

Wild Sheep and Deer in Hawai`i—a Threat to Fragile Ecosystems

The unique native flora of the Hawaiian Islands, which evolved in the absence of ungulates (grazing animals), is highly vulnerable to damage by trampling and browsing. Wild ungulates introduced into Hawai`i in the past 150 years, including mouflon, axis deer, and mule deer, have severely harmed the native flora. Control measures used against feral animals do not work as well against these wild animals. Trophy hunting tends to alter sex ratios and increase population growth. U.S. Geological Survey scientists are studying these wild ungulates in order to develop more effective control measures that help protect Hawai`i's endemic flora.



Mouflon (wild Mediterranean sheep), like these in the Kahuku Unit of Hawai`i Volcanoes National Park, threaten the fragile native flora of Hawai`i by browsing, bark-stripping, and trampling. The Hawaiian Islands originally had no ungulates (grazing animals), but mouflon and several other species were deliberately introduced, mainly for recreational hunting. Traditional control methods—including hunting—have proved largely ineffective in limiting the increase and spread of these introduced wild ungulates. Photo courtesy of Robert Stephens.

For millions of years, the Hawaiian Islands lay undiscovered by humans in the middle of the Pacific Ocean. The fauna and flora that found their way to the islands and evolved there were



Browsing by wild ungulates threatens native Hawaiian plants. This māmane tree sapling in Palila Critical Habitat on Mauna Kea, Island of Hawai`i, has been stripped of most of its foliage.

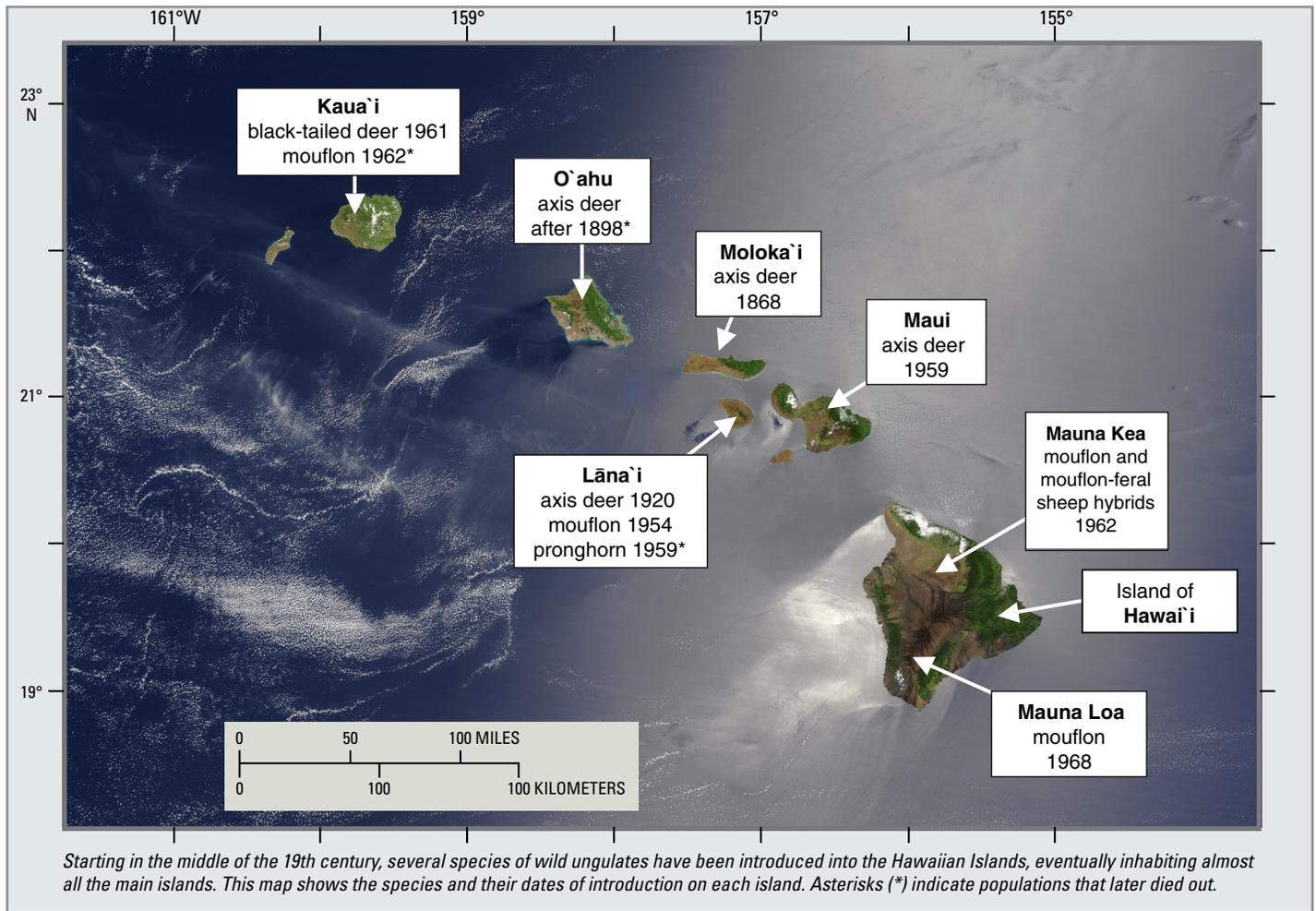
unique, and land animals were mostly limited to invertebrates and birds. Before humans came, the only mammals, apart from seals that hauled up on the beaches, were insect-eating bats. When Polynesians settled Hawai`i more than a thousand years ago, they brought with them domesticated dogs, pigs, and fowl (chickens). Rats arrived as stowaways. Inevitably, some of these animals escaped into the wild and established feral populations, which began to have an impact on the native flora. After the islands were found by Western explorers, the influx of non-native species into Hawai`i increased. Since the middle of the 19th century, this has included deliberate introduction of several large wild ungulates (grazing animals). The native flora, which developed in the absence of large land mammals, is extremely vulnerable to browsing, trampling, and bark stripping by ungulates, and the effects of these introduced species has been severe. Some domesticated ungulates have been in Hawai`i for hundreds of years, but wild species that have never been domesticated are now rapidly increasing in range and numbers. Wild ungulates behave differently and are much more elusive and difficult to manage than livestock species that were once domesticated and have become feral. Thus, Hawai`i's plants are facing a relatively new threat. Controlling these wild ungulates has become a major conservation concern.

