2022.

Maui Island has a land base of 465,280 acres, with 115,241 acres in pasture (almost 25% of the island) and 6,890 acres in mixed produce, specialty, and orchard crop production (about 1.5% of the island) (Hawai'i Department of Agriculture, 2022). **2022 Agricultural Census data shows that 88% of the 1,405 farms in Maui County made less than \$50,000 in sales annually** (USDA NASS, 2022). Not accounting for production-related expenses, the county's total net cash farm income was \$3.7 million (USDA NASS, 2022).

A living wage for a family of four in Maui is \$59,000, while a typical annual salary for full time farmers in the county sits well below that at \$41,951 (Glasmeier, 2023). These statistics, paired with the rising damage and mitigation costs of the deer, inflation, and increasing drought conditions, paint a grim picture for the future of agriculture production in Maui.

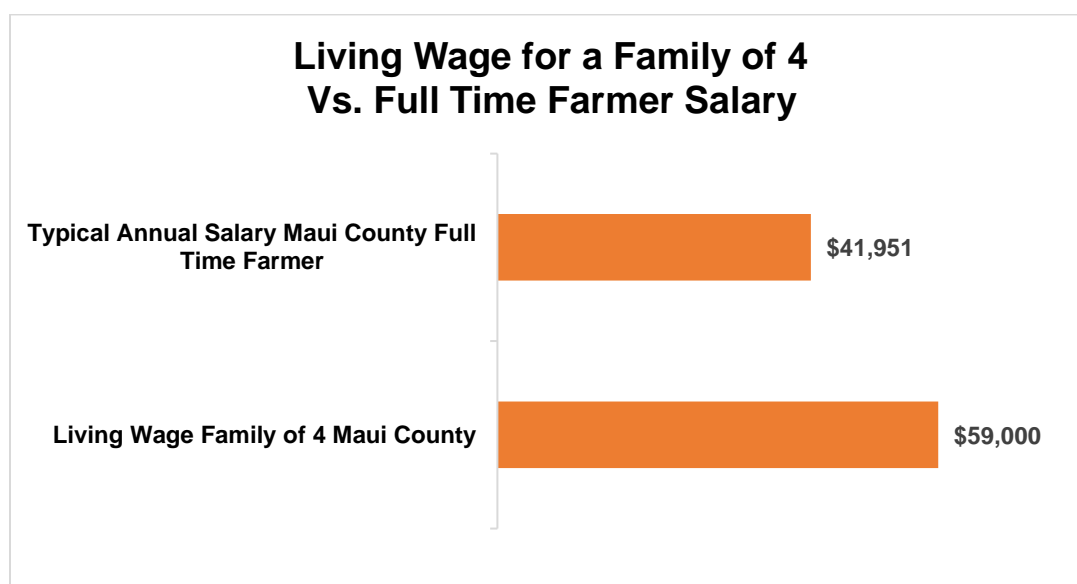


Figure 8: Living wage for a family of four vs. typical annual salary for a full time farmer in Maui County. Source: Glasmeier, 2023.

A 2014 survey found that “29.13% of landowners in Maui had experienced damage from axis deer on their property...19.69% had experienced landscaping / yard damage, 13.39% experienced agricultural damage, 11.02% experienced damage to personal gardens, 3.15% had fencing damaged, and 1.57% experienced competition for forage in their cattle pastures” (Rubino & Williams, 2022, p. 6).

Although ranchers comprise a smaller proportion of the population experiencing deer damage, local livestock producers have seen some of the biggest *economic* impacts. With imported feed costs continually increasing and forage losses due to deer and drought, it is estimated that cattle ranches have had to de-stock herds by 50-60%

(Auweloa, personal communication, July 13, 2023), minimizing opportunities for this important protein source and ultimately impairing the local food system. These economic impacts have long-term negative effects as the generation interval for a ranch to increase production is 4-5 years, and it can take six years to recover the cost of a cow (Caires, personal communication, July 28, 2023). In Lānaʻi, all livestock production has ceased, and any overgrazing is attributed to deer and sheep. There is hardly any livestock production in Molokaʻi due to overgrazing. Some livestock producers' management decisions in the past could have been attributed to overgrazed conditions, but there is hardly any livestock remaining on the island, indicating that feral ungulates are largely to blame for current rangeland conditions on Molokaʻi.

Not only do axis deer threaten livestock by consuming their food, but they also act as reservoirs for diseases like bovine tuberculosis and anthrax (Anderson, 2003). While the axis deer are known carriers of these diseases, they are also highly resistant to their effects. Molokaʻi experienced this in 1995 when three axis deer were documented with bovine tuberculosis (Anderson, 2003). When this occurs, it is standard to remove all cattle on the island (Anderson, 2003). Therefore, the biggest concern to cattle and thus ranchers is that axis deer act as a permanent reservoir for livestock diseases, making them another threat for ranchers to manage (Anderson, 2003).

Maui farmers are suffering great economic losses due to deer-related damage. They have been observed eating various crops ranging from strawberries, corn and sweet potatoes, to avocados, pineapples, and onions (Anderson, 2003). Maui Land & Pineapple Company, Inc. reported around \$35,000 to \$60,000 in deer-related damages in 2000 (Anderson, 2003).

In 2018, the University of Hawaiʻi College of Tropical Agriculture and Human Resources (UH-CTAHR) conducted a trial to assess the viability of corn silage production in the islands for use as livestock feed. Using no-till planting technology and precision harvesting tools, the trial produced a profitable crop at prices lower than then-current import costs. However, it also highlighted farmers' shrinking margins and the negative economic impacts of inflation and deer pressure on production. From 2018 to 2022, input costs increased by 133%, with an estimated \$80/crop acre loss due to deer damage (Caires & Stafford-Jones, 2023). The study also broke down economic losses per deer. Using wholesale prices, a \$50 loss per deer was calculated (Caires & Stafford-Jones, 2023). Were corn silage to become a commonly produced commercial crop in Maui County, the economic loss from axis deer damage would clearly be significant, ultimately cutting into farmers' profits and raising the purchase price for local ranchers.

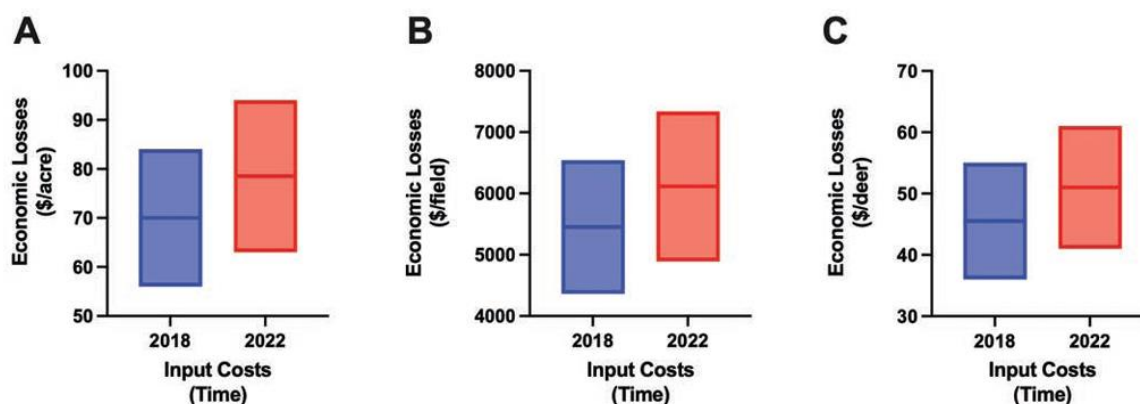


Figure 9: Economic losses of axis deer damage resulting from reduced yields on a (A) per acre, (B) total field, and (C) per deer basis, when corn silage is marketed at \$50/ton (wet) using various input costs from 2018 and 2022. Source: Caires & Stafford-Jones, 2023

Although the forage crop example is significant, economic losses for vegetable crop production were estimated to be much higher at 5.5x that of the corn silage example. Accounting for differences in elevation and rainfall, pasture grass losses are estimated at \$420-\$480 / acre. In terms of quantity, using Pangola grass as an example, this equates to a loss of 37,000 lbs. or an 87% loss of forage / acre (Caires, personal communication, July 28, 2023).

Fencing as a management strategy has been shown to keep axis deer out and allow the land to recover. However, current fencing designed to keep out feral animals, such as pigs, goats, or sheep, is not deer-proof. Axis deer have been observed jumping fences 8 feet tall. Therefore, fences would have to be retrofitted or built high enough to keep deer out, which is a costly endeavor. **Fencing can cost up to \$30 a foot, making it unattainable for farmers or ranchers who own hundreds of acres of land.** While some can afford fencing or qualify for USDA cost-share programs like EQIP, neighboring operations and communities are affected as the deer concentrations increase outside fence lines and exacerbate environmental damage (Auweloa, personal communication, July 13, 2023).

On Moloka'i, farmer and CTAHR extension agent Glenn Teves battled deer damage for years before receiving a grant to fence 6 of his 10-acre farm (Teves, personal communication, 2023). Before fencing, he had to limit his production to crops not palatable for deer, such as bananas and kalo (taro). Teves acknowledged that fencing is not a guaranteed solution and can cause issues for surrounding farms.

A community in Moloka'i began rejecting fencing as a solution after witnessing increased environmental damage in the areas surrounding a fenced property (Auweloa, personal communication, July 13, 2023). **"Fencing is a band aid. It shifts the issue but doesn't fix it,"** said Kyle Caires, Cooperative Extension Service, Maui County. In one example, a 28-acre area was observed to have 120 deer (Caires, personal communication, July 28, 2023). After a neighboring parcel installed fencing, that number skyrocketed to over 600 (Caires, personal communication, July 28, 2023).

Fencing will also require continued maintenance as axis deer have been observed to damage existing fences throughout the western slopes of Haleakalā on Maui (Hess, 2008). A 2022 UH CTAHR sorghum trial on Maui suffered a total loss of three acres when an electric fence failed. The loss was equal to 110 tons of forage, valued at \$30,000 wholesale (Caires, personal communication, July 28, 2023). It took the deer less than three days to consume the entire crop. In another account, deer pushed under fenced areas and consumed 1.5 acres of sweet corn to the ground in less than two days (Caires, personal communication, July 28, 2023).

Table 4: Overview of Axis deer impacts on agriculture in Maui County

Sources: *Rubino and Williams, 2022. Survey data was collected in 2014 and included 180 individual survey respondents on the island of Maui. As the data is almost 10 years old and included only a small sample size, it is surmised that the percentages of residents effected are likely higher, as the deer population has increased multi-fold since that time.

** Based on data from Kyle Caires, personal communication, July 28, 2023

-- Data not found by authors at time of writing

Crop effected	% of landowners effected	\$ / per deer	\$ / crop acre
Diversified High Value Edible Crops	13.39%* (type of agricultural loss was not specified by survey respondents)	\$275**	\$440**
Forage Corn Silage	Though not currently a commercial crop in Maui, UH CTAHR showed that corn silage could be a viable import substitution if grown locally, though with significant loss from deer pest pressure.	\$50** (Utilizing wholesale prices)	\$80** (Utilizing wholesale prices)
Sweet Corn	--	--	\$10k-20k**
Pangola Pasture Grass	--	--	\$420-\$480**
Forage Sorghum	--	--	\$9,375**
Cattle / livestock	1.57%* (Survey respondents who reported "competition for forage in their cattle pastures")	--	--
Personal Gardens	11.02 %*	---	--

Food Security Impacts

As the deer continue to devastate forested lands and move further into agricultural lands and consume crops, it reinforces the need for imported food and has a direct impact on food security. While the original intent of the axis deer was to be a sustainable food source for the population, the deer has become a driver of food insecurity in Maui County.

As covered in the background section of this report, Maui County has significant food insecurity overall, and the situation is anticipated to worsen. At the time of writing, Maui County is responding to unprecedented casualties and losses from a wildfire that swept through Lahaina and the farming region of Kula in August, 2023. It is unknown what impacts the wildfire will have on Maui's long-term food insecurity rates, but the immediate need is significant.

