Eradication of feral goats (*Capra hircus*) from Makua Military Reservation, Oahu, Hawaii

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Abstract Feral goats (*Capra hircus*) were a significant threat to the native habitat and endangered biota unique to the Makua Military Reservation (MMR) on the island of Oahu, Hawaii. The Oahu Army Natural Resource Programme (OANRP) was tasked with the removal of these animals. From December 1995 through February 1997, ground hunts were undertaken by contract hunters from the U. S. Department of Agriculture Wildlife Services while plans for a fence to enclose the 1695 ha MMR were finalised. In 1996-1997, the first stretch of fencing separating MMR from a public hunting area was completed along with fencing around the eastern perimeter of the valley. Contract and staff hunts continued along with snares until the last portion of the fence was finished in 2000. OANRP staff then employed other techniques to complete the eradication, including Judas goats and aerial hunting. When the last goat was eradicated in July 2004, a total of 1565 goats had been destroyed using a combination of techniques.

Keywords: Military training areas, fencing, Judas goats, snares, aerial hunting

INTRODUCTION

Threats to the integrity of native ecosystems from feral ungulates, such as goats (*Capra hircus*) and pigs (*Sus scrofa*), have long been recognised in Hawaii and other islands (Spatz and Mueller-Dumbois 1975; Vitousek 1988; Atkinson 1989; Cuddihy and Stone 1990; Desender *et al*. 1999). These animals can radically alter entire native habitats, as well as jeopardising the component species. They browse on almost any type of vegetation, including native grasses, shrubs and small trees, as well as the seedlings of any life form, which can lead to overgrazing and result in primary and secondary impacts to ecosystems (Campbell and Donlan 2005). These impacts lead to the loss of native biodiversity, the degradation of native ecosystems, acceleration of soil erosion and the colonisation by herbivore resistant non-indigenous weeds. Ground-level ferns, herbs, saplings and shrubs are the plants most susceptible to ungulate damage (Sakai *et al*. 2002). Goats have a very efficient digestive system, a low metabolic rate, and can tolerate very arid environments, which allows them to thrive in habitats unsuitable for many other animals (Silanikove 2000). Goats can be found in extremely steep, rugged terrain, a matter of particular concern because many rare and endangered plants are now restricted to these otherwise inaccessible areas. The native flora and fauna of Hawaii evolved in the absence of large herbivorous mammals. As a consequence, the endemic flora appears to have lost natural defences against herbivory (e.g., Vitousek 1988; Atkinson 1989; Primack 1993; Paulay 1994). Results from Bowen and Van Vuren (1997) support this hypothesis and corroborate the belief that human introduced herbivores are a major contributor to island extinctions. Thus feral ungulate management is one of the primary priorities for any restoration project in Hawaii.

The O'ahu Army Natural Resource Programme (OANRP) is responsible for managing 50 species of endangered plants, eight of species endangered animals, and the ecosystems upon which they depend in U. S. Army training areas on O`ahu. The legal requirement driving the Army's ecosystem management programme is the Endangered Species Act (ESA) Sections 7(a)(1) and 7(a)(2). These sections of the ESA require that Federal agencies use their authority to conserve federally listed species, and ensure that their activities are not likely to jeopardise the continued existence of any federally listed species.

This paper documents how we conducted an eradication programme in a "mainland island" formed by the U. S. Army's Makua Military Reservation (MMR) on the island of O'ahu in Hawaii, USA.

STUDY AREA

MMR is 1695 ha and is the US Army's largest manoeuvre/live-fire training area on O'ahu, Hawaii (Fig. 1). It encompasses two gulches, Kahanahāiki and Mākua, which are the northernmost major valleys on the leeward side of the Wai'anae Mountains (Fig. 2). The terrain at MMR varies from a gradual to moderate valley bottom and sides that increase in steepness with elevation, becoming extremely steep, exposed, and rocky above about 360 m. Elevations range from sea level to approximately 1000 m. While most of the natural habitats within MMR are highly disturbed with large expanses of alien grassland in the lowlands, there are large pockets of primarily native dry