Introduced Wild Sheep and Deer in Hawai`i

European mouflon (*Ovis gmelini musimon*), closely related to the ancestors of domestic sheep (*O. aries*), are wild sheep that originated from Asia Minor. Mouflon were subsequently introduced to many areas of the world, including Hawai`i. On islands lacking native ungulates, populations of introduced mouflon have grown rapidly and severely damaged native flora.

Introduced into the Hawaiian Islands beginning in the 1950s, mouflon currently occur wild on Lāna`i and the Island of Hawai`i. On Hawai`i, mouflon and feral sheep were crossbred and released on the large shield volcano Mauna Kea beginning in 1962. A large hybrid population now surrounds Mauna Kea and extends to the northern part of the volcano Mauna Loa. In 1968 a population of wild-type mouflon was introduced to the Kahuku Ranch (now a unit of Hawai`i Volcanoes National Park) on Mauna Loa for trophy hunting. These animals now range over the southern part of Mauna Loa in the Kahuku area and adjacent public and private lands. Both herds have dramatically expanded their range into forest reserves, where they are destroying endangered native plants such as silverswords (*Argyroxiphium* spp.).

Axis deer (*Axis axis*), otherwise known as chital, originate from India, Sri Lanka, and Nepal.



They have been introduced to many parts of the United States (including California, Texas, and Hawai'i) and to Australia. Axis deer were brought to the Hawaiian Islands from India in late 1867 as a gift to King Kamehameha V and released on Moloka'i in 1868. Some were moved to O'ahu before 1898 and some to Lāna'i in 1920. Axis deer were also released on Maui in 1959. Although axis deer have been wild on Lāna'i and Moloka'i for many decades, the more recently introduced Maui population has rapidly increased

in numbers, threatening native forests in natural areas. The O'ahu population was reduced to a remnant herd in Moanalua Valley by 1962 and eventually died out. Although introducing axis deer to the Island of Hawai'i was debated for many years, it was never undertaken.

Axis deer in the Hawaiian Islands damage agricultural crops and native and ornamental vegetation through browse and bark stripping, cause erosion, are frequently hit by vehicles, and may carry diseases that can infect humans. As a

consequence of their evolutionary history with large predators, many ungulates have very high reproductive rates, causing rapid population growth in Hawai'i, where there are no predators.