An initial assessment by the Pacific Disaster Center (PDC) and the Federal Emergency Management Agency (FEMA) estimates that nearly 1,900 homes have been destroyed and 9,000 daily meals are needed to feed displaced residents. The cost is estimated to be \$5.52 billion to rebuild. (Pacific Disaster Center & Federal Emergency Management Agency, 2023). Hunting for subsistence may play a more significant role in the years to come as families struggle to survive and rebuild in west Maui. In addition, the USDA estimates that **7,036 acres of agricultural land, including rangeland, were burned in the fires** (155.53 acres of diversified crops, 3,720.31 acres of rangeland, and 3,160.89 acres of pasture (USDA, 2023c)).

Table 5: Land cover impacted by wildfires between August 8-13, 2023. Source: USDA, 2023c.

Crops	Acres Impacted	Acres State Total*	%
Diversified Crop	155.53	65179.9	0.23
Rangeland	3720.31	1267150	0.28
Pasture	3160.89	764286	0.34

In the immediate days after the Lahaina and Kula fires in August of 2023, commercial wild axis deer processor Maui Nui Venison was able to produce 10,000 lbs. of venison meat for donation to those effected by the fires – highlighting the deer as an important food source in times of disaster, acting as a notable contribution to a resilient food system (Muisse, personal communication, August 14, 2023). Where cattle require an

investment and overhead by ranchers, and therefore require a return on investment, axis deer serve as a readily available “free” resource that can be quickly put to use in times of disaster. Of notable impact, about 1/8th of 100,000 acres of private lands that Maui Nui Venison utilizes for hunting were burnt in the fires, rendering them unsuitable for supporting either cattle or deer forage (Muisse, personal communication, August 14, 2023). Such increase in fire danger brought on by drought, invasive grasses, and overgrazing will only serve to exacerbate such conditions over time.

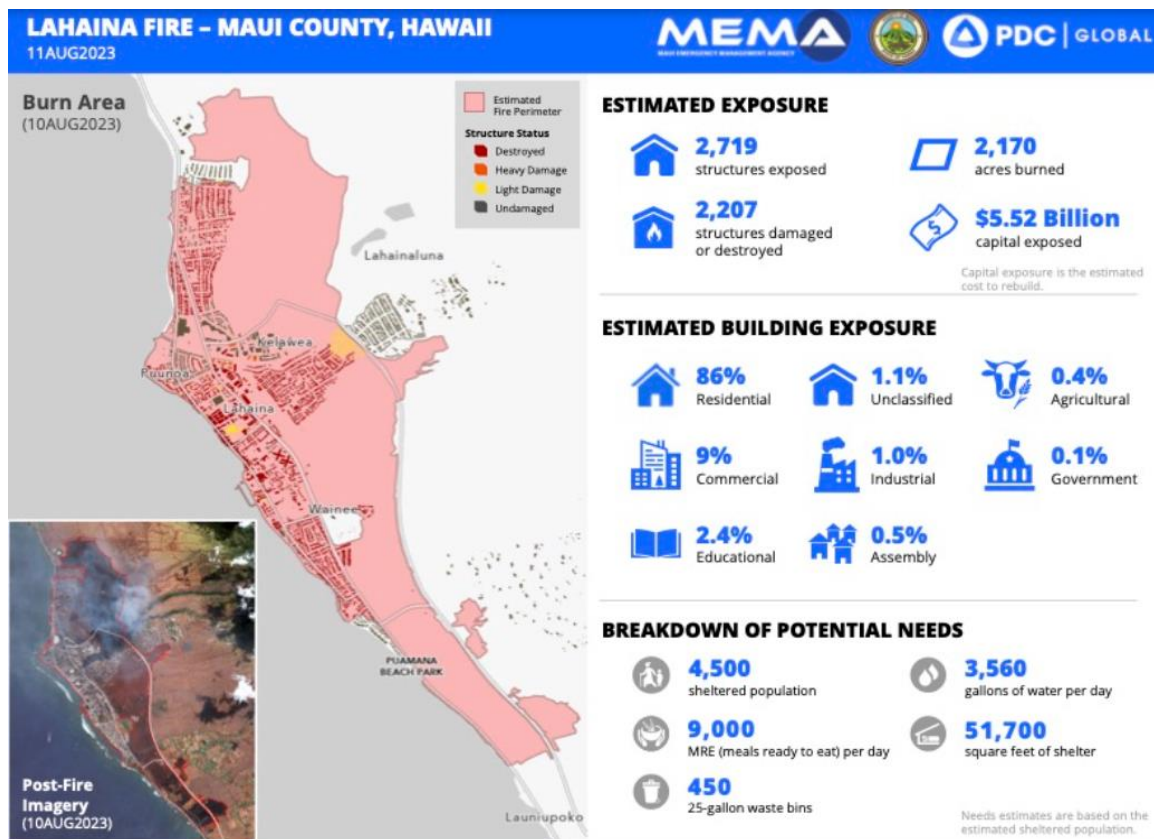


Figure 10: Lahaina Fire Infographic. Source: Pacific Disaster Center & Federal Emergency Management Agency, 2023.

Public Health Impacts

In addition to carrying and transmitting animal diseases, axis deer carry parasites like leptospirosis, cryptosporidiosis, and strains of e. coli, which can be harmful to public health (Anderson, 2003). Therefore, deer grazing on food crops pose food safety issues as they can spread fecal matter and urine in agricultural fields. Droppings and urine also enter streams and can contaminate watersheds and drinking water. Overpopulation exacerbates these issues. Reports of deer dying due to starvation during a drought in 2020 created “apocalyptic” conditions, according to one Maui resident. They could not

walk outside due to the flies and terrible smell (Boneza, 2022a). Decomposing carcasses also have the potential to contaminate drinking water, streams, and the ocean.

Another increasing public health concern is the number of traffic accidents caused by axis deer, many of which go unreported. According to the Maui Police Department, “in 2018, seven motor vehicle accidents were reported involving deer in Maui County. That number more than doubled to 16 the following year. In 2020, there were 25, and by 2021 the number jumped to 100” (Boneza, 2022b). Axis deer have also caused concern for airports, with deer spotted on runways and 700 deer observed surrounding the airport fence, prompting Kahului Airport to spend \$100,000 to reinforce their fencing (Associated Press, 2022).

Cultural Impacts

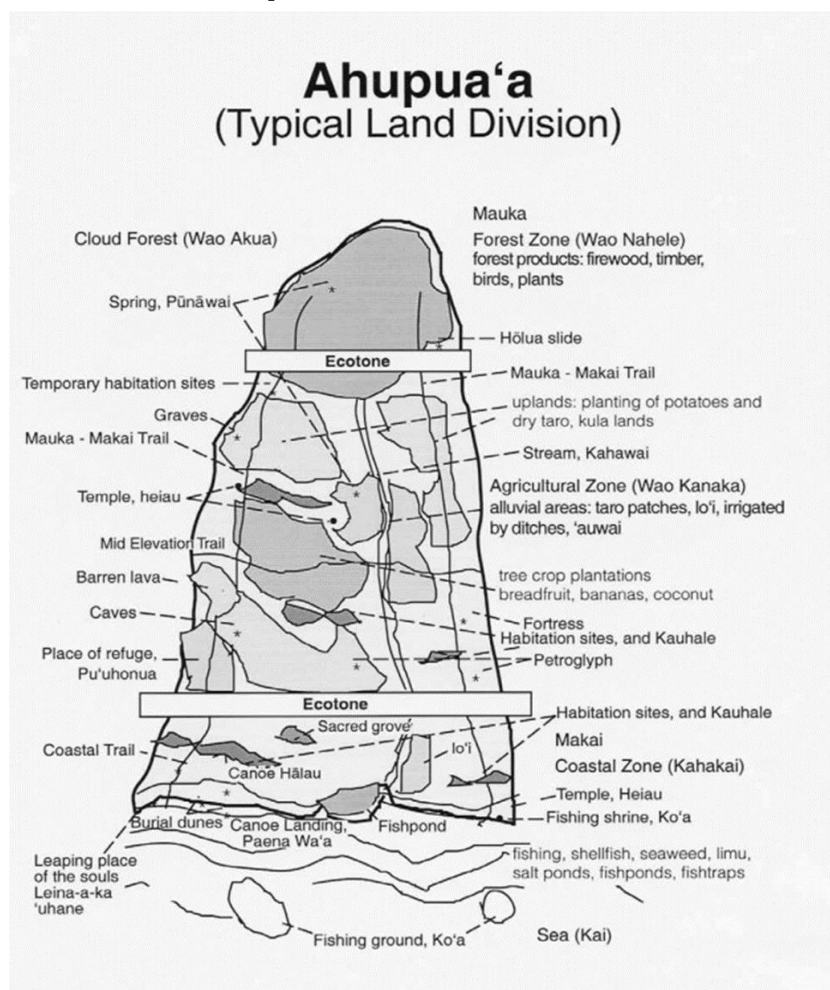


Figure 11: Ahupua'a land division. Source: Mueller-Dombois, 2007.

Native Hawaiians have an 'ōlelo no'eau or proverb that states “He ali'i ka 'āina, he kauā ke kanaka. The land is chief, man its servant.” In Hawaiian culture, kinship is shared with the land and its resources. There is no separation between cultural and natural resources; they are the same (University of Hawai'i, 2023). Wai, or water resources, were held in such high regard that the Hawaiian word for wealth is also wai, with waiwai signifying abundance and prosperity (Puleloa, 2023).

The traditional land tenure system in Hawai'i was centered around water, and careful attention was paid to the impacts of activities from mauka (upland) to makai

(seaward). Hawaiians developed sophisticated resource management systems that ensured water resources were used efficiently and shared across the farmable region in wedge-shaped land segments called ahupua'a - collectively known as moku or ecoregions (Winter et al., 2018). "Moku provide ideal units for examining management systems for key resources. While they are often understood as political boundaries, their alignment facilitated decentralized resource management under ali'i 'ai moku, the royal title for those who administered resources in a moku" (Winter et al., 2018, p.8).

The ahupua'a land management system was practiced around the 14th-15th century until 1848, when King Kamehameha III enacted the "Great Mahele" or Land Distribution Act. This act gave land ownership rights to foreigners for the first time. This is also the time period that brought plantations to Hawai'i (University of Hawai'i at Mānoa Library, 2023).

The shift in land use to large monoculture systems diverted water away from traditional planting areas used to grow culturally significant crops such as kalo/taro, significantly altering the watershed. The introduction of ungulates, including deer, has further devastated the watersheds that feed the streams, lo'i, ponds, and oceans in Maui County.

The wao nahele, or forested regions, are where Hawaiians gather resources, but many of the native plants have been lost due to heavy grazing by feral and domestic ungulates (University of Hawai'i, 2023).

Working to manage the ungulate population in the islands is not a new issue. There is documentation that Hawaiians have been trying to manage ungulate populations to preserve precious water and plant resources since 1894, when forest reserves were established and the first statewide program to reduce ungulate populations was implemented. A few years later, hunters were hired from California to kill 3,500-4,000 deer on Moloka'i (Auweloa, personal communication, July 13, 2023). There is also an account in a 1922 article of the Nupepa Kuokoa of a request of \$80,000 (~\$1.5 M in 2023 dollars) to the local legislature to destroy all the wild goats on Hawai'i island which also mentions the deer impacts on Moloka'i (Nupepa Kuokoa, 1922). Below is an excerpt of the article that has been translated from 'Ōlelo Hawai'i (Hawaiian).

Excerpt translation from Nupepa Kuokoa: Last summer, around 7,000 goats were killed by parents and children, but it's unknown how many are on the mountains of Hawaii. There's a lot left going all over and damaging the trees that catch the rain, so the bulk of the water that is needed for plants to grow is gotten. The goats are spread out on not just the island of Hawaii. It is on all the islands. It isn't just the goats that are killing the young trees; it is the wild deer as well that are moving around on Molokai. Let's get all the animals damaging the plants. We need to, or the plants will die (Nupepa Kuokoa, 1922).

Unchecked ungulate populations have been having negative effects on the natural landscape of Hawai'i for over a century. Through grazing contributing to deforestation and subsequent disruption to the water cycle, traditional cultural land management systems are unable to function as designed and important native plant species are threatened. Implementing effective management practices is therefore necessary for protecting and perpetuating traditional cultural practices in the islands.