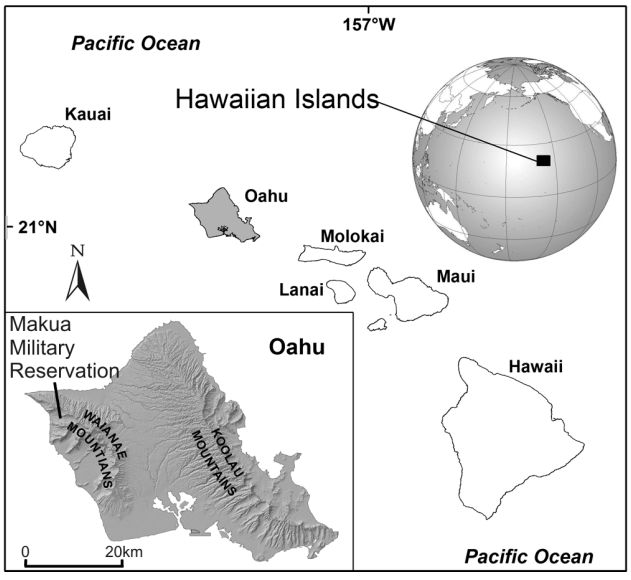

Fig. 1 The Hawaiian Islands and the Makua Military Reservation on O'ahu.

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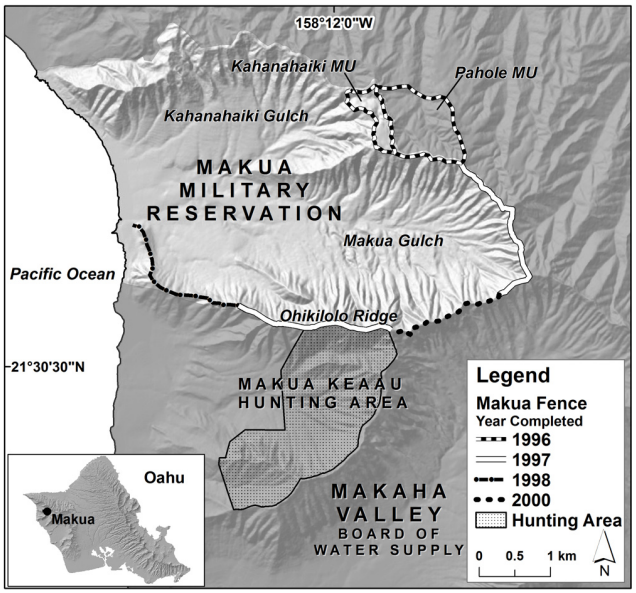

Fig. 2 Fences constructed by year at Makua Military Reservation (MMR).

and mesic forest dominated by *Diospyros sandwicensis*, *Diospyros hillebrandii*, and *Metrosideros polymorpha*. There are also large expanses of native dry cliff vegetation, ridge-tops with mesic native shrub land and forest, including areas dominated by *Dodonaea viscosa* and *Metrosideros tremuloides*. There is one rare natural community, the *Pritchardia kaalae* lowland mesic forest.

The Mākua Kea'au public hunting area, Mākaha Valley and ʻŌhikilolo ranch are adjacent to the southern border of MMR (Fig. 2). These areas contain large numbers of goats as there is little population control. Without a barrier to prevent ingress, feral goats would migrate over the long southern ridge of MMR (ʻŌhikilolo). Due to military training and unexploded ordnance (UXO) public hunting is not allowed in MMR. Furthermore, other access to the area is restricted to times when there are no military activities.

METHODS

In order to eradicate all of the feral goats from MMR, we employed a multi-faceted approach throughout the campaign (Fig. 3). To eliminate ingress from the high density goat population to the south, a fence was constructed in five phases. The fencing was coupled with ground hunting, using a combination of contractors and staff. Three 500 m ungulate-sign, belt transects were installed to detect tracks and/or scat (goat sign) to monitor the success of the eradication effort. As fence construction came to an end and goat numbers decreased, three other control techniques were employed to increase the removal rates: snares, aerial hunting, and ground hunting using radio-collared Judas goats. The final phase of the eradication was confirmation of the absence of goats.

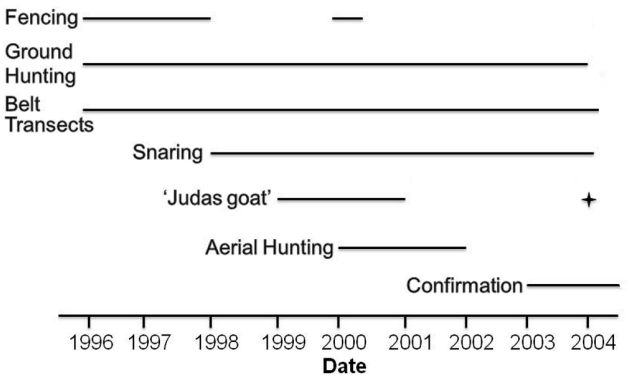

Fig. 3 Timelines of methods employed during goat eradication operations at Makua Military Reservation. The star denotes the time of the last "Judas goat" deployment.

