INDIGENOUS KNOWLEDGE AND FACTORS INFLUENCING DETECTABILITY OF PUEO (HAWAIIAN SHORT-EARED OWL, *ASIO FLAMMEUS SANDWICHENSIS*)

A THESIS SUBMITTED TO THE GRADUATE DIVISION OF THE UNIVERSITY OF HAWAIʻI AT MĀNOA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN NATURAL RESOURCES AND ENVIRONMENTAL MANAGEMENT

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ABSTRACT

Apex predators such as raptors play important roles in ecosystem regulation. In addition to these important roles and the charismatic nature of apex predators, apex predators often have a mirrored cultural significance for Indigenous Peoples. When their symbolic and spiritual value is so great that it affects that culture's relationship and adaptation to the environment, they are considered Cultural Keystone Species (CKS). In addition to supporting ecosystem complexity, these species support cultural complexity regarding social identity, cultural practices, and beliefs. Pueo are the only remaining native raptor that breed across the Hawaiian archipelago, and as such play key ecological and cultural roles. In this thesis research I aimed to: (1) highlight the breadth of Indigenous Knowledge of Pueo documented in Hawaiian language newspapers and (2) identify factors influencing Pueo detectability on Hawaiʻi Island. Pueo have relationships with multiple akua (elemental forces) who play vital roles in ecosystem functionality and nutrient cycling, and have relationships with 35 species across articles, indicating our kūpuna (ancestors) understood the system stability that Pueo supported, and the functionality of the pilina (relationship) that Kānaka (Native Hawaiians) have with Pueo. Results from field surveys demonstrate that Pueo utilize every available terrestrial habitat type in Hawaiʻi, but their occupancy and detection probability are constrained by elevation and temperature respectively. On Hawaiʻi island, where Pueo co-occur with ʻIo (*Buteo solitarius*), we observed a potential temporal shift in their behavior. Together, the results of these chapters support the notion that Pueo are a Cultural Keystone Species and a generalist apex predator with critical cultural and ecological functions.

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LIST OF HAWAIIAN TERMS

Ae‘o	Hawaiian Stilt (*Himantopus mexicanus knudseni*)
‘aho pueo	main beams or purlins of a house
‘aihue	thief
akamai	intelligent
akua	gods, deities, elemental forces
akua kumupa‘a	ancient family god; foundational deity
‘Alae ‘Ula	Hawaiian Gallinule or moorhen, *Gallinula galeata sandvicensis*
alaka‘i	leader, to lead
‘Alalā	Hawaiian Crow; *Corvus hawaiiensis*
ali‘i	chiefs
ānuenue	full rainbow
‘Apapane	*Himatione sanguinea*
‘aumakua	ancestral guardians, deified ancestors
‘aumākua	plural of ‘aumakua
‘awa	*Piper methysticum*
haili	spirit, ghost
hānau	born, to birth
Haumea	primary female akua associated with earth, fertilizer, reproduction, and all things that grow (Kanahele 2011)
hāwanawana	whisper, silent
heiau	temple, place of worship, sacred sites
hekili	thunder
hīhīmanu	spotted eagle ray, *Aetobatus narinari*
hihi‘o	dreams or visions

Hi‘iakaikapoliopele	daughter of Haumea and Moemoea‘ali‘i; Pele’s favorite sister, travels to Kaua‘i to fetch Pele’s love Lohi‘au.
Hina	female akua associated with the moon, who pulls water like a magnet causing ebb and flow (Nu‘uhiwa 2022)
Hoaka	second (waxing) phase of the Hawaiian lunar month; a crescent or arch; to cast a shadow; ghost or apparition
hō‘ailona	omen or sign
ho‘ānoano	sacred
ho‘okalakupua	magician, enchanter, sorcerer, shapeshifter
ho‘okolo	consult
ho‘omana	Hawaiian spiritual practice that creates a reciprocal relationship between the object of worship and the practitioner whereby energy is reciprocated, ensuring the health of both akua and kānaka
hula	traditional Hawaiian dance accompanied by oli (chanting)
‘ie‘ie	*Freycinetia arborea*
‘I‘iwi	Scarlet Honeycreeper; *Drepanis coccinea*
ikaika	strong
‘ike	knowledge
‘ike ku‘una	Indigenous Knowledge (IK)
‘Io	Hawaiian Hawk, *Buteo solitarius*
‘iole	Pacific rat (*Rattus exulans*)
‘Iwa	Great Frigatebird (*Fregata minor*)
iwilei	length from collarbone to fingertip
kāhili	feather standards
ka‘ao	legends
kāhuli	Hawaiian land snails
kāhako	macron; elongates a vowel
kahiko	ancient