Deer Management Options

Commercial Harvesting

Large-scale commercial harvesting has been used in various countries to manage invasive species, including red deer in New Zealand, and a similar strategy could be implemented in Maui. This will require some investment, however. The Hawai'i Department of Agriculture estimates that it would cost \$1 million to restore and recalibrate existing slaughter and processing infrastructure to accommodate axis deer (Heaton, 2023). However, there are USDA resources available to support such meat processing infrastructure. In 2023, USDA Rural Development made additional grant funding available to meat processors to help improve the food supply chain (USDA, 2023d). These programs could potentially support expansion of existing operations or create new markets.

There is great potential and support for utilizing the overabundant axis deer population as a commercial food source for Maui County. However, regulations regarding hunting, slaughtering, and meat processing non-amenable species such as the axis deer can be complex. Below, we outline these federal and state level regulations.

Federal Regulations on Slaughter for Commercial Meat Products

The **Federal Meat Inspection Act** (FMIA) governs the processing, packaging, and labeling of “amenable” animal species for human consumption to ensure healthy, safe and properly marked meat products in interstate and foreign commerce (Federal Meat Inspection Act, 21 U.S.C. § 601, et. seq., 2022). Under this act, inspection of slaughter facilities is provided at no cost to establishments processing amenable species, (excluding any overtime worked by inspectors) (Food Safety and Inspection Service, 2012). Being that axis deer is a *non*-amenable species under the **FMIA**, any person slaughtering and processing axis deer and undergoing voluntary inspection must pay for the cost of both an ante-mortem and post-mortem inspection out of pocket, including all related travel and overtime costs (Federal Meat Inspection Act, 2022). **Title 9 C.F.R. Part 352** covers voluntary inspection of non-amenable or “exotic” animals by Food Safety Inspection Service (FSIS) to be sold interstate (Exotic Animals and Horses; Voluntary Inspection, 1985).

Under **FSIS Directive 12600.1**, a field antemortem inspection is required prior to the slaughter of exotic species. The following must be approved by the inspector in the field antemortem: sanitation of the area, the safety of the Inspection Program Personnel

(IPP), proximity to the slaughter facility, and availability of a veterinarian (Voluntary and Other Reimbursable Inspection Services - Revision 2, 2022).

A significant measure in the antemortem process that is the responsibility of the inspector is ensuring humane handling as dictated by the **Humane Methods of Slaughter Act, Title 7 U.S.C. 48 § 1902** (Humane Methods of Slaughter Act [amended], 1978). This Act provides that livestock must be slaughtered by way of a single blow that renders the impossibility of any further pain to that animal. In the context of the axis deer, this means a single gunshot to the head and requires each and every kill to be inspected to verify this (Title 7 U.S.C. 48 § 1902(a), 1978).

Post-mortem inspection should be conducted “according to **9 CFR 352.11**, which refers to **9 CFR part 310**,” treating large deer utilizing the same procedures as those for cattle, and small deer utilizing those for lamb or sheep (Voluntary and Other Reimbursable Inspection Services - Revision 2, FSIS Directive 12600.1, 2022, p. 12). Specified Risk Material (SRMs), which consist primarily of brain and spinal tissue, are required to be removed in cattle, however this is not required for exotic species, as they are not at risk of spreading Bovine Spongiform Encephalopathy (BSE, or mad cow disease) as in cattle (Voluntary and Other Reimbursable Inspection Services - Revision 2, FSIS Directive 12600.1, 2022).

Title 9 C.F.R. Part 352, Exotic Animals and Horses; Voluntary Inspection does not require inspections on non-amenable species, including deer (though meat that goes uninspected cannot be sold across state lines). When not under the purview of FSIS inspection, the Food and Drug Administration (FDA) regulates the safety of meat under the **Federal Food, Drug, and Cosmetic Act (FFDCA)**. More specifically, **Title 21 C.F.R. Part 110 – 110.110** defines the **Good Manufacturing Practice in Manufacturing, Packing, or Holding Human Food** requirements for establishments that sell or give away food (Federal Food, Drug, and Cosmetic Act, 2018; Good Manufacturing Practice in Manufacturing, Packing, or Holding Human Food, 1986). This is the intersection where the laws surrounding game meat for sale are, at best, confusing and, at worst, contradictory. While **21 U.S.C. 601, et seq. (Federal Meat Inspection Act)**, requires that all meat sold commercially be inspected and passed by FSIS, this requirement is only applicable to amenable species. At the same time, under **21 U.S.C. 661**, individual states are given the authority to establish state meat inspection programs that are “at least equal to” Federal law. Under this section, meats inspected this way are only to be sold intrastate, but again, they only refer to amenable species. So the question begs, if an establishment processes and sells non-amenable species intrastate, are they required to follow the regulations under the **FFDCA**, or are they also regulated by **21 U.S.C. 601, et seq.** and **21 U.S.C. 661**? Regardless of the

answer, it seems that any slaughter operation would fall under the jurisdiction of **Title 7 U.S.C. 48 Section 1902**, Humane Methods of Slaughter Act.

State Regulations on Slaughter for Commercial Meat Products

Hawai'i Revised Statutes Section 159, Hawai'i Meat Inspection Act is very similar in language to the Federal Meat Inspection Act, making non-amenable species inspection voluntary (Hawai'i Meat Inspection Act, 1969). Under **Hawai'i Administrative Rules Section 11-29-8**, Hawai'i adopts **21 C.F.R. Part 110, Current Good Manufacturing Practices** (Other Food Rules, 1992). Thus, again, it creates a confusing scenario in which it appears meat can be sold intrastate under FDA regulation as long as the slaughter abides by the Humane Methods of Slaughter Act.

Meat Donation

In 1996, the **Good Samaritan Act** was passed by Congress, giving persons or gleaners and nonprofit organizations civil and criminal liability protections for food donation in the absence of “gross negligence” (Bill Emerson Good Samaritan Food Donation Act, 1996). Recently, the State of Hawai'i Legislature passed **H.B. 1382** which was signed into law as **Act 054**, allowing for game meat donation under certain circumstances (Relating to Meat Donation, 2023). The harvest of the meat must be done in a “food-safe” manner, and the meat must have been processed according to federal law. With the Humane Methods of Slaughter Act in mind, this seems to indicate that any game meat not instantly killed by a single blow cannot be lawfully donated. Further, this creates confusion regarding whether voluntary inspection by FSIS is required or if the FDA's Good Manufacturing Practices suffices. It seems as if Hawai'i State law is more restrictive than Federal law.

H.B. 1382, which was signed into law as **Act 054** in June of 2023 also establishes “a meat processing task force to develop and implement a plan to expand the meat processing capacity in the State to allow for meat from axis deer and other wild game to be processed for distribution by nonprofit food distribution services” and appropriates \$50,000 for fiscal year 2023-2024 towards this end (Relating to Meat Donation, Hawai'i Revised Statutes § 145, 2023). The act, however, does not include the lawful donation of domestic livestock animals in addition to wild species, as initially hoped by some (Caires, personal communication, July 28, 2023).

Table 6: Overview of laws and regulations

<u>Federal Laws and Regulations</u>	
Law or Regulation	Implication
Title 9 C.F.R. Part 352, Exotic Animals and Horses; Voluntary Inspection	Federal Regulation defining amenable and non-amenable species & voluntary inspection of non-amenable species
Federal Meat Inspection Act (FMIA, 2022)	Axis deer are considered a non-amenable species under the FMIA, and thus, both an antemortem and post-mortem inspection is considered voluntary, and the burden of the cost falls on the processor
FSIS Directive 12600.1 Voluntary and Other Reimbursable Inspection Services	Outlines how FSIS inspectors can determine whether non-amenable species' slaughter facilities meet the requirements for USDA inspection, and what to inspect when providing voluntary inspection services, including ante-mortem and post-mortem processes
Humane Methods of Slaughter Act (1978)	Defines that a single shot or blow to the head that instantly renders livestock incapacitated is a method of humane slaughter
Federal Food, Drug, and Cosmetic Act (2018) Title 21 C.F.R Part 110 – 110.110 Good Manufacturing Practices in Manufacturing,	Appears to allow for the intrastate sale of game meat under the Food and Drug Administration's enforcement when in compliance with this Act

Packing, or Holding Human Food	
21 U.S.C. 601, et. seq. 21 U.S.C. 661	These codes require that amenable meats must be inspected to be sold commercially. 21 U.S.C. 661 allows states to establish their own meat inspection services, but those meats may only be sold intrastate. These codes do not reference non-amenable meats such as the axis deer
Bill Emerson Good Samaritan Food Donation Act (1996)	This act abolished liability for those who donated foods in good faith and belief that those foods are safe for human consumption
<u>State Regulations</u>	
Law or Regulation	Implication
Hawai'i Revised Statutes Section 159, Hawai'i Meat Inspection Act	Similar in language to the Federal Meat Inspection Act, defining voluntary inspection of non-amenable species
Hawai'i Administrative Rules Section 11-29-8	Adopts the Food and Drug Administration's current Good Manufacturing Practices, essentially making the sales of non-amenable meats legal intrastate
H.B. 1382: Relating to Meat Donation (2023), Act 054	Allows for the donation of game meat that was harvested in a food-safe manner but seems to direct that harvesting must be done in accordance with the Humane Methods of Slaughter Act, possibly limiting donations from hunters and private landowners

Case Study: Maui Nui Venison

Maui Nui Venison is a leader in the harvest, processing, and selling of axis deer meat in Maui County and has successfully navigated the USDA and state level regulations discussed above in order to bring commercial venison to market. Their mission is “[t]o help balance the axis deer population for the good of our environment, communities, and harvest” (Maui Nui Venison, 2023). We spoke with founder Jake Muise on the operation’s business model.

Marrying conservation with food systems resiliency, Maui Nui Venison acts as a service or benefit to the private ranches with whom they have agreements to hunt on. Ultimately, the ranches determine where they would like the team to harvest deer from and Maui Nui Venison pays the ranches on a per pound basis for the venison that they harvest. This provides a double incentive to the private landowners to allow the continued operation of Maui Nui on their lands – clearing their pastures of invasive pests while also providing the ranches an additional source of income (Muise, personal communication, August 14, 2023).

They operate using a mobile slaughter unit and separate chill storage and processing facility to harvest and process axis deer for local and national markets. According to their website, **having harvested 9,526 deer in 2022 will help to reduce the addition of over 35,000 deer over the next five years** (Maui Nui Venison, 2023).

Starting as a small operation of two, Maui Nui Venison has since grown to a full time staff of 41 in 2023, with an additional two full-time USDA FSIS staff, including a veterinarian and an inspector on hand to certify deer harvests. Although operational, the program is costly as Maui Nui Venison invested over \$1.2 million in 2022 to increase harvesting and processing capacity (Maui Nui Venison, 2023). As a non-amenable species undergoing voluntary inspection, the cost falls squarely on the shoulders of the operation. **USDA inspection costs were estimated at \$10,000 / week for Maui Nui Venison** in 2023 (Muise, personal communication, August 14, 2023). In addition to maintaining USDA inspection in order to sell their meat interstate, Maui Nui maintains a Department of Land and Natural Resources Division of Forestry and Wildlife (DLNR DOFAW) permit for night harvesting of the animals (Muise, personal communication, August 14, 2023).

With these high costs in mind, Maui Nui Venison’s success comes partly from its business model and pricing structure. By charging a premium to customers on the US continent, estimated at 70% of sales, the operation can cover its high operating costs and charge a lower price to local consumers, estimated at about 30% of sales. Recent investments in infrastructure and collaboration with local distributors are allowing Maui

Nui Venison to reach economies of scale to shift 50% of sales to local markets in the near future. Without USDA inspection which allows them to sell across state lines, therefore, the operation would likely not be viable (Muisse, personal communication, 2023).

In addition to the cost of USDA inspection, Muise cited the need for more USDA FSIS inspectors in order to increase the capacity of wild venison harvest operations. USDA FSIS inspectors are scarce in the islands, therefore the availability of inspectors for such *voluntary* inspection of non-amenable species has been even scarcer. Over the years, Maui Nui Venison has managed to show that there was a great enough need for more inspectors to be made available, ultimately now leading to the two full-time USDA FSIS staff dedicated to their operation. The harvest teams utilize infrared binoculars that are connected to a video feed that FSIS inspectors monitor nightly in order to regulate each and every kill. Inspectors were previously rotated through every few months, rendering the possibility of building good working relationships with inspectors difficult. This has shifted over time as well, with inspectors rotating out less often.