Fence construction

Fencing materials used were: 1) 87 or 122 cm tall, graduated mesh pattern, galvanised, hinge lock woven wire fence; and 2) either an 87 or 132 cm × 4.88 m, 4 gauge, graduated mesh pattern, galvanised fence panels. Terrain dictated which type of fencing was used.

Ground hunting

Ground hunting with staff and contractors from the U.S. Department of Agriculture Wildlife Services (WS) began in December 1995 and continued through to July 2004. Hunting teams consisted of 2-4 groups of 2-3 people. Teams split up onto separate consecutive ridges spotting for each other. A variety of calibres (.308, .270, .223) and actions (bolt, lever, semi-auto) of firearms were used depending on the preference of the hunter. Ammunition ranged from 150-180 grain. All personnel wore blaze orange so they were visible from a distance and carried two-way VHF FM radios in order to communicate with each other and with the Army's Range Control at MMR.

Snaring

In 1998, customised multi-strand, aircraft quality steel cable snares were obtained from the Raymond Thompson Snare Co. (Lynwood, WA). They were placed along narrow trails with the noose suspended at 75-125 cm from the ground. The size of the suspended nooses ranged from 25-40 cm diam. In order to asphyxiate the animals quickly, all snares were placed in steep areas so that footing would be lost and unable to be regained.

Aerial hunting

Aerial shooting operations were conducted from 2000-2002 using a Hughes 500D helicopter with one shooter aided by spotters on the ground. Pilots and shooters were experienced and certified by the U.S. Department of Agriculture for this type of operation. The shooter used a Benelli semi-automatic 12 gauge shotgun with 00 buck shot.

Judas goats

In 1999, we attempted to use "Judas goats" (Taylor and Katahira 1988) to track goat movements and locations and determine herd associations in MMR. Four goats were fitted with Telonics (Mesa, AZ) VHF MOD500 transmitters that emitted a unique radio signal. Transmitters could be tracked from the ground or air using a Telonics TR2 telemetry receiver with a Telonics RA-2AK (Yagi-Uda) "H-Type" 2-element antenna. The first two goats released were domestic animals purchased from a local ranch (1 female and 1 immature male) and with a white coat to facilitate later sightings. The other two goats (immature males) were live captured in MMR using modified snares.

In 2004, we contracted WS to capture goats in Kea'au using a net-gun from a helicopter. Two animals were captured; one was fitted with a Telonics VHF MOD500 transmitter and the other with a satellite GPS receiver. Both goats were then released.

Transects

We used three belt transects to monitor changes in feral goat sign over time. Transects were 500 m long × 5 m wide. Monitoring stations were tagged and labelled every 10 m along each transect. Observers recorded all ungulate sign, including feeding, scat, and trails for goats within each of the 10 × 5 m transect sections. Only presence/absence data was taken and no measures of the overall density were measured within the plots.

RESULTS

Fence construction

Fence construction at MMR began in 1996 with the work done by the Hawaii Natural Area Reserves System staff, remote fencing service providers from Hawaii Volcanoes National Park, and John Hinton and Southwest Fence and Supply Co. Inc. The fence followed the upper reaches of Kahanahāiki and Pahole gulches, which enclosed a 2 km portion of the northeast rim. In 1997, the fence was extended along the northeast rim and about 500m down ʻŌhikilolo. This was built in conjunction with the initial 2 km of fence on ʻŌhikilolo, which headed seaward from the highest point. In 1998, the seaward section of the fence on ʻŌhikilolo was completed. The fencing material for all of these sections was 122 cm tall, graduated mesh pattern, galvanised, hinge lock woven wire fence. In 2000, the final and most treacherous portion of the fence was completed to close the gap along ʻŌhikilolo ridge. We used 132 × 490 cm, 4 gauge, galvanised fence panels for this section because of the rugged terrain. These rigid panels are portable and can be cut and manipulated to fit the landscape. In total, 12 km of fencing was erected around MMR. This completely isolated the goat population in MMR from the adjacent populations to the south but did not encompass the entire valley as there are no populations of goats to the north (Fig. 2).