kahu	caretaker, keeper
kākūʻai	deification, ritualistic feeding of a dead loved one's corpse to become an ʻaumakua
kalo	taro (*Colocasia esculenta*); main staple food that is also considered the older sibling of kānaka
Kamapuaʻa	pig deity; kupua who can change form between a pig and a handsome man. Son of Hina.
kanaka	person
kānaka	people
Kānaka ʻŌiwi	Native Hawaiian people with genealogical descent from original inhabitants of Hawaiʻi, all our more-than-human relatives, and ultimately the cosmos
Kanaloa	ocean akua, related to foundational knowing, ancestral continuum and environmental balance (Nuʻuhiwa) and death
kānāwai	laws or edicts enacted to preserve kapu
Kāne	1. heat of the earth in the atmosphere, fresh water, evapotranspiration, and growth (Kanahele 2011, Kanahele 2021) 2. 27th moon phase during the dark waning phases of the moon 3. man
Kānehekili	akua of thunder and lighting; child of Haumea and Moemoeaʻaliʻi (Kanahele 2011)
Kānehoalani	the sun; Pelehonuamea's father (Kanahele 2011)
Kāneikapahuʻa	Kāne kinolau with the body of a Pueo who stands at the edge of the forest; syn. Kānekūpahuʻa
Kānemilohaʻi	child of Haumea and Moemoeaʻaliʻi; vertical movemement of magma (Kanahele 2011)
kani	voice, sound, song, call
kanikau	funeral dirges

kapa	tapa
Kapōʻulakinaʻu	famed sorcery goddess capable of giving or taking life, associated with deep thought and learning through dreams, resides in Keʻalohilani with Uli (Kanahele 2011)
kapu	level of sacredness
kaona	multiple layers of meaning
KawailoaikapolioLokoea	moʻo akua who is defeated by Niuloahiki, a coconut tree kupua
Keʻalohilani	heavenly abode of the akua, specifically Kapōʻulakinaʻu and Uli (Kanahele 2011); Pueo ascends here through Nuʻumealani highest strata of the heavens or sky
keʻu	to croak, hoot
kiaʻi	guardian
kinolau	physical manifestations, multiple forms
kīpuka	a net fastened between short sticks with a long, pointed stick that had a rat tied to it beneath the net called an ʻolokaʻa, which would pierce the stomach of the Pueo when the Pueo pounced on the rat or chicken tied to the ʻolokaʻa
koʻihonua	cosmogonic chants that recount the origins of the world
Kōlea	Pacific Golden Plover (*Pluvialis fulva*)
Kū	the akua that rules over growth, the sky and earth together, the works of man, and war (Kanahele 2021)
Kūkauakahi	akua kumupaʻa who people were offered to to become Pueo ʻaumakua. According to Beckwith, related to Kāne worship. Handy and Pukui (1998) state that he associated with "Kāne of the Pele clan". Son of Haumea and Kanaloa in the Kumulipo (Kalākau 1889), and of Wākea and Papa in another moʻokūʻauhau (Poepoe 1906)
kuku	to beat as kapa
kula	plains; dryland agroecology
kuleana	responsibility
kumu	teacher, source, tree

Kumulipo	one of many cosmogonic chants
kupanaha/kupaianaha	wonderful, amazing, strange
kupua	demi-gods, shapeshifters, supernatural beings capable of wondrous acts
kūpuna	ancestors, elders
lāʻau	plants, vegetation
lāhui	nation, people
Laka	hula deity associated with forest health and evapo-transpiration
lama	*Diospyros* spp.
lapuwale	vain, worthless, foolish
lele	to fly
liʻiliʻi	small
Lilinoe	akua of mist, fires, and desolation; daughter of Kāne and sister of Poliʻahu (Yuen 2016)
loʻi kalo	wetland taro agroecology
Lono	one of four principle male akua, associated with fertility, farming, and the clouds and rain of the four month long Makahiki season (Nuʻuhiwa 2018); to listen
Māhealani	third of four full moon phases; 16th night of the lunar month
māhele	to divide, land division and subsequent land claims
mahiʻai	farmer
makaʻāinana	common people, people in general, citizens
makani	wind
makāula	prophet, seer
malu	calm, serene
mana	energy, force, power
manō	shark

mānowai	heart and circulatory system, or figuratively the source of water and of life
manu	birds, flying creatures including bats and insects
mauna	mountain
mele	song
moa	chickens, junglefowl (*Gallus gallus domesticus*)
mōhai	offering, sacrifice
Mokuhinia	moʻo akua on Māui whose hair swaying in the wind was a sign of a Pueo above
moʻo	succession, lineage; reptile, lizard, serpent, water spirit; ridge; narrow path or strip of land; story, tradition
moʻo akua	reptilian water deities who inhabit freshwater and have the power to enchant people
moʻokūʻauhau	genealogy, lineage
moʻolelo	literally a succession of spoken words; traditional knowledge, histories—while moʻolelo are stories, histories, and accounts, the term history does not encompass deeper meanings within moʻolelo that includes the thoughts and emotions of the person narrating, making it "personal and emotional as well as scholarly" (Young 1998)
naʻau	gut, intuition, seat of knowledge
naʻaupō	ignorant
niu	coconut
Niuolahiki	kumu niu kupua (coconut tree shapeshifter)
Noio	Noddy; *Anous minutus melanogenys*
Nuʻumealani	lower strata of the sky or heavens, below Keʻalohilani
ʻohana	family
ʻōhiʻa lehua	*Metrosideros polymorpha*
ʻŌiwi	native
ʻokina	glottal stop