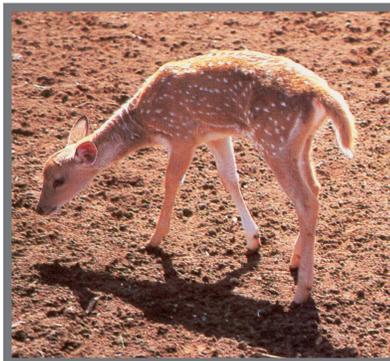
The Columbian black-tailed deer (*Odocoileus hemionus columbianus*) is a subspecies of mule deer from the northwestern United States. In 1961, 35 animals were introduced from Oregon to Pu'u ka Pele Game Management Area on Kaua'i. This herd has grown to a population of more than 700 on both sides of Waimea Canyon, including Kōke'e State Park.

American pronghorn antelope (*Antilocapra americana*) were brought to Lāna'i in 1959 from Montana. After an initial population increase to 250 animals in 1966, pronghorn declined to fewer than 12 by 1983 and apparently now no longer exist on Lāna'i. Pronghorn represent one of the few introductions of a wild ungulate to Hawai'i that failed entirely.

Impact on Hawaiian Flora and Fauna

Since 1778, nine percent of the native Hawaiian flora has gone extinct, in good part as a result of the introduction of non-native species. In addition, where non-native herbivores (plant-eating animals) have been introduced, in Hawai'i and elsewhere worldwide, there is usually also an increase in the relative abundance of invasive plants from their native range, which then often outcompete local species. The wild

Axis deer (fawn)



Columbian black-tailed deer



Two species of wild deer have been introduced into Hawai'i, axis deer and Columbian black-tailed deer. In their native range, many axis deer fawns fall victim to predators; with no predators in Hawai'i, the deer's numbers can increase rapidly. Photographs courtesy of Charles van Riper III.

ungulates discussed here have caused tremendous damage to Hawai'i's native flora. On Mauna Kea, the habitat degradation in the māmane-naio forest, which the endangered Hawaiian finch, Palila (*Loxioides bailleui*) rely on, resulted in two court orders to eradicate both pure and hybrid mouflon, along with feral domestic sheep and goats. Nearly two decades of intensive population control were required for habitat conditions to improve on Mauna Kea. The Mauna Kea silversword (*Argyroxiphium sandwicense*), an endangered plant, still suffer browse damage when even small numbers of hybrid mouflon are present.

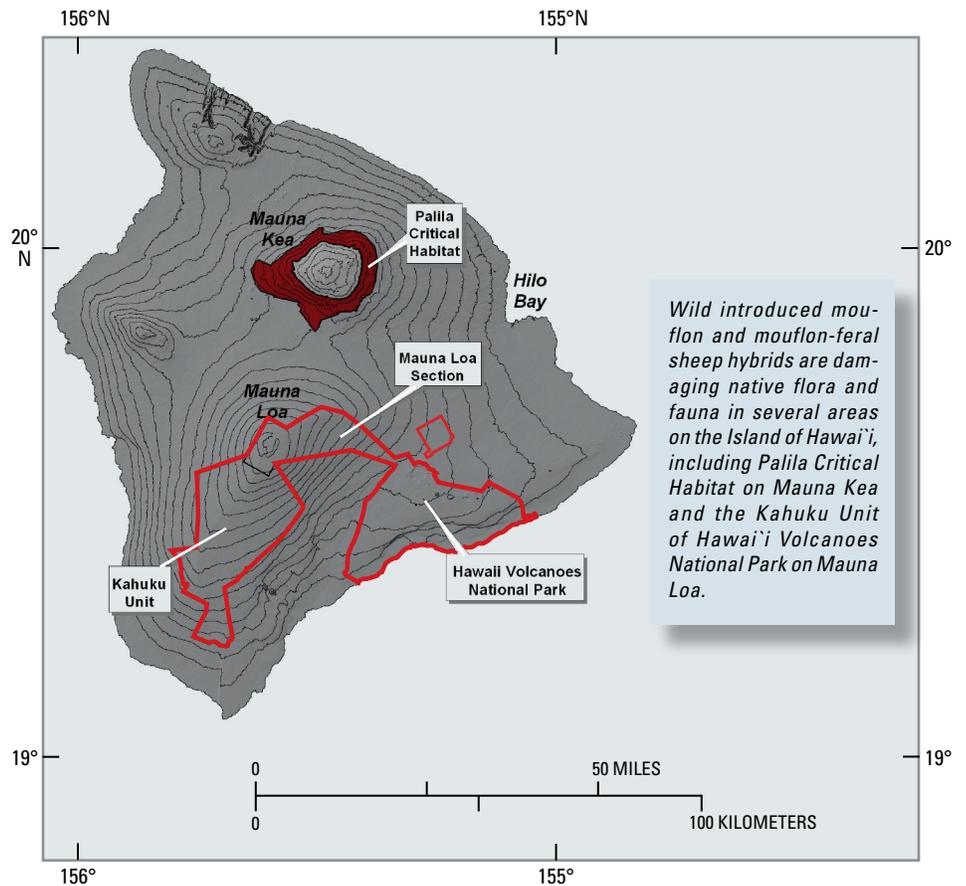
Where mouflon have occasionally invaded fenced areas in the Mauna Loa strip of Hawai'i Volcanoes National Park, they have destroyed outplanted Ka'ū silverswords (*A. kauense*)—another endangered plant, damaged the threatened Hawaiian catchfly (*Silene hawaiiensis*), and stripped bark from important forest trees, such as koa (*Acacia koa*) and māmane (*Sophora chrysophylla*). A large and growing population of mouflon continues to threaten and degrade endangered plants such as the Ka'ū silversword and the habitats of endangered forest birds throughout Mauna Loa.