Ground hunting

When military training commenced, access for hunting was forbidden. In 1997, MMR was used quite extensively by the military for training purposes. A series of range fires closed MMR to training from 1998-present, which enabled the eradication campaign to be completed. Some areas were also of limited access or off-limits due to UXO. All ground hunts were escorted by an UXO technician to identify potential hazards. Staff were also required to wear Kevlar flak jackets and helmets as a precaution.

A total of 560 hunter days (4478 hunter hours) were required for 1232 goats removed by hunters. For simplicity, the very small number of animals and hours from December 1995 were combined with the total for 1996. From 1996-1999, ground hunting removed a large percentage of the animals in MMR (Fig. 4). An average of 2.2 staff hours/goat removed was observed during this period. From 2000-2004, more time was spent searching and the effort required per kill increased twenty-fold to an average of 44.8 staff hours/goat removed.

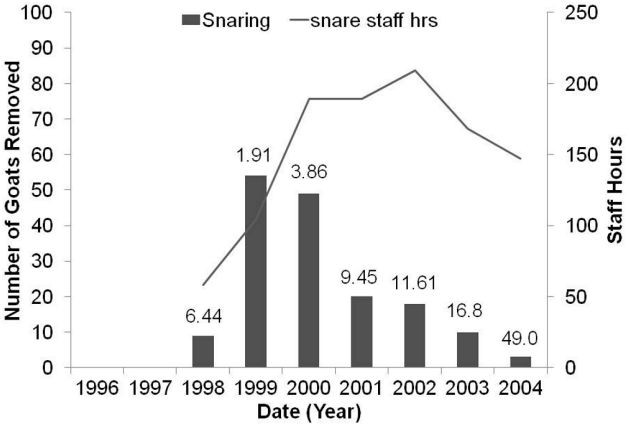

Fig. 5 Total number of goats removed (bars) and snaring effort of staff (line) by year during the MMR eradication campaign. The numbers above each bar represent the average number of staff hours expended per goat each year.

Snaring

Snares were set in 17 clusters of 20-40 snares apiece throughout the head of the valley. After the initial set, snares were checked on subsequent trips for catches and condition, then reset or removed as needed. New snare clusters were installed when animals were seen moving into new areas. In total, 336 snares were set logging about 559,440 snare hours. The total effort required 1064 staff hours and removed 163 goats (Fig. 5). From 1998-1999, snaring required an average of 4.2 staff hours/goat removed. As goat numbers decreased, more effort was required to increase the number and location of snares so the mean increased to 18.1 staff hours/goat removed.

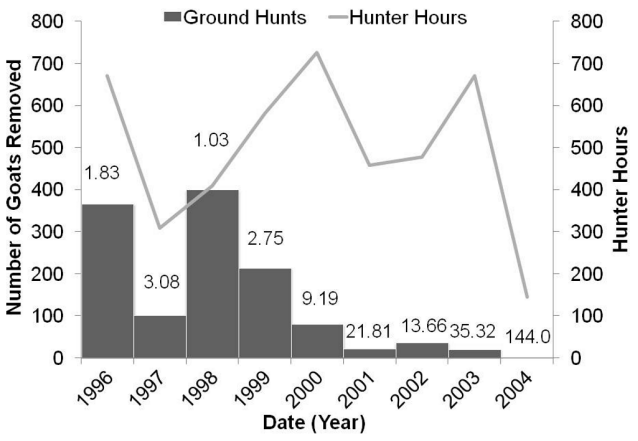

Fig. 4 Total number of goats removed (bars) and ground hunting effort (line) by year during the MMR eradication campaign. The numbers above each bar represent the average number of staff hours expended per goat each year.

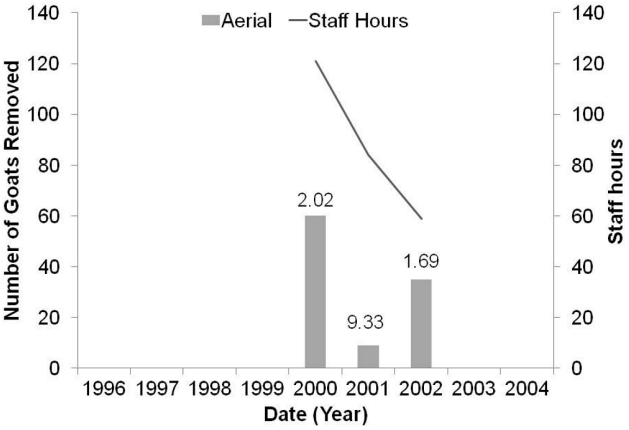

Fig. 6 Total number of goats removed (bars) and aerial hunting effort (line) by year during the MMR eradication campaign. The numbers above each bar represent the average number of staff hours expended per goat removed each year.