‘Ōlelo Hawai‘i	Hawaiian language
‘ōlelo no‘eau	Hawaiian proverbs or poetical sayings that reflect and preserve Hawaiian worldviews and traditional knowledge
oli	chants
‘oloka‘a	pointy stick in a kīpuka that would pierce the stomach of a Pueo when it pounced on the prey tied to it
‘o‘opu	goby
‘o‘opu hi‘u kole	red-tailed goby; *Sicyopterus lagocephalus*
pae ‘āina	islands
palapala	to add diacritical marks, ‘okina and kahakō
pāpale	hats
pe‘epe‘e Pueo	to hide in the forest like an owl
Pīkoi	‘Alalā kupua from O‘ahu who is famed for his accuracy in shooting arrows
pilina	relationship
pō	night, darkness
po‘e	people
pōhaku	boulder, rock
po‘i	to cover or catch between cupped hands, pounce, or snatch; reduplicated: popo‘i, po‘ipo‘i and ‘ūpo‘ipo‘i
Pueo	Hawaiian Short-eared Owl; *Asio flammeus sandwichensis*
Poli‘ahu	akua of snow, daughter of Kāne and sister of Lilinoe
puhi	eel
ua	rain
uakoko	low-lying rainbow
‘uala	sweet potato, *Ipomoea batatas*
Uli	akua of deep thought and knowledge acquisition through dreams, is “of higher consequence” than Kapō‘ulakinau, who she resides

	with in Ke‘alohilani (Kanahele 2011); another famed sorcery goddess; represents potentiality (Kanaka‘ole 2022)
uwila/uila	lightning
wā	epoch, time period
wa‘a	ship, boat
wahine	woman
wāhine	women (plural)
wāhine ‘e‘epa	women with miraculous powers, strange women
Wahine‘ōma‘o	Hi‘iaka’s ‘aikāne (same sex companion or lover) and traveling companion in her journey fetch Lohi‘au.
Wailuku	destructive waters; land division in West Māui
waimaka	tears
Waka	mo‘o akua who appears to Kapō‘ulakina‘u in dreams
wao	social-ecological zones, horizontal land divisions moving up in elevation
wao akua	cloud forest where sacred elements left undisturbed
wao nāhele	remote forest, rarely accessed
wao kele	forested uplands
Welo	lunar month around April/May

ʻŌLELO HOʻOLAUNA (PREFACE)

Hānau ʻo Līloa he kāne, noho iā Akahiakuleana he wahine,
Hānau ʻo ʻUmi-a-Līloa he kāne noho iā Kapulani he wahine,
Hānau ʻo Keawenuiaumi he kāne noho iā Koihalawai he wahine,
Hānau ʻo Kanaloakuaʻana he kāne noho iā Kaikilani he wahine,
Hānau ʻo Keākealani he kāne noho iā Kaleiheana he wahine,
Hānau ʻo Moana he kāne noho iā Piʻilani he wahine,
Hānau ʻo Ilikiamoana he wahine, noho iā Kauhiahaki he kāne,
Hānau ʻo Moana he wahine, noho iā Palila he kāne,
Hānau ʻo Kāneikoliʻa he wahine, noho iā Kawaʻahoeʻole he kāne,
Hānau ʻo Nākoʻolaniohākau he wahine, noho iā Lonoaea he kāne,
Hānau ʻo Kaeakamahu he wahine, noho iā Hehena he kāne,
Hānau ʻo Kalepa Kahonu he kāne noho iā Kukana he wahine,
Hānau ʻo Maihui Kalepa he kāne noho iā Lilia Pali he wahine,
Hānau ʻo Susan Paʻaoʻao Kalepa he wahine, noho iā Harry Johnson he kāne,
Hānau ʻo Havana Leinani Johnson he wahine, noho iā Norman McLafferty he kāne,
Hānau ʻo Daniel Paul McLafferty (Pōhaku) he kāne, noho iā Suzanne Louise Kemp he wahine,
Hānau ʻo Kaleiheana-a-Pōhaku Stormcrow he māhū.
ʻO Nāpoʻopoʻo kuʻu kulaiwi,
ʻO Koʻolaupoko kuʻu ʻāina kamaliʻi,
ʻO Kapuʻeuhi kuʻu ʻāina noho,
ʻO Mauna Kea a me Kānehoalani kuʻu mau mauna,
ʻO ka ua pakakū kuʻu wai.