The team utilizes two different mobile slaughter processing units that move every second night. With this increased capacity of inspectors and harvest staff, as well as processing facilities, Maui Nui Venison is now able to harvest deer every night of the month. **They have the capacity for harvesting and processing up to 30,000 deer annually.** In terms of food safety regulations, the team follows HACCP Plan (hazard analysis and critical control points) and SSOPs (sanitation standard operating procedures) for their mobile slaughter units, handling all their cleaning internally (Muisse, personal communication, August 14, 2023).

The only bottleneck for the company now, according to Muise, is building enough demand for the product outside of Hawai'i at a premium price (\$30-\$70 / lb.) in order to be able to provide less expensive meats to Hawai'i residents for long-term sustainability (\$6-\$8 / lb.) (Muisse, personal communication, August 14, 2023).

Population Control Regulations

Beyond the processing of deer for human consumption, eradication of axis deer as a nuisance species is also a potential management solution. Under both **Hawai'i Administrative Rules 13-123-9** and **13-124-7**, the Department of Land and Natural Resources (DLNR) has specific authority to issue control measures or destroy permits for nuisance wildlife (Nuisance or Crop Damage, 2015; Crop Damage, nuisance, and threat to human health and safety permits, 2015). To be considered for control under these statutes, the wildlife in question must be doing one of the following: causing

damage to agriculture, being considered a nuisance, causing harm to native wildlife, or threatening human health and safety. No specific method of controlling or destroying is listed in these rules, and it is left to the discretion of an authorized agent of the Hawai'i Department of Land and Natural Resources as to the appropriate method of destruction or control of the nuisance species. It is surmised that destroy permits are given for killing a certain number of species. Being that axis deer cause significant damage to native and agricultural landscapes, accessing such destroy permits for wildlife species should be a viable option for landowners seeking to eradicate deer on their lands.

Table 7: *Hawai'i Administrative Rule pertaining to the control of axis deer as a nuisance species. Source: Nuisance or Crop Damage, 2015; Crop Damage, nuisance, and threat to human health and safety permits, 2015*

<p>Hawai'i Administrative Rules 13-123-9 and 13-124-7</p>	<p>Allows for issuing destroy or control permits for any species causing a nuisance, damaging crops, or threatening human health or safety. An authorized agent of the Hawai'i Department of Land and Natural Resources determines the limits and methods of these permits.</p>
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Hunting

As Honolulu Civil Beat reports, “[t]here were just 10,608 Hawaii residents with hunting licenses in 2021, according to U.S. Fish and Wildlife statistics” (Heaton, 2023). Axis deer provide an opportunity to grow this number and establish a big game hunting industry in Maui Nui. Hawai'i is a popular tourist destination for domestic and international travelers. The Department of Business, Economic Development & Tourism (DBEDT) for Hawai'i projects there will be 9.9 million tourists visiting the islands in 2023 and an estimated \$19.3 billion in visitor spending (State of Hawaii, 2023). Providing travelers the opportunity to hunt axis deer could be one means to generate revenue and help control the population. In 2019, Hawai'i's DLNR reported \$605,000 in total revenue from hunting. Globally, the wildlife hunting tourism market is anticipated to grow at a compound annual growth rate of 26.8% between 2020-2028 (Research and Markets, 2022).

As the Maui.gov website recognizes, “the visitor industry is Maui's leading economic sector” (County of Maui, 2023). Further “[t]he visitor industry touches every aspect of our three islands – approximately 80% of every dollar is generated directly or indirectly by the visitor industry – it is irrefutably the “economic engine” for the County of Maui”

(County of Maui, 2023). Capitalizing on the high levels of visitors, hunting is a recreational activity that provides additional visitor revenue for the county and could be grown.

Guided hunts and hunting clubs are organizations that offer hunting options to visitors. On Maui, Arrow One Ranch is one such organization offering consumers guided hunting tours. The prices for guided axis deer hunts range from \$850 to \$3,600 and provide different experiences, from meat harvesting to a trophy hunt (Maui Deer Hunting, 2023). Arrow One Ranch provides processing, refrigeration, and handling options. However, some local hunters in the community feel it is disingenuous for operations to charge visitors thousands of dollars to hunt invasive species (Heaton, 2022).

Existing Maui County clubs include Moloka'i Hunting Club, Maui Hunter, Sportsman's Club, and All Axis Hawai'i. The two latter organization's online presence are limited to their Facebook pages, which contain 1,700 members and 900 members respectively. Private corporate and non-corporate landowners can sell hunting rights to individuals, groups of people, and hunting clubs through the leasing process. This is an opportunity for hunting enthusiasts to access land, while also being advantageous for landowners who can earn additional income by leasing the rights to their land.

Hunting clubs have also been utilized to access land and establish hunting communities throughout the United States. A 2012 study found the following preferences for hunting clubs among hunters in the southeastern US. In general, hunters surveyed preferred clubs that offer successful harvests, game diversity, and accessibility, as well as those with more acreage and fewer members. Regarding harvest regulations, the least preferred option among hunters was one buck without size restriction, while the most preferred regulation was a two-buck limit with size restriction. Preferences regarding forest management were mixed, with some hunters preferring thinning of half of the lease's acreage while others preferred no forest management. However, the least preferred forest management option consistently involved a clearcut of half of the lease's acreage (Mingie, 2017). Keeping such preferences in mind may encourage the growth of more hunting clubs in the islands and increased membership levels among existing clubs.

Hunting Regulations

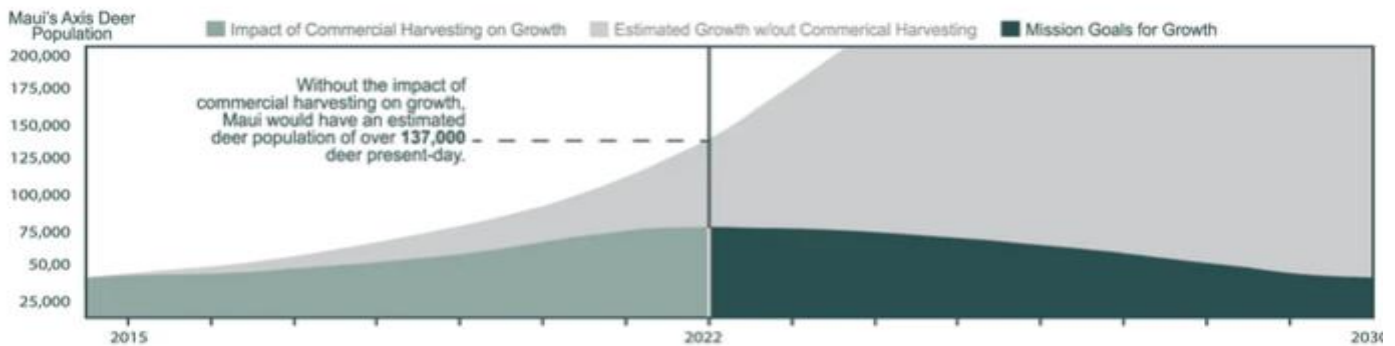
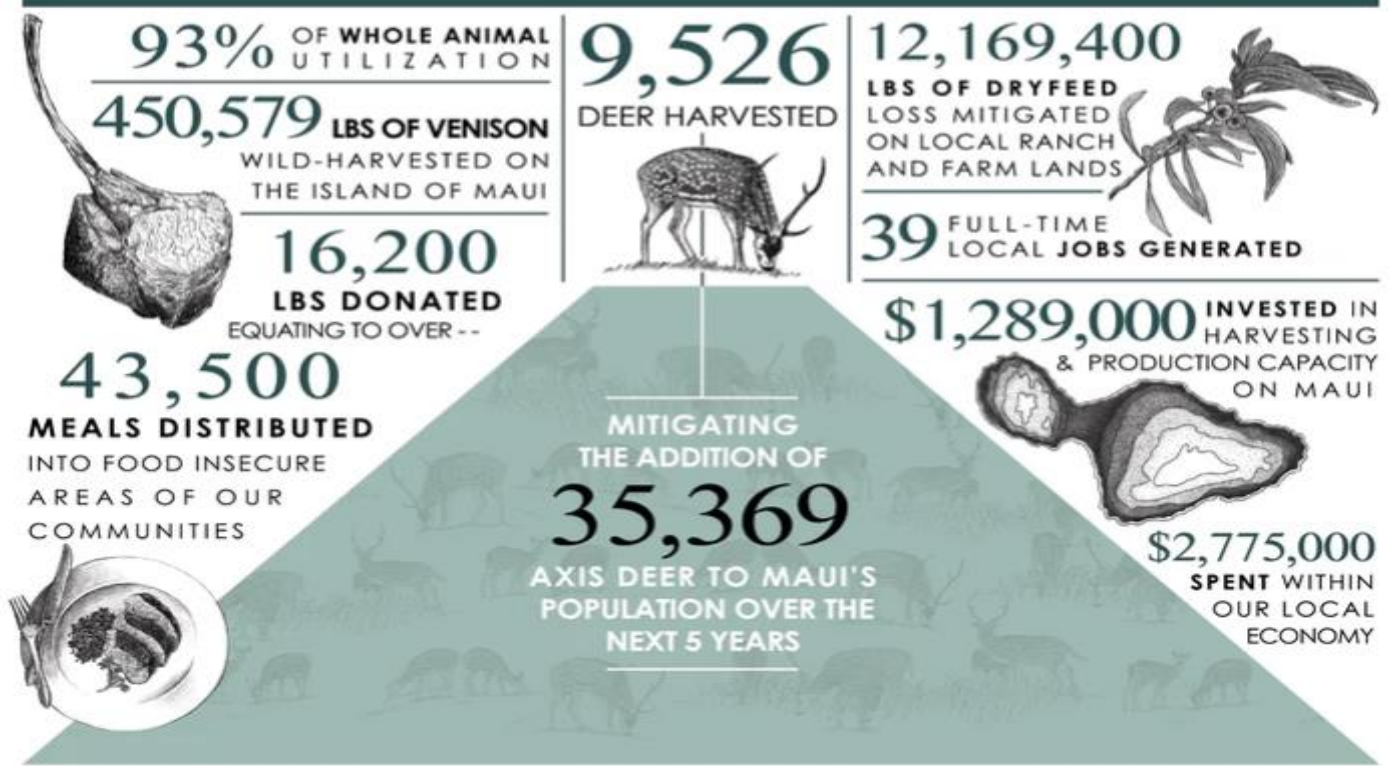
Hunting on private land is covered under **Hawai'i Administrative Rules 13-123-8**, which allows for hunting on private lands with landowner permission and a valid hunting license (Game Mammals, 2015). Not much restriction exists as to harvest methods, but

it appears there is a fundamental lack of liability protections for landowners who allow hunters on their lands.

Currently, the island of Maui has no restriction on the number, sex, or season regarding public land hunting of axis deer. In light of the reproduction rate of axis deer, harvesting restrictions on the sex of axis deer should be explored further and perhaps codified, with consideration also given to the preferences of hunters. Current population estimates suggest that female deer comprise 60%-70% of the population (Hess et al., 2021). Therefore, reducing the female population would dwindle the birth rate. Given that hunters prefer to hunt the trophy buck, a balance must be found that appeases both the hunters and limits the breeding capabilities of the female population.

MAUINUI VENISON

JAN-DEC 2022



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Figure 12: Maui Nui Venison Infographic. Source: Maui Nui Venison, 2023.

Though there has already been a discontinuation of hunting seasons and bag limits for deer on public lands in Hawai'i, allowing for unrestricted levels of hunting year-round, there are other rules that could be implemented to increase the effectiveness for decreasing the deer population. For example, various states have "earn-a-buck" programs for deer hunting, which require hunters to harvest young or female deer before harvesting an adult male (Hess et al., 2015). In addition, "Hunters for the Hungry" is a multi-state program allowing hunters to donate wild game meat to local food banks, and could be implemented in the islands with the proper regulations in place.

In exploring options to manage the growing axis deer population, considerations must be made for handling the waste of large-scale commercial harvesting. The sections below provide an overview of potential waste management options and an analysis of their pros and cons.

Waste Management

Landfill

Disposal of animal carcasses in landfills is a simple but unsustainable disposal method that wastes potentially valuable resources. In Hawai'i, slaughterhouses used to send their waste to landfills, which was a costly process and added to labor costs. Today, many have switched to composting and selling or donating waste to local pet food companies looking to fill the growing raw pet food market.