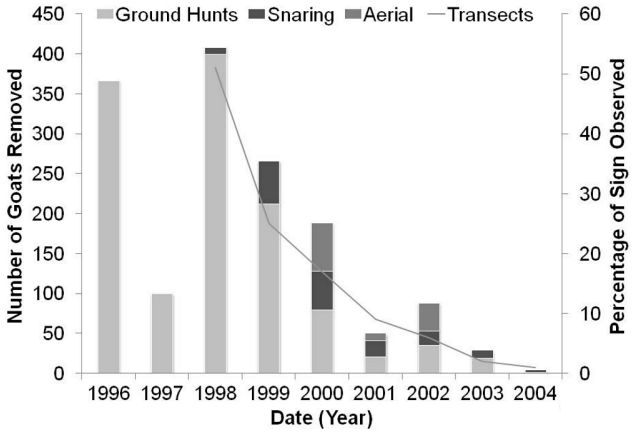

Fig. 7 Total number of goats removed with all removal methods used combined by year. The line represents the progression of the goat eradication over time, which was a measure of the percentage of sign observed along transects.

Aerial hunting

The effort required for this part of the operation was 2.0 staff hours/goat in 2000 (Fig. 6) because up to nine spotters were used each time, many of which were flown into position. As goats became shy of the helicopters, the effort required increased to 9.3 staff hours/goat in 2001, even though we decreased the number of spotters in the field. In 2002, we expanded the aerial hunts to the north side of Mākua Gulch after goat herds were observed there and further decreased the amount of spotters in the field. This decreased the amount of effort required to 1.7 staff hours/goat removed. The mean effort required for all three years was 4.4 staff hours/goat removed. We combined UXO technician escort, shooter, and spotter hours for this total. Overall progress of the eradication campaign was indicated from sign along the transects (Fig. 7).

Judas goats

The 1999 deployment of Judas goats was unsuccessful. The two white domesticated goats did not move from their drop point for almost two years until one jumped over the fence into Kea‘au and the other herded up with a nanny and kid. These three were subsequently shot. However, the wild-caught Judas goats immediately united with others and we were able to track them down to eliminate their associates. After this, we found it very difficult to locate either animal easily as they strayed from the original snare spot. We were able to approximate their location but due to difficult terrain and access, visual verification was impractical.

The 2004 deployment was unsuccessful as well. The radio collared individual was able to escape back over the fence into Kea‘au and the satellite collared one was snared soon after release. It was not unexpected for animals to leave MMR as the fence was constructed with high spots on the inside to allow escapes. High points were strictly avoided on the outside making the fence permeable in one direction.

DISCUSSION

In any eradication campaign, immigration must be eliminated. In our case, ~8 km of fencing was needed to create a “mainland island”. The fence took four years to complete with the last section in very rugged country where safety lines and rappelling were necessary during construction. Once immigration by goats ceased, most of the animals were eliminated before the fence was completed. Constant upkeep of the fence is necessary, so we conduct quarterly inspections. The environment in MMR is very harsh with constant salt spray, high/gusty winds with a dusty/gritty substrate, solar radiation and occasional fires. All of these environmental factors have taken their toll on the integrity of the fence, especially the seaward sections.

In 1998, we experimented with snares as control option in conjunction with ground hunting. Although they are controversial because of concerns over animal welfare, snares are cost effective and efficient for feral pig control (Anderson and Stone 1993; Hess *et al*. 2006). They are small, light weight, and simple to erect, making it easy to set out a large number in a short period of time over multiple areas. Unlike any of the other management tools used on this campaign, snares work 24 hr/day seven days/week. The designation of MMR as off limits for hunting allowed for the extensive use of snares, which effectively removed goats after their populations were reduced by ground hunting. The first snares were installed in December 1998 and numbers were increased in 1999, when ground hunts were still quite effective. The percentage of goats snared was only 2% in 1998 and 20% in 1999. By 2000, ground hunts were becoming less effective so the percentage of goats snared gradually increased from 26% in 2000 to 75% in 2004. The mean percentage of goats removed from 2000-2004 was 43% for both ground hunting and snaring but the effort (staff hours/goat) was over half for snaring (18.2/44.8).