I composed this oli moʻokūʻauhau from the ʻohana Kalepa moʻokūʻauhau compiled by my Uncle Terry Kanalu Young. We can trace our lineage through Līloa back to Wākea and the cosmos through Mele a Pākuʻi. Pueo is also connected to our genealogy through this chant. Another pule that was chanted before someone ate lāʻau (plants) for healing also links our genealogy to Pueo through Kauakahi-akua:

> "Nā ʻaumākua i ka pō, iā Kauhakiko, iā Kauakahi-akua, iā Līloa i ka pō, iā Hākau i ka pō, iā ʻUmi i ka pō, iā Kakuhihewa i ka pō, iā Iheihe i ka pō, pale ka pō, nā ʻaumākua i ka pō, ʻaʻohe ʻo ʻoukou mana, eia iaʻu ka mana i ka mea e ola ana i ke ao" (Poliala 1864).

My ʻohana is also related to William Lunalilo through Moana, the grandmother of Charles Kanaʻina. Lunalilo (Kamehameha V) courageously revived some of our "heathen" practices when Christianity had taken hold of the hearts and minds of the lāhui (Emerson 1892).

Starting with genealogy grounds us in the world around us and allows us to understand kuleana through our relationality to the world. I chose moʻokūʻauhau methodology for my research because it reaffirms ʻŌiwi worldviews and connections, between ourselves, our research subject, and the world. I have included a list of Hawaiian language terms used in this thesis. Some of the terms are translated into English the first time they appear in a chapter for the convenience of readers not fluent in ʻŌlelo Hawaiʻi with the caveat that English is insufficient at capturing the full meaning of an ʻŌlelo Hawaiʻi word. Unless otherwise stated all definitions are my own, and are not an exhaustive list of the meanings of each word, which I hope you will take the time to look up and learn.

Engaging in this work was difficult, to say the least. I had to gain fluency in a language that my Tūtū was never taught by her parents. Language reclamation is a powerful act. It is humbling, it connects us to the worldviews of our ancestors, and it enriches and reinforces our place in and connection to the world.

My first memories of owls stem from childhood living at a house in Eliot, Maine called "Hootin' Hollow", named for the large hollowed out snag in the front yard that functioned as a seasonal abode for breeding owls. As far back as I can remember owls have visited me in my dreams, protecting me, and guiding me away from danger in the dream world and the waking. My deep connection to raptors led me to take an apprentice falconry course with Kate Marden at West Coast Falconry in Marysville, California. Kate is an amazing teacher, a ceremonial magick practitioner, and does raptor education and rehabilitation in Northern California. After moving to Portland, Oregon, I quit my falconry apprenticeship and focused on studying raptors, botany, and ecology at Oregon State University. My friend Dominee Cagle and I conducted a field study comparing raptor diversity and species richness across habitat types in Finley National Wildlife Refuge. I later documented nest tree types and plant assemblages of Northern Goshawk territories at Colville National Forest under the guidance of wildlife biologist Kelsey Retich, which was supposed to continue the year Covid hit, and eventually be published.

When I finished my undergraduate degree in Fisheries and Wildlife Sciences at Oregon State University, I started asking the ancestors for permission to come home. Around that time my dreams of owls intensified, and without much delay I was offered a graduate research assistant position by Melissa Price, studying the cultural function of Pueo. I cannot think of a more fitting hōʻailona.

I met many roadblocks on this journey. Doors would close, others would open, and when I listened with my naʻau I could tell which way my ancestors wanted me to go. The first day I started digging deep into ʻaumākua and kākūʻai articles in Nūpepa, I looked up to see a Pueo flying outside the window above my desk, another hōʻailona: I was on the right path.

I hope this research is meaningful and useful to the lāhui. My intention is to weave the threads that I found into a tapestry wherein we can find some gem of knowledge passed down from our ancestors, to connect us in some way to their worldview, and the poetry that they found in their environment. Since prose is not generally an acceptable form for a graduate-level thesis, I leave you with this hoʻolauna as my mōhai (offering) to our ancestors, and our more-than-human relatives.

As you read this, please remember that there are different ways to translate and understand things, and that each of our abilities to do so are predicated by our experiences as individuals. I have a strong ceremonial magick background with a ritual practice that has spanned decades of my life. I started reading about witchcraft at 11 (a book that my father promptly stole and read himself), and acquired my first tarot deck when I was 15, which was illustrated by H.R. Giger. In my never-ending thirst for knowledge, I have studied many knowledge systems: different sects of Buddhism, Asatru (Germanic "paganism"), Eastern mysticism (Blavatsky, Ouspensky, Gurdjieff), and classical philosophy. I have had a meditation practice for over 20 years, practiced yoga for a decade, learned to read and write sanskrit, and went to India in search of answers. All of these practices kept eventually pointing me towards home.