Landfill disposal poses a risk to biosecurity as it is difficult to dispose of animal waste safely (Swette Center for Sustainable Food Systems, 2020). Hawai'i landfills also cannot take on large amounts of additional waste. Food waste already accounts for 19% of the landfill waste in Maui, equating to an estimated 82 million pounds of food discarded in 2019 (Riker, 2023).

Maui Nui Venison utilizes organs, hides, and bones to create value-added products for human and pet consumption, leaving only the head of the carcass as waste, which are buried on site per HI DOH rules. Because they process the carcasses in the field, all bleeding of the animals occurs on site upon harvest, and there is no need for waste water disposal units. Maui Nui makes bone broth with the venison bones, and pet products with almost all of the nonedible organs. In 2022, they built a permanent butcher facility to process all of their harvests in the islands. Previously, they had to quarter and ship carcasses to the continent because there was no single facility in the islands that could process the amount that Maui Nui was harvesting at the time (Muisse, personal communication, August 14, 2023).

Rendering

A rendering plant uses discarded animal carcasses to produce various materials. The carcasses are cooked at high temperatures to kill harmful bacteria and remove excess moisture. The resulting material is then sorted into edible and inedible categories and is processed for human or animal consumption. The resulting proteins may also be processed into powders or cakes and used as fertilizers. Any remaining material that cannot be processed is safe for disposal in a landfill.

There are no rendering plants in Hawai'i, and they have overall become less popular due to safety concerns regarding mad cow disease (Alao et al., 2017). The FDA requires the removal of brain and spinal cord material, also known as specified risk material (SRM), for any rendered products intended for animal food. This can add costs to the rendering process (North Dakota State University, 2023). This rule applies to cattle 30 months or older but does not seem to apply to rendering cervid (deer) carcasses as a non-amenable species.

Only a small portion, around 32%, of the fresh carcass can be processed through dry methods, while the rest, or about 78%, consists of wet components drained out during the initial cooking process (EnviroZyme, 2023). Disposing this wastewater can be challenging due to the high concentration of organic compounds (EnviroZyme, 2023). Rendering plants generate wastewater from various sources, such as plant sanitation, hide operations, wet material transport, cooling water, and blood processing. This wastewater contains natural elements like phosphorus, potassium, and nitrogen, making it important to use precise and effective methods to remove biological substances or create added value by turning them into blood meal or other high-quality plant fertilizers (EnviroZyme, 2023). Investment into an industrial filter press could be a means to recover these valuable elements present in the wastewater from rendering, allowing for the production of a bone or blood meal type product as a pressed product. Though the initial investment may be expensive up front, UH CTAHR extension agent Kyle Caires shared that it would be relatively inexpensive to operate once it is up and running (Caires, personal communication, July 28, 2023). Another option is anaerobic treatment, which produces biogas as an alternative fuel source (EnviroZyme, 2023).

Rendering plants are associated with the emission of Volatile Organic Compounds (VOC), producing bothersome and sometimes dangerous levels of smell that effect surrounding communities (Sazakli & Leotsinidis, 2020). Any consideration of building such a facility in Maui County should take this impact into account when determining siting locations, and understand that some levels of NIMBY (not in my back yard) pushback may occur.

A 2020 estimate by Hana Ranch found that a commercial rendering facility would require an investment of \$700,000 (Swette Center for Sustainable Food Systems, 2020). The potential benefits given Hawai'i's high fuel, input, and animal feed costs make it a worthwhile consideration.

Compost

Maui County does not currently have a government-run composting facility and West Maui Green Cycle is the only privately-run commercial facility in operation on the island that is permitted by the Hawai'i Department of Health to accept food waste, including carcasses (Riker, 2023). Though public and private options are currently limited, ultimately composting is a useful way to recycle and repurpose slaughterhouse byproducts. Animal compost is high in nitrogen, phosphorus, and potassium, making it a great fertilizer for farms. Studies have shown that using finished slaughterhouse waste compost on agricultural fields can increase crop yield and boost soil nutrient levels (Swette Center for Sustainable Food Systems, 2020).

Small processors or Mobile Slaughter Units (MSUs) have some flexibility in waste disposal options. Hawai'i is one of 43 states where compost is considered an acceptable method of disposal for slaughter wastes (Bonhotal et al., 2014). Different composting methods can be used as part of an approved waste management plan under USDA Natural Resources Conservation Service (NRCS) (Hancock, 2012). These plans address nutrient management, runoff, and water quality issues.

Composting animal offal can have many benefits, but it can also pose health risks if not managed correctly. Improperly managed compost can spread zoonotic diseases and contaminate soil and water supplies. Offal can carry harmful bacteria, viruses, prions, and parasites that can harm animals and humans (Franke-Whittle & Insam, 2013). Most of these pathogens can be destroyed if compost reaches a temperature of 130 degrees or higher for at least six consecutive days. However, prion diseases like Transmissible Spongiform Encephalopathy (TSE), also known as Scrapie, and Bovine Spongiform Encephalopathy (BSE), also known as Mad-Cow Disease, can survive at high composting temperatures. It is best not to compost animals suspected of having neurological diseases, and it is recommended to certify flocks and herds as Scrapie or Mad-Cow Disease-free before slaughter to minimize the risk of prion diseases (Auvermann et al., 2006). Compost piles should be built on non-porous surfaces and surrounded by carbon-rich compost material like wood chips to avoid toxic gasses and leaching. The ideal carbon: nitrogen ratio for animal composting is 30:1 (Auvermann et al., 2006). Composting facilities should be built at least 200 feet away from water sources or sinkholes, monitored frequently, and surrounded by at least a 12-inch layer of compostable carbon material. (Hawai'i Island Meat Cooperative, 2020).

Discussion

While any approach towards axis deer mitigation needs to be multi-pronged and consider all stakeholders, it is highly unlikely that every stakeholder will be happy with every solution. One thing is certain; however, something must be done to reduce the overpopulation of deer.

Below is an overview of potential short-term mitigation and long-term management strategies and their pros and cons.

Short-Term Mitigation

Population Control through Fertility Treatment

Fertility treatment aims to control the population by disrupting the natural reproduction cycles of deer. There is growing evidence of the effectiveness of the immunocontraception vaccine porcine zona pellucida (PZP) in curbing the fertility rate in adult female deer and other animals (Kirkpatrick et al., 2011). PZP is a vaccine extracted from pigs' ovaries and is used to immunize the deer by attacking the hormones needed for reproduction (City of Bloomington, 2018). A successful field trial of the PZP vaccine intervention in deer populations has been documented by the Smithsonian Institute's Conservation and Research Center (Kirkpatrick et al., 2011) but is still considered experimental (City of Bloomington, 2018).

GnRH is another contraceptive that prevents eggs from being released from the ovaries. According to the City of Bloomington's Deer Task Force in Indiana, GonaCon™ is the only commercially available approved GnRH vaccine (City of Bloomington, 2018). Although there are no known dangers to humans or wildlife from eating vaccinated deer, more research is needed to understand the long-term impacts of potential bioaccumulation of the vaccines in the food chain (City of Bloomington, 2018).

Although fertility control may seem like a simple solution it can be complex in its application. Treated populations must be isolated, and 70-90% of the female deer must be treated in order to effectively reduce population growth (City of Bloomington, 2018). Cost is another factor, which is estimated at \$600-\$800 per deer, plus ongoing maintenance (City of Bloomington, 2018).

Surgical sterilization is closely related to the fertility method of sterilization as a mitigation approach. While this method could prove valuable in reducing the axis deer population, it remains a cost-prohibitive intervention that still requires more research. Merrill et al. (2006) questioned the use of surgical sterilization as fertility control in white-

tail deer and smaller wildlife while noting the difficulties in subjecting the animals to stress from capture.

Massei, (2023) stated that incorporating wildlife fertility control would be most effective where other control methods are deemed either ineffective or unacceptable as a population control intervention.

Maui Nui Venison founder Jake Muise worked to look at the option of fertility treatment of deer in Maui County in partnership with the DOA. Partly because the vast majority of such fertility treatments have to be applied annually for continued effectiveness, they found that the per unit cost of fertility treatment is significantly higher than that of harvesting deer for human consumption (Muise, personal communication, August 14, 2023). This indicates that it may make more financial sense to ease the ability of hunters to harvest and sell deer than it would to implement a wide-scale fertility treatment program.

Fertility treatment as an intervention for controlling wildlife including axis deer populations often attracts equal levels of both concern and acclaim from the community and public at large, however it is considered a humane method of managing a deer population. The Humane Society of the United States argues that employing fertility treatment to control wildlife populations is preferable to extermination programs (The Humane Society, 2023). Based on 2014 survey data, Maui resident support for the use of fertility treatment also follows this trend of mixed sentiment, with about a third fully opposed to it, a third fully in support, and about 20% neutral on the issue. This is shown in Figure 13 below.

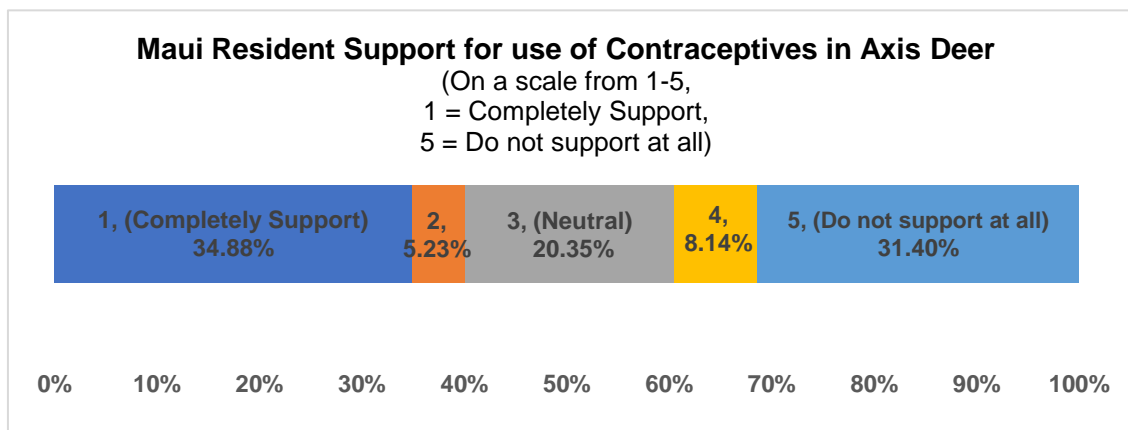


Figure 13: Maui Resident Support for the use of Contraceptives in Axis Deer as a Management Strategy. Source: Authors utilizing data from Rubino and Williams, 2022.

Exporting Axis Deer to Foreign Country

As part of a comprehensive program to bring the axis deer population on Maui to a sustainable level, this study explored the idea of designing a program to export the deer to a needy foreign country. The idea is to solve the problem of axis deer overpopulation in Maui Nui while contributing to the nutritional security of another country.

Though Maui resident survey respondents were not directly asked about their support for sending live deer to another country, they were asked about their attitudes towards the more general strategy of “trap and transfer” in 2014. Support appears mixed, as shown in the Figure 14 below, with about 46% having a negative view towards this strategy, and about 40% having a positive view of this strategy (Rubino and Williams, 2022).

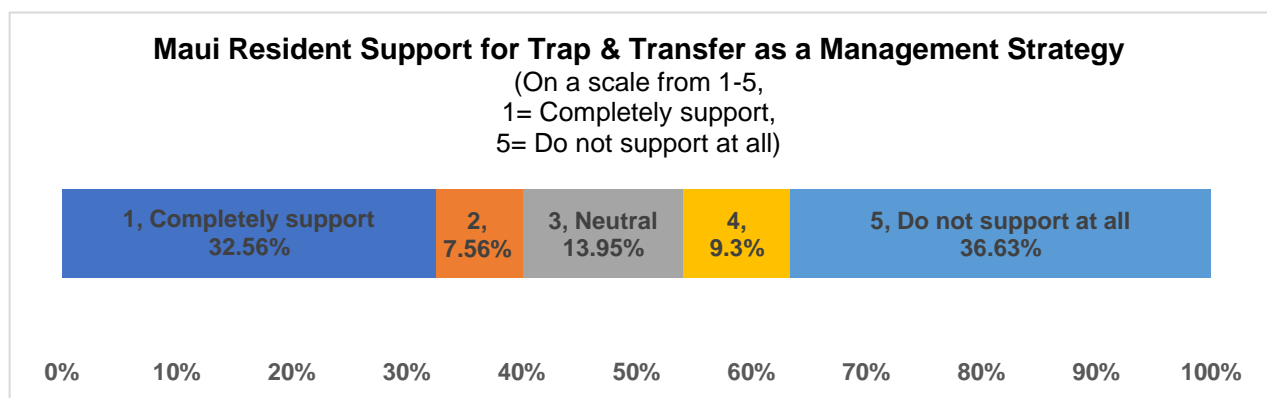


Figure 14: Maui resident support for trap & transfer as a management strategy. Source: Authors utilizing data from Rubino and Williams, 2022.