Aerial hunting was also effective method of removal, particularly since it allowed shooters access to goats in areas that were inaccessible to the ground based hunting and snaring. The helicopter was also able to cover the entire range in a couple of hours. The mean percentage for animals removed via aerial hunting was 30% from 2000-2002, while the mean effort required was only 4.4 staff hours/goat. This method was quite effective when compared to ground hunting (42% at 14.9 staff hours/goat) and snaring (29% at 14.9 staff hours/goat) during this same time frame.

In contrast, ground based radio-tracking of “Judas goats” (Taylor and Katahira 1988; Rainbolt and Coblentz 1999; Campbell 2002) in MMR was problematic. There appeared to be association issues between goats that were purchased or captured offsite and the goats already present. These same association issues have been observed in other eradication campaigns such as Sarigan Island in the Northern Mariana Islands; Desecheo Island, Puerto Rico; Tasmania; and West coast of south island, NZ (Howell and Atkinson 1994; Kessler 2002; Karl Campbell pers. comm.). The steepness and rocky terrain appeared to cause the radio signal to create an echo, simulating a false location. The simultaneous use of snares had a direct impact on the survival of at least one collared goat. WS shooters or trackers were unable to utilise the “Judas goats” in any of their aerial or ground based operations to verify these issues. It would have been preferable to test this method from the air to see if the applicability would have been worth the cost.

Prior to the completion of the seaward section of fence in 1998, an unsuccessful goat drive was attempted using a helicopter piloted by an experienced pilot/rancher. The Wai’anae community expressed their concerns about the eradication techniques and wanted to explore another “non-lethal” option. No animals were removed using this technique but it likely educated goats to the helicopter as a threat.

We found that flexibility of multiple eradication methods was a key to the eradication of goats from MMR. As the effectiveness of one method diminished other methods were employed in order to prevent the population from learning to avoid specific techniques. When multiple management methods were combined, goat removal rates were higher than if only one method was employed. Selecting the timing of the eradication methods employed is always challenging. Other successful eradication campaigns found that ground hunting followed by aerial hunting was successful (Rainbolt and Coblentz 1999; Kessler 2002; Campbell *et al*. 2004; Campbell and Donlan 2005; Cruz *et al*. 2009). In our campaign, this same progression of methods worked well. The addition of snaring increased the effectiveness of the eradication campaign at a crucial time when goat numbers were low and "Judas goats" were found to be ineffective. Without the use of snares, it is likely that the eradication campaign would have required a longer period of time.

ACKNOWLEDGEMENTS

We would like to thank the Army Garrison Hawaii for their continued financial support of these efforts. This work was supported under a cooperative agreement between the Pacific International Center for High Technology Research and the U.S. Army. We greatly appreciate the hard work that the crew from the U.S. Department of Agriculture put into this project (Bernard R. Daite, Michael Imada, Homer Leong, Jim Murphy, Terrence Noda, Tim Ohashi, M. K. Solomon Ono, Darin Phelps, Steven Tanaka, Bryan Tom, Charles K. T. Tom, Akio Bert Ushijima, and all of their volunteers). We want to thank the staff, interns, and volunteers at OANRP for all the dedicated assistance to complete this campaign (Naomi Arcand, Nick Argostas, Jane Beachy, Seth Cato, Susan Ching, Geoff Cloward, Pat Conant, Vince Costello, Anay Ego, Julia Gustine, Daniel Forman, Springer Fryberg, Kapua Kawelo, Matthew Keir, Trae Menard, Reuben Mateo, Leanne Obra, Dave Palumbo, Kost Pankiwski, Hector Perez, Dave Preston, Leanne Punua, Matt Ramsey, Joby Rohrer, Robert Romualdo, Lasha Salbosa, Jen Saufler, Dominic Souza, Brian Stevens, Dan Tanji, Talbert Takahama, Daniel Toibero, William Weaver, Micah White, Kaleo Wong, Charlotte Yamane, Nalu Yen, and the students from the Waianae High School Hawaiian Studies Programme). We would also like to thank the editors of this manuscript for the helpful insights (Dr. James Jacobi, Kapua Kawelo, Michelle Mansker, Joby Rohrer, Dr. Cliff Smith and Dr. Eric VanderWerf). We would like to express a final thank you to Krista Winger for her exceptional work on the maps for this manuscript.

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