CHAPTER 1: GLOBAL INTRODUCTION

Worldwide, owls hold significant places in cultural narratives and creation stories. Symbology surrounding owls varies widely across cultures. They are considered messengers from the spirit world (Phillips 1963; LaPointe, personal communication), protective guardians (Judson 1912; Harrington 1921; Phillips 1963), shapeshifters, omens of death (Saxby 1893; Wilson 1950; Garagarza 2020), seasonal indicators (O'brien 1986; Ana'atsa, personal communication), are associated with wisdom and prophecy (Saxby 1893; Ana'atsa, personal communication), possessive of magickal powers related to shamanism, witchcraft and sorcery (Opler 1941; Wilson 1950; Garagarza 2020), and are related to gods (Saxby 1893; Garagarza 2020).

The list of cultures who consider owls as the source of power for their medicine people is inexhaustive. In the Great Plains this list includes the Teton Sioux (North and South Dakota; Densmore 1918), Atsina (Montana/Canada; Curtis 1909), Kiowa (Oklahoma; Mooney 1897), and Menominee (Wisconson/Michigan; Densmore 1932), and in the Pacific Northwest, the Clayquot (British Columbia; Curtis 1916; Wilson 1950). Teton Sioux medicine people receive their power through dreams at night, and do not harm owls for fear their power will wane (Densmore 1918). In the Northeast (modern day Delaware, New Jersey, New York, and Connecticut) the Lenape believe that if an owl appears in your dreams, they become your guardian and ally (Harrington 1921). The power held by owls is also related to magic or sorcery for the Yakama (southcentral Washington; Charley 1918), Cherokee (Southeastern U.S.; Mooney and Olbrechts 1932), Apache (Southwest; Opler 1941), and Aztec (central and southern Mexico; Garagarza 2020), among others. Owls taught the Hidatsa of the region now known as Missouri and North Dakota their Earth-naming ceremony and were considered soothsayers and were consequently kept at temples (Curtis 1909).

Many Indigenous people relate owls to war. For the Pima (Arizona), owls cut off their enemy's power through dreams and by destroying trees and springs (Densmore 1932). In the Pacific Northwest owl hoots were war cries for the Nootka (Curtis 1916) and Tlingit (Swanton 1909). War shamans of the Tohono O'odham from the Sonoran Desert would dream of owls (Underhill 1946). Similarly, owls helped the Norse with success in battle, and in navigating life after death (Saxby 1893). Indeed, owls were also considered omens of death by the Norse (Saxby

1893), Diné (Navajo; Ana'atsa, personal communication), Aztec (Garagarza 2020), as well as the Tsimshian (Pacific Northwest), Cocopa (Southwest), Kalapuya (Willamette Valley), Texas Alabama, Taklema (Rogue Valley, Oregon), Choctaw (Oklahoma), and Puyallup (Washington) (Wilson 1950).

Traditionally, owls were also related to multiple gods across cultures. The Norse god Katyogel is an owl who was consecrated to the goddess of wisdom (Saxby 1893). Similarly, the Greek goddess of war and wisdom, Athena, kept an owl on her shoulder who revealed truths to her (Deacy and Villing 2001; Berger 2005), thus being the source of her wisdom and prophetic powers. Owls were the messengers of the Aztec Lords of Death and Destiny (Garagarza 2020).

Owls are also known as ancestors or family spirits. Māori (Aotearoa) believe that owls are spirits of deceased ancestors, and are revered guardians (Phillips 1963). Tlingit people in the islands off the Pacific Northwest also associate owls with family clans: the Raven Moiety in the Yakutat area and the Wolf/Eagle Moiety in the Prince of Wales area, which share the name Tsisk'w Hít (Hope III 2003). Kānaka ʻŌiwi (Native Hawaiians) have a similar relationship to owls, with Pueo (Hawaiian Short-eared Owl; *Asio flammeus sandwichensis*) being acknowledged as ancestors, and ʻaumakua (deified ancestors, guardians). Interestingly, Kānaka ʻŌiwi also share genetic markers (Hill and Serjeantson 1989) and cultural practices with Tlingit and Māori.

Pueo are thought to have journeyed here from Alaska (Wiggins *et al.* 2020). They appear in the subfossil record only after the arrival of Kānaka ʻŌiwi to the islands (Burney *et al.* 2001). Pueo are the last remaining native raptor to breed on all the islands (DLNR 2005), and like other raptors play critical roles in ecosystem function (Palacio *et al.* 2016). Pueo utilize every terrestrial ecosystem in the islands (DLNR 2005). Like other island endemic subspecies of Short-eared Owl, they have higher site fidelity than continental subspecies (Village 1987; Schulwitz *et al.* 2018, Wilhite 2021), and are more flexible in prey selection (Henshaw 1903; Mostello and Conant 2018, Luther 2021). Though Pueo hold cultural significance for Kānaka ʻŌiwi, there are no state-wide population estimates for the species and they are state-listed as endangered on Oʻahu. Short-eared Owls remains a global species of conservation concern (Holt 1986; Booms *et al.* 2014), and information on the subspecies is likely to be informed by Indigenous Knowledge