Axis and Columbian black-tailed deer cause similar environmental damage. They consume progressively less palatable plants until no edible vegetation is available. Under extreme drought conditions, axis deer will eat bark from trees. In addition to stripping bark, bucks also rub their antlers on tree trunks and branches. This can effectively girdle the tree and result in the death of mature trees. Deer have their highest concentrations in the fragile, seasonally wet areas below the cloud forests. Here, they create trails and pathways through thick vegetation and cause erosion through hoof action. In wet forest areas, the trails increase runoff through soil compaction and by decreasing the mossy layer available to retain water. These trails also damage cultural and archaeological resources. The interaction of browsing and soil compaction by feral pigs, goats, and axis deer on east Moloka'i has reduced the 'ōhi'a-hapu'u rainforest to a grassy scrubland, and runoff of silt from this degraded habitat threatens the coral reef ecosystem on the southern coast.

Without fences, deer will increase and invade new areas, particularly on Maui and Kaua'i. Axis deer have been observed to jump fences 8 feet (2.6 m) tall. Building fences high enough to totally exclude deer is expensive and difficult. Therefore, supplementary control efforts are often needed within areas enclosed by lower fences. Axis deer are also damaging existing fences throughout the western slopes of Haleakalā on Maui presenting a major concern to natural resource managers.

Biology and Spread of Wild Ungulates

In the five decades since their first introduction to the Hawaiian Islands, mouflon have become locally abundant, as they have on other island groups. In the Kahuku Unit of Hawai'i Volcanoes National Park on the



island of Hawai'i, a founding population of 11 individuals has increased to more than 2,500 in 36 years, even while under substantial hunting pressure for trophies. Mouflon are polygamous, and their populations can grow rapidly when the ratio of females to males is high. An abundance of high-quality food can also lead to a lower age of first pregnancy and higher lamb survival, further increasing population growth.

Axis deer have high reproductive rates, which compensate for predation by leopards, tigers, and Indian wild dogs in their native range. In the absence of predators, as in Hawai'i, introduced populations exhibit annual population growth rates of 20–30%. On Lāna'i and Moloka'i, some females reach sexual maturity by 4–6 months of age, and most do so by the end of their first year. In years when forage conditions are good, more than 90% of mature females produce fawns.

Axis deer graze and drink water in open areas during the twilight of morning and evening and rest in cover during the warmest part of the day. They are usually found in small family groups of 15–24, and harems are uncommon. However, herds of nearly 100 animals are reported on Lāna'i and Moloka'i, and a herd as large as 300 was recently reported on Maui ranch pasturelands. Although axis deer are rarely found above 1,160 m (3,800 ft) elevation in their native range in Nepal, they have been observed above 2,150 m (7,050 ft) on Maui. They are present from sea level to the highest point on Lāna'i (1,030 m; 3,380 ft), and they exist throughout all but the most remote areas of Moloka'i.

In the native range of Columbian black-tailed deer, mountain lions and other predators account for as much as 40% of fawn mortality. In Hawai'i the deer suffer no predation other than human hunting.

Unlike feral sheep, goats, and pigs, which were domesticated before their arrival in Hawai'i, mouflon and deer were never domesticated. These wild ungulates present new challenges to control efforts in Hawai'i. They are able to jump over most fences designed for feral animals, and when being pursued, they disperse into small groups and hide in dense cover. Social behaviors also differ. Mouflon segregate by sexes and only form large groups when breeding, thus limiting efficient hunting periods. Because they disperse widely over the landscape alone or in small groups, common control techniques that rely on radiotelemetry are largely ineffective for mouflon.