The idea of sending livestock to a foreign country in live form and as carcasses is not a novelty. According to Sosnowski (2013), Australia is the world's largest exporter of live farm animals. The program could be designed to humanely capture and transport the axis deer to a willing recipient country that requires supplemental nutrition for its people.

At conception, the team explored the idea of slaughtering the deer in-country and then exporting the carcasses to the recipient country. However, reservations were raised regarding the stringent USDA regulations for slaughtering and processing livestock and wildlife as food sources (21 U.S.C. 601, et seq. & 21 U.S.C. 661). While this remains an option for the axis deer population control, an alternative choice is safely capturing and transporting the live axis deer to willing recipient countries.

An argument could be made that any attempt to export live deer to a foreign country would amount to transferring an invasive species and thus, the problems associated with keeping the deer in the host country. However, the program of exporting axis deer

could be designed to supplement the nutrition and protein needs of the recipient country and not release the animals to the wild. Developing countries like Sierra Leone and Guinea are already familiar with receiving donated lamb carcasses from Saudi Arabia annually to distribute meat slaughtered during religious rites (The Media Line, 2022).

Hunting

According to one source, Maui resident support for recreational hunting as a management strategy for axis deer is high at 76% of survey respondents “completely supporting” it. It was the most preferred management strategy as compared to commercial harvesting, fencing, hired sharpshooting, contraceptives, trap and transfer, and taking no management action (Rubino and Williams, 2022).

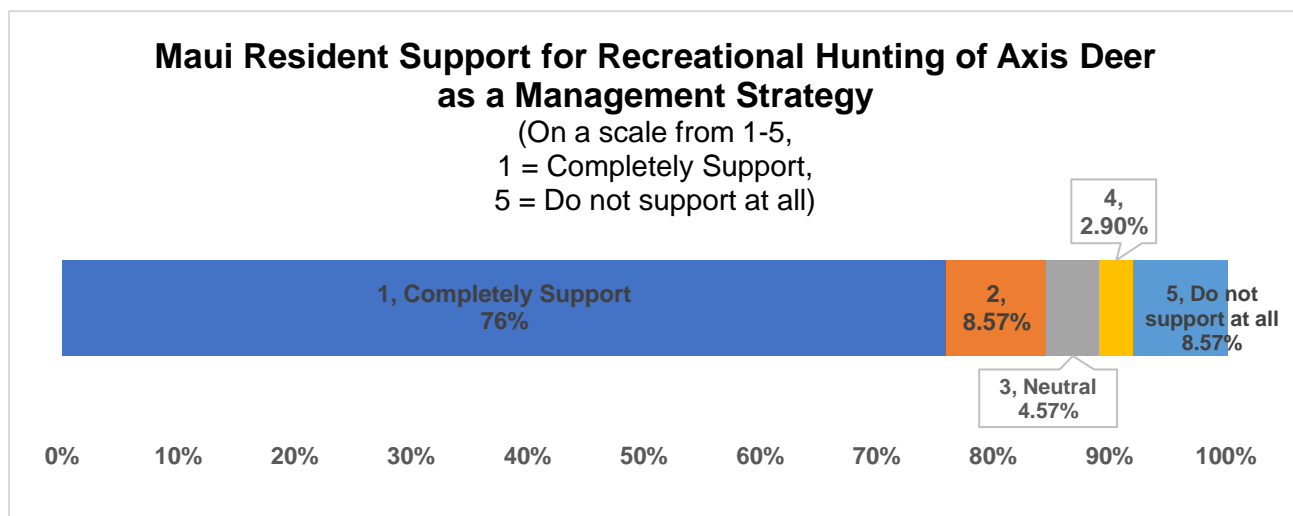


Figure 15: Maui Resident Support for Recreational Hunting as a Management Strategy. Source: Authors using data from Rubino and Williams, 2022.

In addition to being well supported among residents, implementing a comprehensive hunting policy and action plan is a valuable and necessary tool in controlling the axis deer population in Maui Nui. It is essential to establish effective monitoring and regulatory measures to ensure that the population falls to sustainable levels and remains within manageable limits. Policies aimed at hunting female deer are crucial to achieving this long-term population control. This deer species' high fertility and reproductive capability is well documented (Kelley, 2020).

95% of adult female axis deer can breed by one year of age and removing male deer may not necessarily reduce breeding rates due to their polygynous behavior (Hess et al., 2021). However, as discussed previously, if 30% of the deer population is removed at a ratio of four female deer for every one male, this would result in a population reduction of 22.3% (Hess and Judge, 2021). Some state game management agencies,

such as Virginia, have implemented the "earn-a-buck" program as a solution. **Virginia administrative code 4VAC15-90-89** requires hunters to first harvest young or antlerless deer in a specified county before being allowed to harvest an adult male within the same county. This approach can increase the harvest of female deer, improve the adult sex ratio, and ultimately positively impact forest regeneration and biodiversity.

New Zealand, an island nation, has effectively controlled ungulate populations through various measures, including hunting. The country's hunting regulations are flexible, assessed annually, and are considerate of both recreational hunting and environmental conditions (Fish and Game New Zealand, 2023). Similar to Hawai'i, ungulates lack natural predators in New Zealand. The country's long-term strategy involves coordinating stakeholder organizations, defending existing deer-free areas, targeting critical areas, offering free permits for hunting, and allowing regulated commercial organizations to harvest ungulates, process, and sell the meat (Fish and Game New Zealand, 2023).

New Zealand has implemented more flexible and adaptive policies for harvesting ungulates thanks to monitoring investments under their collaborative framework called the Te ara ki mua document (Department of Conservation, 2022). This has resulted in better control of the pest population while creating opportunities for people to prosper through activities such as hunting, farming, and other commercial ventures associated with these species.

New Zealand's Approach to Wild Deer Management

- Flexible hunting regulations that are assessed annually
- Free hunting permits
- Coordinate stakeholder organizations
- Defend existing deer-free areas
- Target critical areas
- Allow commercial operations to harvest, process and sell venison meat

Jake Muise of Maui Nui Venison recommends a basic plan for monitoring existing harvest levels. He notes that DLNR DOFAW currently collects numbers of deer harvested via aerial shooting, game harvest permits, wildlife control permits, and deer harvested within game management areas (Muise, personal communication, August 14, 2023). Through aggregation of these existing data sources, current harvest levels of female deer can be quite accurately assessed, with the understanding that some

subsistence harvests may go unreported. Through this monthly or annual data analysis, the following year's harvest levels can be set from a well informed place (Muise, personal communication, August 14, 2023).

In a survey conducted by Maui Nui Venison in 2022, it was found that over 50% of the deer population were on the lands of large landowners having 50-100 acres (Muise, personal communication, August 14, 2023). However, assistance for smaller landowners with more limited resources to be able to harvest more deer from their lands is needed. One way for the county to do this is through assisting with coordination between local hunters and smaller landowners.

Eco-Tourism

Hunting tourism is an option that creates revenue while effectively managing wildlife. In 2021, visitors to Hawai'i spent just short of \$140,000 on close to 1,300 licenses and tags associated with deer hunting. This number is close to double the 2016 numbers, according to Fish and Wildlife Services, indicating recent growing visitor interest in hunting (Heaton, 2022).

One place where visitors can book guided hunts is on hawaii hunts.com. One visitor review of their hunting experience on the website highlights the competitive advantages of Hawai'i axis deer hunts:

"They have bigger Axis bucks than Texas by far. They manage their herds well and it's all wild game. I tagged out in the first day because I knew I wouldn't see a bigger buck than the one I got. I would recommend this hunt to anyone traveling to Maui. It's worth every penny."
-Pleased Maui Hunting Tourist (Hawaii Hunts, 2023)

With Hawai'i already being an economy largely reliant on tourism, this can be one tool for effectively mitigating deer populations if done right. Issues remain in finding a balance between attracting and utilizing hunters to manage populations effectively. Since most hunters prefer to hunt the trophy buck (a larger male deer with a large antler rack) and the fact that population mitigation is most effective with the culling of does, laws and regulations pertaining to axis deer hunting need to be updated to reflect both goals.

A second issue is the location of the deer. Based on the input provided by stakeholders, it is evident that axis deer are posing a challenge in residential areas. Hunting axis deer at night is preferable to get close to the animals, resulting in loud gunfire. This creates a

nuisance and concerns for public safety. Ultimately, axis deer on private lands and in residential zones is causing an access barrier for hunters as landowners have liability and noise concerns.

Long-Term Management

Commercial Harvesting and Processing

A 2022 survey of Maui residents found that 54.29% of individual resident survey respondents “completely support” commercial harvesting as a management action for axis deer on the island (Rubino and Williams, 2022).

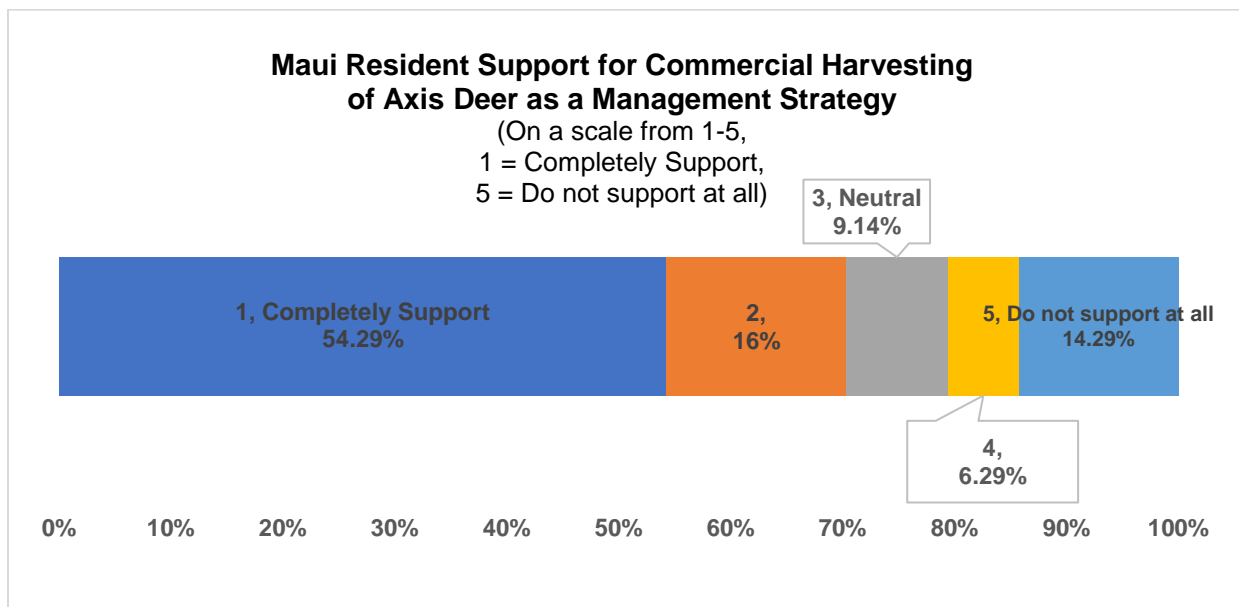


Figure 16: Maui resident support for commercial harvesting of axis deer as a management strategy. Source: Authors using data from Rubino and Williams, 2022.

Slaughtering and processing venison as a sustainable food source in Maui County has continuously been championed as a solution to both feeding residents and mitigating other damages caused by axis deer. However, due to the severe nature of the problem and the overwhelming economic cost of slaughtering and processing, this is a long-term approach that needs to be more thoroughly investigated before placing it ahead of other, more immediate options.