CHAPTER 2: ‘IKE KU‘UNA (INDIGENOUS KNOWLEDGE) OF PUEO

ABSTRACT

Indigenous people have a long-term relationship with the environment that allows us to recognize patterns and cycles, known as Indigenous Knowledge (IK), or ‘Ike Ku‘una, which is encoded in cultural practices. In Hawai‘i, this knowledge is in mo‘olelo (traditional knowledge), ka‘ao (legends), oli (chants), mele (song), and kanikau (funeral dirges). When a particular species holds significant cultural value to be necessary for the stability of a culture over time it is considered a Cultural Keystone Species (CKS). CKS often have similar ecological and cultural functions. Pueo (Hawaiian Short-eared Owl; *Asio flammeus sandwichensis*) is considered an ‘aumakua (deified ancestor, family guardian) and is the only remaining native apex predator that breeds on all islands. Thus, they play critical roles in ecosystem function. In this study I utilized knowledge held in Hawaiian Language Newspapers, the largest archive of Indigenous Knowledge in the world, to (1) explore IK about Pueo and (2) determine whether Pueo is a CKS. Pueo are akua (gods, elemental forms) and have relationships to multiple akua that represent ecosystem function and nutrient cycling, as well as to a multitude of other species. This indicates that the functional relationship of Kānaka ‘Ōiwi, specifically ali‘i (chiefs), to Pueo as akua and ‘aumakua would allow them to recognize when the environment was destabilizing, which is essential for longevity in an island ecosystem. There is also evidence that Pueo were persecuted at the turn of the 20th century, further separating Kānaka from cultural practices such as ho‘omana (Hawaiian spiritual practice invoving reciprocal energy exchange between the practitioner and the akua being worshiped).

INTRODUCTION

359. ‘O kāne iā Wai‘ololī, ‘o ka wahine iā Wai‘ololā
360. Hānau ka Noio noho i kai
361. Kia‘i ‘ia e ka Pueo noho i uka
362. He pō uhe‘e i ka wāwā
363. He hua, he ‘i‘o ka ‘ai a ka manu
364. ‘O ke akua ke komo, ‘a‘oe komo kānaka

(Kalākaua 1889)

359. Man for the narrow stream, woman for the broad stream
360. The Noddy is born living at sea
361. Guarded by the Pueo living upland
362. Darkness slips into light
363. Seed and flesh are the food of the bird
364. Gods enter, people do not enter.

This opening passage occurs in the third wā or epoch of the Kumulipo (ko‘ihonua, or Hawaiian creation chant; a cosmogonic chant indicating the origins of the world), where the Noio (Noddy; *Anous minutus melanogenys*) lives near the ocean and is guarded by Pueo (Hawaiian Short-eared Owl, *Asio flammeus sandwichensis*), living onshore, or upland. Ko‘ihonua (cosmogonic chants), such as the Kumulipo, are mo‘okū‘auhau (genealogies) and are a way to trace the origin of each living thing that came into existence (Kame‘elehiwa 1992). Mo‘okū‘auhau allow us to examine and understand our place in this lineage and how we relate to the world and our more-than-human ancestors (Kame‘elehiwa 1992). Beginning with mo‘okū‘auhau is a way to provide background information, authenticate an account (Nu‘uhiwa 2019), and “frame the narrative” (ho‘omanawanui 2019). From an ‘Ōiwi perspective, every living being that came into existence before us is both an akua (deity, elemental force) and an ancestor (Kame‘elehiwa 1992; Brown 2022). This relationship defines our kuleana to care for these species, because they are ‘ohana (family; Kealiikanakaoleohaililani and Giardina 2016).

Indigenous People like Kānaka ‘Ōiwi are long-term inhabitants of Place, engaged in an ongoing dialogue with nature that allows us to know daily, seasonal, and evolutionary cycles and patterns, defined as ecological literacy (Orr 1989). This awareness includes an understanding of how people and nature are interrelated, and the intricacies of how the local natural systems work (Orr 1989; Diver *et al.* 2019; Morishige *et al.* 2018). This cumulative body of knowledge about the interrelatedness of humans and other living beings to the environment is known as

Indigenous Knowledge (IK)—ʻike kuʻuna in ʻŌlelo Hawaiʻi—and is passed down through generations by cultural transmission (Berkes 1999). IK evolves through local observational knowledge of species and ecosystems over long periods of time, and is coded in cosmology, ritual, ceremonies, and cultural practices such as chants, dances, songs, and stories (Feyerabend 1987; Woodley 1991; Berkes 1999; Whap 2001; Garibaldi and Turner 2004; Efi 2005; Sato *et al.* 2018, Kealiikanakaoleohaililani 2018). These forms of knowledge have often been dismissed by conventional scientists as cultural lore, but this is a false dichotomy which assumes the superiority of a neoclassical worldview and the knowledge derived from conventional scientific approaches (Winter *et al.* 2023). Indigenous Knowledge is an accurate portrayal of reality that is compatible with science (Deloria Jr. 2003), and Indigenous approaches to ways of knowing are parallel and equal lines of inquiry and meaning making (UNEP 1998; Kimmerer 2013; Patrick and Biiius 2021). IK is integral to biodiversity conservation and ecosystem management (Turner *et al.* 2000; Senanayake 2006; Díaz *et al.* 2015) and has the potential to help solve challenges in the Anthropocene such as the extinction and climate crisis (Kimmerer 2013).