The hybrid mouflon-feral sheep of Mauna Kea are larger than wild-type mouflon and have a wider variety of coat colors. Managers are concerned that under intense hunting pressure or control efforts, the variation in coat coloration may lead to selection for cryptic colors that blend with the environment. These superior physical traits of size and color variation are examples of hybrid vigor. Although feral sheep and goats have been effectively eliminated from Mauna Kea, hybrid mouflon continue to expand their range and have invaded other natural areas, including Hawai'i Volcanoes National Park, despite the presence of fences designed for feral animals.



A flowering Mauna Kea silver-sword (foreground) has been trampled and browsed by wild mouflon or mouflon-feral sheep hybrids. Behind it stands a surviving silver-sword. The active volcano Mauna Loa dominates the horizon.

develop and implement monitoring protocols that will allow managers to understand the effectiveness of different strategies.

The work of scientists in studying the wild ungulates of Hawai'i is part of the U.S. Geological Survey's efforts to understand and help preserve threatened ecosystems. If effective control measures for these wild ungulates are not implemented, it may be difficult if not impossible to prevent them from expanding their ranges and numbers in Hawai'i. This in turn would make it far more difficult to protect Hawai'i's vulnerable endemic flora.

Further Reading

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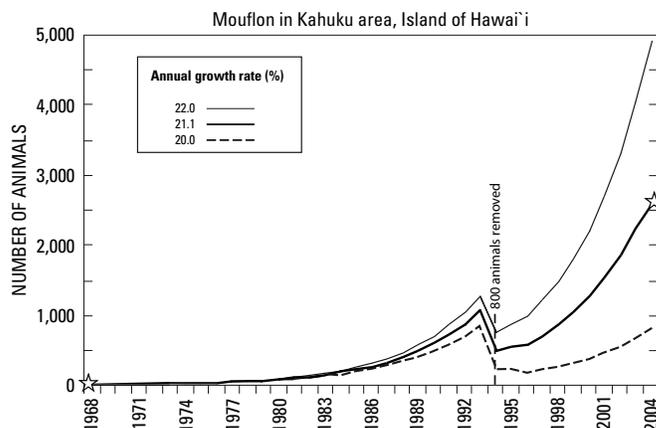
Control and Management of Wild Ungulates

The conservation of rare and endangered species in Hawai'i often includes the construction of enclosures that protect only a few individuals within a small area. If rare plants are relegated to such small areas, there is little hope of guarding their long-term survival—plants cannot effectively disperse and adapt to environmental changes under these conditions. If, however, wild herbivores are controlled over large areas, natural population processes and local adaptation can occur, as well as recovery for entire native plant communities. To ensure long-term survival of native plants, effective fence designs and management strategies are needed to exclude wild ungulates from protected natural areas in Hawai'i.

Managing wild ungulates for sustained-yield public hunting is problematic, because they are extremely difficult to census, hunt, contain, and control in the remote and rugged terrain of

Hawai'i. These ungulates do not stay on public land, and in many areas, limited land access precludes hunting. Previous efforts at eradication have not generally been successful, because of the evasive behavior of the animals. More effective hunting programs and control techniques are needed for wild ungulates in Hawai'i. Unsupervised public hunting has generally been ineffective for controlling ungulates in Hawai'i. Although a closely directed hunting program has reduced mouflon abundance in the Kahuku area, it has also resulted in increased reproduction, which could slow future control efforts. This is because trophy hunting, which focuses on males with impressive horns, can shift the sex ratio of populations and contribute to higher population growth. If control efforts are directed at females, however, growth rates could be reduced.

Population monitoring is critical for understanding management actions, growth rate trends, and range expansion. It is also important to develop effective strategies to reduce the expense and effort of control programs and to



The mouflon population in the Kahuku area of Mauna Loa doubled every 3-4 years from its initial introduction of 8 animals in 1968 to an estimated 2,586 in 2004. An assumed annual rate of increase of 21.1 percent (the bold black line) best accounts for the known abundance at those two points in time (stars) and the removal of about 800 individuals in 1994.

Steven C. Hess

Edited by
Peter H. Stauffer

Graphic design by
Stephen L. Scott

COOPERATING ORGANIZATIONS
Haleakala Forest National Wildlife Refuge
Hawai'i Volcanoes National Park

For more information contact:
Steven C. Hess
(808) 967-7396 x286
U.S. Geological Survey
Pacific Island Ecosystems Research Center
Kilauea Field Station
P.O. Box 44
Hawaii National Park, HI 96718
Email: shess@usgs.gov
<http://biology.usgs.gov/pierc/>

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