In 2007, Moloka'i resident Desmond Manaba became the first in the state to obtain a permit to harvest and sell axis deer for public consumption as a USDA approved sharpshooter through his company Moloka'i Wildlife Management (Krebs, 2021). The

novel concept of harvesting deer in their natural habitat versus a USDA-approved slaughter facility came with challenges and the need to develop new processes (Krebs, 2021). Manaba estimates that he has harvested over 20,000 deer since he started and is looking to expand his processing capabilities (Manaba, personal communication, 2023).

Mobile slaughter units seem to be the most economical option, but they are still costly, estimated at \$250,000 for a trailer facility (Wagoner, 2021). Added equipment, waste disposal, and chill/storage unit costs can easily triple the start-up costs. Then, there are the operational costs to consider. Mobile units must meet the same federal inspection requirements as brick-and-mortar facilities, though they cannot process as many animals and if processing non-amenable species, must cover any voluntary inspection costs. This greatly increases the cost of production, requiring processors to charge more per pound to try to break even (Wagoner, 2021). This is a problem of a lack of scale to reach output efficiency: though the costs to operate are comparable to that of a brick and mortar facility, the output is less.

The deer problem is too significant for mobile processing to serve as a singular solution. Small-scale slaughter facilities with mobile slaughter units for field dressing may be a more viable option.

Deer Farming

Commercial deer farming in New Zealand started in the 1970s and has grown into a NZ \$280 (U.S. \$175) million annual export earner (USDA, 2023a). Deer farming has expanded to one of the fastest-growing industries in the rural United States, supporting tens of thousands of jobs and generating \$7.9 billion for the U.S. economy (North American Deer Farmers Association, 2023).

Venison is one of the most nutrient-dense red meats, having 22% higher protein and 2-4 times the antioxidants of beef (Maui Nui Venison, 2022). Axis deer are very lean in particular, with 0.2% fat or less, which, according to the North American Deer Farmers Association, makes them legally “fat-free” (North American Deer Farmers Association, 2019). Demand for deer meat in the U.S. is growing as more people look to source more natural, grass-fed meats. Venison has even made its way onto the seasonal menus of fast-food chains like Arby’s (Vanorio, n.d.). In addition to venison, deer are farmed for velvet production and stocking tourism hunting operations.

Although the economic potential for farm-raised deer is high, many challenges exist. Deer farming requires specialized paddock and yard designs to handle animals safely. Axis deer are considered one of the most timid and excitable deer species, making

them difficult to raise and requiring a high level of skill to manage (Rural Industries Research and Development Corporation, 1998). Escaped deer quickly revert to their wild state (Queensland Government, 2023) and lose their domesticated traits within a few generations (Muisse, 2023).

Axis deer are highly valued for their superior meat quality and often fetch a higher price than other deer species (Texas A&M University, 1999). However, they comprise a minority percentage of farmed species, constituting only 10% of deer cultivated in Queensland, Australia (Rural Industries Research and Development Corporation, 1998). This is likely due to handling issues with axis deer, which has resulted in higher mortality rates and frustrated farm owners (Texas A&M University, 1999).

A hybrid approach that manages deer populations alongside cattle or sheep, allowing them to maintain their wild traits, may be more successful and profitable (Deer Association of Australia, 2023). For comparison, stocking rates for axis deer are estimated at 6-7 deer/1 cattle using dry feed rates (Muisse, personal communication, August 14, 2023).

Policy

Policies surrounding axis deer processing, hunting, and donation are complex and often contradictory between federal, state, and local guidelines. These policies are covered in depth under the *Commercial Harvesting* section of this report.

An aspect of policy that needs development is Maui County's local ordinances. Gaining public support for controlling axis deer is paramount for implementing change, but cultural ideologies may discourage cooperation with such regulations. With recognition of the barriers of controlling the axis deer in more densely populated areas, more investigation is needed to assess opportunities for the Maui County Department of Agriculture to create local ordinances that incentivize citizens and large landowners to work towards mitigation efforts.

The Hawaiian people occupied Hawai'i before the formation of the United States, yet they are not afforded many of the same benefits given to Native American tribal members. In conjunction, Hawai'i faces a litany of burdensome costs in food production that continental states do not have to deal with. Maui County Department of Agriculture, in collaboration with federal representatives, may consider introducing legislation in U.S. Congress to create a carve-out for Hawaiian agriculture that allows more freedom in production and processing for wild game meats including axis deer.

Case Study for Collaboration

On April 12, 2011, an axis deer was captured on a game camera set up by the Big Island Invasive Species Committee (BIISC) on Hawai'i Island. Due to the concerns of farmers and ranchers, as well as the history of axis deer destruction in Maui County, the Hawai'i Department of Land and Natural Resources and BIISC collaborated on an axis deer control project, taking their first deer in April of 2012 (HDLNR, 2012).

A United States Fish and Wildlife Services (USFWS) report later detailed how the axis deer had appeared on Hawai'i Island, finding that a helicopter pilot from Moloka'i had flown four axis deer in a trade for twelve moufflon sheep. Before this, neither species had been present on those respective islands. Both trade partners were criminally prosecuted in violation of the Lacey Act for transporting animals with the intent to provide guide hunting (Hess et al., 2015).

BIISC encountered several hurdles in removing the axis deer on Hawai'i Island, the most prominent being that axis deer would move from state land to private land, where permission from landowners was needed to hunt. Hess et al.'s 2015 paper concluded that community engagement was paramount to the success of removal efforts. BIISC came to the same conclusion upon officially declaring Hawai'i Island free of axis deer in 2017 (Callis, 2017). When private land owners allow agencies such as BIISC or the DNLR access to their lands, it allows for more thorough removal, and in this case, eradication.

"We were really grateful to the community for their efforts in reporting possible deer sightings. It was demonstrated that people are aware of the threats the deer pose, and they were very invested in making sure axis deer didn't get out of control on the Big Island." - Brett Gelinas, Wildlife Biologist, BIISC

Hawai'i Island had the example of Maui County to show the devastating effects of deer, which ultimately helped to cause alarm and ignite action in Hawai'i County early on when deer were introduced. Without that head start, Maui County and its residents now face a complex problem requiring innovative thinking and action plans that include many short- and long-term strategies. Environmental degradation, public health concerns, and food insecurity will only worsen as the problem is discussed and not acted upon.

Recommendations

Population Assessments

Population assessments should be conducted regularly with indicators identified to assess whether progress is being made on all fronts. New AI and machine learning technologies paired with drone technology are being piloted to assist conservation efforts for large scale species monitoring (Varela-Jaramillo et al., 2023). This novel technology convergence can be deployed in remote, hard to access areas (Varela-Jaramillo et al., 2023). Early adoption of these technologies could provide more accurate axis deer population estimates in the near future.

Establishment of an Area-Wide Management Plan

A common issue raised by multiple interviewees in this study was the need for a comprehensive area-wide management plan incorporating mitigation strategies for both public and private lands. The majority of our interview participants expressed a long-term interest in finding ways to sustainably manage populations for economic returns.

Deer Impact Concerns by Order of Importance

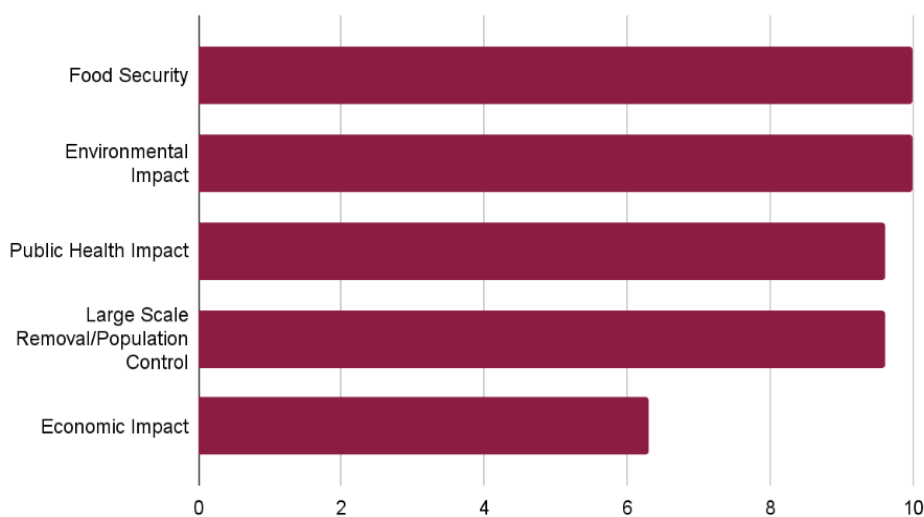


Figure 17: Deer impact concerns by order of importance
Source: Primary data from interviewees on this research study

However, when asked to rate various deer impact concerns by order of importance, with one being “not important at all” and ten being “extremely important,” our 6 interview participants rated economic impact as less important than finding immediate

solutions to manage deer populations to address food security and environmental impacts. This is represented in Fig. 17 above.

With that in mind, it is recommended that the Maui County Department of Agriculture continue the work of the Deer Task Force established in 2021 in collaboration with state and federal agencies and large private landowners and hunting clubs, to develop a comprehensive management plan. The plan should be dynamic and use an ahupua'a resource management approach based on social-ecological zones (wao) (Winter et al., 2018) to understand the short and long-term impacts any proposed intervention or management strategy may have from mauka to makai. The task force should consider collaboration with New Zealand's Department of Conservation and use of the Te ara ki mua framework for adaptive management as a starting point (Department of Conservation, 2022).

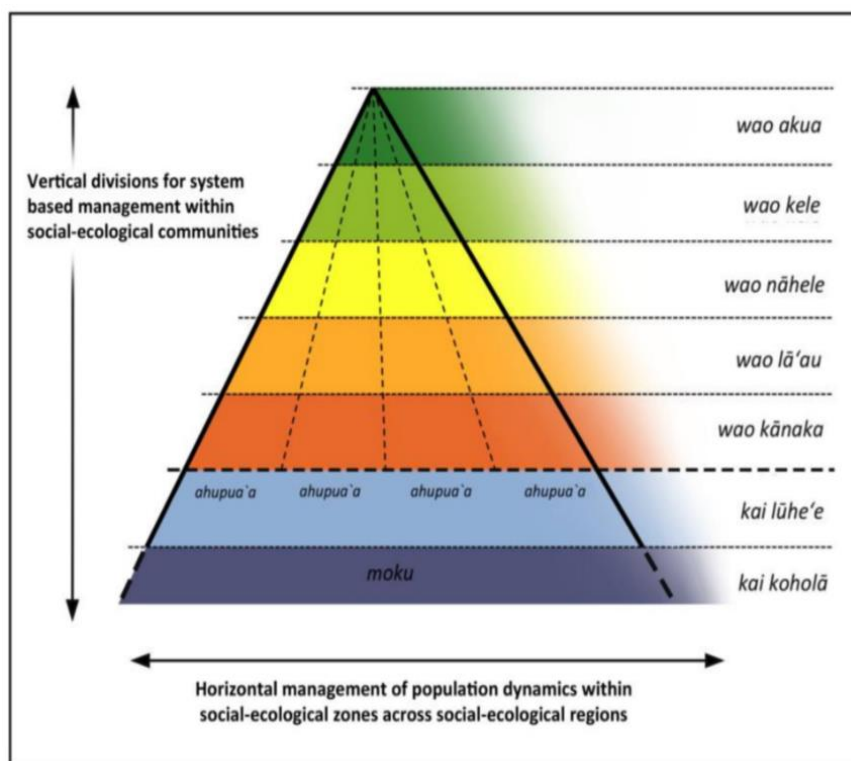


Figure 18: Model depicting the layout of a single social-ecological region (moku). Source: Winter et al., 2018.

Policy

Policies surrounding axis deer mitigation, processing, hunting, and donation are complex and often contradictory between federal, state, and local rules. Due to this, it is recommended that the Maui County Department of Agriculture work alongside local advocacy groups like the Hawai'i Farm Bureau and Hawai'i Farmers Union United in collaboration with state representatives to introduce statutory amendments that align with federal guidelines or clearly acknowledge the presiding authority with jurisdiction

over the matter. Navigating the confusing and arduous processes creates barriers to entry for market actors and stifles social entrepreneurs seeking to strengthen the local food economy.