Further, species that hold significant importance to Indigenous Peoples may be defined as Cultural Keystone Species (CKS) (Garibaldi and Turner 2004; Cristancho and Vining 2004). CKS are species who hold so much spiritual and symbolic value to a culture that their existence is critical to that culture's "relationship with and adaptation to the environment" which is culturally essential over time. CKS have comparable cultural and ecological functions, which have some essential function that supports cultural complexity concerning social identity, cultural practices, and beliefs (Garibaldi and Turner 2004; Platten and Henfrey 2009). Garibaldi and Turner (2004) and Christancho and Vining (2004) proposed several criteria for designating a species as a CKS (Table 2.1).

Table 2.1 Criteria for determining CKS designation from Garibaldi and Turner (2004) and Christancho and Vining (2004).

Intensity, type, and multiplicity of use
Naming and terminology ● Seasonal or phenological indicators; names of months or seasons, place names, specialized vocabulary
Persistence and memory of use in relationship to cultural change ● Pervasiveness in the collective cultural consciousness and discussed frequently
Irreplaceability ● Unique position in culture that is impossible to replace with another similar species
Use in trade or resource acquisition
Psycho-socio-cultural function ● Prominently featured in narratives, ceremonies, dances, songs, or as a major crest, totem, or symbol ● Plant and animal species whose existence and symbolic value are essential to the stability of a cultural group over time
Interaction with other species
Presence/abundance in the human community

Species with cultural importance are often present in moʻolelo (traditional knowledge)[1], kaʻao (legends), mele (song) and oli (chants), and have exceptional conservation value (Morishige *et al.* 2018), which were traditionally passed down orally through generations. However, today, a substantial and relatively unexplored collection of IK held by Hawaiians can be found in the Hawaiian language newspapers, hereafter Nūpepa (1834-1948), which is the largest archive of printed IK in the world (Arista 2019). While experiencing a 90% loss in the human population over a single century due to diseases introduced by colonizers, and a shift in religion which further eroded cultural knowledge systems, many kūpuna (ancestors) recorded knowledge in Nūpepa for future generations to preserve knowledge that was otherwise being lost (Winter 2012; Chinn *et al.* 2014; Silva 2017; Businger *et al.* 2018, Gon *et al.* 2021).

[1] I define moʻolelo as traditional knowledge—while moʻolelo are stories, histories, and accounts, the term history does not encompass deeper meanings within moʻolelo that includes the thoughts and emotions of the person narrating, making it "personal and emotional as well as scholarly" (Young 1998)

In Hawaiʻi, biocultural knowledge from Nūpepa has been used to improve natural resource management and conservation, and to optimize ecosystem services for sustainability and resilience (Winter 2012; Sato *et al.* 2018; Winter *et al.* 2020b; Luat-Hūʻeu 2021). For example, biocultural knowledge from Nūpepa has been used to reconstruct a pre-contact Hawaiian footprint (Gon *et al.* 2018), inform restoration actions (Kurashima *et al.* 2017), and improve coral reef conservation (Calamia 1996). Further, biocultural restoration meets conservation goals for rare and endangered species (Winter *et al.* 2020a). Restoration of loʻi kalo (wetland taro agroecology) has increased habitat for federally endangered endemic waterbirds like ʻAlae ʻUla (Hawaiian Gallinule or moorhen, *Gallinula galeata sandvicensis*) and Aeʻo (Hawaiian Stilt; *Himantopus mexicanus knudseni*) in areas like Heʻeia (Winter *et al.* 2018a; Opie 2022).

Further, Nūpepa have the potential to inform management for rare and endangered species that were more abundant in the past. For instance, oli describe the historical distribution of endangered and extinct kāhuli (Hawaiian land snails) across the islands and convey how highly esteemed they were by Kānaka ʻŌiwi (Sato *et al.* 2018). Similar data for other species are contained in Nūpepa, such as habitat use, behavioral ecology, and distribution. Given the scarcity of current data about life history or historical distribution for many endangered and rare native species, collation and dissemination of this historical knowledge from Nūpepa is critical to improve conservation outcomes and return these species to abundance.

Pueo are culturally important as ancestors, with different ʻohana having different forms of relationships that range from ʻaumakua (deified ancestors)[2] to kinolau (multiple forms; physical manifestations)[3] of the akua (deity)[4] Kāne (Handy and Pukui 1998) or Kū (Gon *et al.* 2021). According to Malo (1951), Pueo are a deity worshiped by many, and their feathers were

[2] ʻAumakua is defined in the Hawaiian Dictionary as "family or personal gods, deified ancestors" who can take many forms including owls; "a symbiotic relationship existed; mortals did not harm or eat ʻaumākua, and ʻaumākua warned and reprimanded mortals in dreams, visions and calls" (Pukui & Elbert 1986).