Hunting Policy

It is important to prioritize policies aimed at hunting female deer, which will be crucial to achieving long-term population control. Virginia's "earn a buck program" is a model to consider. Providing hunting permits free of charge would also be an additional incentive to encourage increased recreational hunting, modeled after New Zealand's policies to manage ungulate populations.

The establishment of liability protections for private landowners who allow recreational hunters onto their lands was also shown to be needed in Maui County. This incentivizes private landowners who may otherwise not feel protected enough to allow such activities on their lands. In concert with such protections, the county may consider providing assistance via coordination between local hunters and landowners.

Meat Processing Policy

The Hawai'i meat inspection program, defunct since 1995, allows for the sales of amenable species intrastate (Heaton, 2023). This program could be reinstated. However, axis deer would additionally need to be added to the Hawai'i Meat Inspection Act (**Hawai'i Revised Statutes Section 159**) as an amenable species, as currently only "cattle, sheep, swine, goats, horses, mules, or other equines" are currently listed (Hawai'i Meat Inspection Act, H.R.S. § 159, 1969).

HB609, introduced in the 2023 legislative session, would have appropriated funds for 4 full time positions to perform meat inspection services, addressing a major barrier in reinstating the state-level inspection program (HB609, 2023). The bill ultimately died in conference committee. However, if passed, this would go a long way for allowing the intrastate sales of venison.

Small Scale Processing

In addition to streamlining meat processing policies, Maui County should continue to explore collaborating with existing operations like Maui Nui Venison, Moloka'i Wildlife Management and Makana Provisions, as well as other animal processors. Building the capacity of small processors to either increase throughput or expand their facilities to handle multiple species can help develop the supply chain and provide a pipeline for

hunters and entrepreneurs, including value-added producers. Small scale processors can serve as aggregators and provide access to markets for hunters and mobile processing units. Federal USDA funding such as the Meat and Poultry Expansion Program available in 2023 (USDA, 2023d) and other USDA programs may be available to support these efforts.

Obtaining USDA inspection as a non-amenable species can be cost-prohibitive for processors. Programs to help support such processors through reimbursement for such costs could be a valuable tool for increasing local axis deer processing.

Further Research into Population Control

Understanding that additional processing infrastructure may take several years to accomplish, further research should be done to immediately explore options to lower population density and carrying capacity across the county. Further research should assess the feasibility of shipping live animals, or slaughtered, frozen carcasses for out-of-state processing for U.S. consumption and export markets. This could help immediately reduce populations to manageable sizes without the waste, costs, and controversy of eradication.

Conclusion

Since the introduction of axis deer in Maui County, the population has risen nearly unabated. More recently due to drought conditions and increasing impacts on private lands, the axis deer population issues have come to the forefront. Still, much more work must be done to increase public awareness and garner legislative and market-driven support to address the issue.

Our results found that the population of axis deer in Maui County is unsustainable and that economic and environmental damages likely far exceed current estimates. Insufficient population data creates challenges in thoroughly assessing the impacts and developing effective management strategies.

While the pioneering work of Maui Nui Venison in developing industry and assessing populations using infrared technology is a great start, a much more comprehensive population assessment should be done to truly understand the current and potential impacts.

Increasing access to slaughtering and processing can help create economic viability for the venison industry and lower food insecurity in Hawai'i. Specifically, intrastate sales of meat allowed through a state-run inspection program, or temporary subsidies implemented to cover USDA inspection costs could have an immediate impact on the deer population.

Public support for any singular solution may not be overwhelming but nonetheless is needed. Public and private cooperation will be integral to a multi-faceted set of solutions as the cost of mitigating the deer population sustainably may far exceed any governmental budget.

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Appendix

Appendix A: Interview Questions

Interview Questions for Agricultural Business Owners:

- When did you start your business and what is the size of your operation? (in acres)
 - What percentage of your income comes from your agriculture business?
 - Have you suffered any crop or herd loss in the last year due to the axis deer? If so, what is the estimated value of that loss?
 - Are there additional anticipated losses or impacts to your operations if axis deer populations continue to expand?
 - What mitigation measures such as deer fencing, hunting/culling or others are you utilizing, if any?
 - Which mitigation measures have you found to be most effective?
 - What are the estimated costs associated with using these measures? (linear ft fence costs, material costs, additional labor, etc.)
 - What are the one-time costs associated with deer management vs. ongoing/annual costs?
 - What are your top 3 biggest challenges in mitigating deer impacts?
 - Do you see axis deer as a potential source of food for Hawaii?
 - How do you feel about large-scale axis deer harvests?
 - Do you allow commercial or subsistence hunting on your land?
 - If hunting is allowed on your operation, what is your policy/process and how many head are harvested annually?
 - If no, are you interested in allowing hunting on your lands for the purposes of deer management? And what are the barriers to you allowing hunters on your property?
 - On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is deer hunting/culling for food security?
 - On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is managing deer populations for environmental impact?
 - On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is managing deer populations for economic impact?
 - On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is managing deer populations for social impact and public health?
 - On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is it to obtain economic value from deer culling or hunting activities?
 - Are you looking for ways to economically capitalize on the axis deer population? If so, how?
 - Are there any policy changes that could help with managing axis deer populations?
 - Is there an interest in collectively managing deer populations in collaboration with other large landowners and if so, what would be needed to move that forward?
-

Interview Questions for government officials, support organizations, agribusiness experts, etc.

- How do you feel about large-scale axis deer harvesting or destocking?
- Do you see axis deer as a potential commercial food source for Hawai'i?
- What mitigation measures are currently taking place to manage axis deer?
- Are there any policies that could help the state or private landowners better manage or mitigate the impacts of axis deer?
- What are the infrastructure needs/requests that you hear from constituents/residents?
- Is there an interest in collectively managing deer populations in collaboration with other large landowners and if so, what would be needed to move that forward?
- Is obtaining economic value from deer culling more or less important than population management?
- Are there any policy changes that are needed to reduce barriers to processing axis deer?
- On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is deer culling for food security?
- On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is managing deer populations for environmental impact?
- On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is managing deer populations for economic impact?
- On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is managing deer populations for social impact and public health?
- On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is it to obtain economic value from deer culling or eradication activities?

Interview Questions for meat processors

- When did you start your operation and how many people do you employ?
- Is your facility a permanent facility or is it considered a Mobile Processing Unit (MSU)? If MSU, how many units do you have and how many locations do you utilize for your operations?
- Were there any special permits or infrastructure required to install your facility?
- What species of animals do you process and do you process axis deer?
- If yes, what is the total cost to process one axis deer? And how much revenue does one deer generate?
- How many deer are processed each year? And what is the average weight?
- What is the daily processing capacity in pounds or animal count for your mobile processing unit?
- If not, are you interested in processing deer and what has prevented you from doing so?
- For operations processing multiple species - Are there any challenges or barriers to processing multiple species?
- Do you harvest or raise your own animals for processing or purchase from other farms/ranches? If so, how many farms/ranches do you source from?
- What type of cleaning schedule is required for a mobile processing unit?

- Do you clean your own processing equipment or is cleaning outsourced?
- How do you handle processing waste (carcass, offal and grey water)?
- How do you store and refrigerate the meat post slaughter and processing?
- What are your primary markets?
- Do you have any plans for on-site tourism or other ancillary enterprises (compost or other agricultural inputs, value-added products)?
- How can lower costs for processing be obtained?
- Are there any policy changes that are needed to reduce barriers to processing axis deer?
- On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is deer hunting/culling for food security?
- On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is managing deer populations for environmental impact?
- On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is managing deer populations for economic impact?
- On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is managing deer populations for social impact and public health?
- On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is it to obtain economic value from deer culling or hunting activities?
- Do you sell or donate game meat intrastate? If so, do you follow the FDA regulations regarding slaughter and processing or do you follow the USDA anti and post-mortem inspections?
- Please explain the role of the USDA inspector and USDA veterinarian
- Are there any loopholes in the regulations that you have needed to utilize?
- Are you directly affected by the Humane Slaughter Act? If so, what are you required to do to be in compliance?

Interview Questions for hunters

- Do you hunt commercially or for subsistence?
- What are your motivations for hunting?
- Are you part of a hunting club?
- Where do you conduct your hunting activities? (private, county or state land? Location or region)
- Do you have any agreements with private landowners to hunt?
- How often do you hunt and how many head to you harvest annually?
- Do you sell or donate any of your meat?
- Are you aware of any regulations that keep you from donating or selling your meat?
- How do you feel about large-scale axis deer harvests?
- On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is deer hunting/culling for food security?
- On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is managing deer populations for environmental impact?

- On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is managing deer populations for economic impact?
- On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is managing deer populations for social impact and public health?
- On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is it to obtain economic value from deer culling or hunting activities?
- If access to processing for axis deer increased, would you hunt more?
- Would you be adverse to regulations regarding a higher doe to buck tag ratio?
- Do you participate in or have any concerns regarding ecotourism related to hunting?
- Are there any policies or regulations that could help increase hunting as a deer management strategy?

Interview Questions for large landowners

- How many acres do you own or manage in the affected area? (Maui, Moloka'i, Lāna'i)
- Have you suffered any financial losses in the last year due to the Deer? If so, what is the estimated value of that loss?
- What mitigation measures such as deer fencing, hunting or others are you utilizing, if any? What are the estimated costs associated with using these measures? (linear ft fence costs, material costs, additional labor, etc.)
- Do you allow hunting on your lands?
- If no, are you interested in allowing hunting on your lands for the purposes of deer management?
- What hesitations do you have for allowing hunters on your land?
- Is obtaining economic value from deer culling or hunting more or less important than population management?
- If hunting is allowed on your lands, what is your process and how many head are harvested annually?
- Are there any policy changes that could help landowners privately manage axis deer populations?
- Is there an interest in collectively managing deer populations in collaboration with other large landowners and if so, what would be needed to move that forward?
- On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is deer hunting/culling for food security?
- On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is managing deer populations for environmental impact?
- On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is managing deer populations for economic impact?
- On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is managing deer populations for social impact and public health?
- On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is it to obtain economic value from deer culling/destocking?

Interview Questions for Natural Resource Specialists

- What are the current known impacts of axis deer on forage, native flora and fauna, watersheds and near shore marine areas?
- How do you feel about large-scale axis deer Harvests?
- How does the impact of axis deer compare to the impacts of goats and pigs (alien weeds and goats and pigs identified as top 2 threats)?
- Out of all the axis deer management strategies, what are the most feasible? Which ones would be more difficult to implement (corralling of axis deer, culling of the deer to sustainable levels, clearing vegetation along fence lines, and erecting and/or reinforcing fence lines to keep axis deer away from roadways, airports, and runways)?
- What mitigation measures are currently taking place to manage axis deer?
- Is the Department of Land and Natural Resources developing an axis deer management plan?
- Are there any policies that could help the state better manage or mitigate the environmental impacts of axis deer?
- On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is deer hunting/culling for food security?
- On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is managing deer populations for environmental impact?
- On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is managing deer populations for economic impact?
- On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is managing deer populations for social impact and public health?
- On a scale of 1-10 (1-not important at all, 10 - extremely important) how important is it to obtain economic value from deer culling or hunting activities?

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About the Authors

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Samking Braima is a multifaceted professional with an extensive background in banking, development finance, agribusiness, and politics. Mr. Braima has held positions at JP Morgan Chase in Columbus, Ohio, the African Development Bank in Tunisia, Côte d'Ivoire, and the Government of Sierra Leone as Deputy Minister of Agriculture and Forestry. Mr. Braima is a Personal Banking Officer at the First Hawaiian Bank in Lihue, Hawai'i, and a local farmer.

Still driven by his passion for contributing to reducing global hunger and food insecurity, Samking joined other farmers in Kauai with the GoFarm project to continue his work in the ag sector. Motivated by the challenges of the island's vulnerability to food insecurity as evidenced by food shortage and the logistical nightmare experienced during the height of the COVID-19 outbreak, Samking joined a community of experts at Arizona State University in the program of Sustainable Food Systems to enhance his ability to contribute to the local Food Systems in Kauai and globally.

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Karen was born and raised in Phoenix, Arizona where she still resides. She studied natural resource management and conservation at Phoenix College and holds a Bachelor of Science in Sustainability and Justice Studies from Arizona State University. She is currently a Project Management Assistant with the City of Phoenix Office of Environmental Programs where she assists with programs aimed to strengthen the local food system.

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