[3] Kinolau are based on resemblance between plants, animals, and some natural phenomena such as "ancestral nature gods" (Handy and Pukui 1999).

[4] Akua are generally defined as gods, or deities. However, akua are also elemental forces (Kanahele 2011). Mākua (parents), ʻaumākua (deified ancestors), and akua (gods), are all functions of time (Kaʻimikaua 2000). All of these terms are connected in a succession through time. ʻAumākua are ancestors deeper back in time, and when remembered over thousands of years they become akua. Indeed, the terms are almost inseparable because all people who are remembered over time because of their talent at particular hana (acts, work, deeds) could have been considered akua.

made into the finest quality kāhili (feather standards). An akua with a Pueo body, with the names Kānekūpahuʻa (man standing at the forest edge), Kūʻemanu, and Kānepueo, lived at the edge of the forest and protected people from harm (Emory 1942). The view of Pueo as akua are reflective of the depth of presence of this species in Hawaiʻi, both in relative abundance and also in the meaningful interactions had and continue to have with them.

Pueo are endemic to the Hawaiian Islands and appear in the subfossil record only after the arrival of Kānaka ʻŌiwi to the islands, perhaps due to the simultaneous introduction of ʻiole (Pacific rat; *Rattus exulans*) coupled with the transformation of landscapes to agroecology like loʻi kalo, which increased available foraging resources (Burney *et al.* 2001). Pueo are a generalist species that occur at low densities across every terrestrial vegetation type in the pae ʻāina (islands), and are the only raptor known to breed on all the islands (DLNR 2005; Luther 2020). Despite the common belief that they are diurnal, Pueo have been found to roost in the forest during the day, and hunt over open fields at night (Wilhite 2021). This indicates that Pueo may selectively use edge habitat, or a variety of different habitats in their daily life. Other studies have shown that Short-eared Owls prefer heterogeneous landscapes with structural complexity (Miller *et al.* 2016), and are most active during nocturnal periods (Craighead and Craighead 1956; Clark 1975; Clarke 1983; Reynolds & Gorman 1999; Calladine *et al.* 2010; Calladine & Morrison 2013; Larson & Holt 2016; Johnson *et al.* 2017; Tseng *et al.* 2017). Pueo are state-listed as endangered on Oʻahu due to habitat loss, and Short-eared Owls globally are a species of conservation concern due to evidence of population decline over decades (Holt 1986; Wiggins *et al.* 2020; Booms *et al.* 2014).

Here, I examine IK of Pueo by exploring Nūpepa and other sources on Papakilo Database (www.papakilodatabase.com) to: (a) deepen our understanding of the pilina (relationship)[5] between kānaka and Pueo and the ecological knowledge relating to Pueo held by kānaka in that time; and (b) determine if Pueo are a Cultural Keystone Species using the criteria listed above (Table 2.1). IK of Pueo may inform the management of this species by deepening our understanding of their relationship to the environment and to kānaka. From a cultural

[5] Pilina means relationship, but is also attunement, or "degree of relational exchange one entity has with another" (Kanahele *et al.* 2017).

perspective, this is important because Pueo are ancestors, ‘aumakua, and kinolau, and deserve to be understood and acknowledged in order to deepen our relationship to them.

METHODS

Data Collection

I followed moʻokūʻauhau methodology, which examines ancestry, genealogical ties, and kuleana to better understand relationships between the subject and the world (hoʻomanawanui 2019). Moʻokūʻauhau methodology connects us to ancestral wisdom and helps us to embrace a cultural worldview that is in itself Hawaiian (hoʻomanawanui 2019). Using this approach allows us to recognize common themes and understand relationships and the depths of inter- and intra-connection among articles (hoʻomanawanui 2019). I have applied this framework in a way that allows examination of the continuum of biocultural knowledge within multiple lineages of knowledge associated with multiple genealogies. This examination includes relationships between species, ecosystems, and akua from a Kānaka ʻŌiwi lens to help us better understand the ecological knowledge held by Kānaka ʻŌiwi ancestors.

Nūpepa are written in ʻŌlelo Hawaiʻi (Hawaiian language), and words, phrases, and moʻolelo often have multiple layers of meaning, known as kaona, that cannot easily be translated. However, given the multiple layers of meaning often present in ʻŌlelo Hawaiʻi, the most robust meaning is likely to be derived when articles are read by persons fluent in the ʻŌlelo Hawaiʻi where multiple layers of meaning can be explored (Luat-Hūʻeu 2021, Chinn *et al.* 2014). Thus, only a few articles representing key themes were fully translated to English to provide key examples for readers not fluent in ʻŌlelo Hawaiʻi, and the remainder of articles were interpreted in ʻŌlelo Hawaiʻi. Uncommon words in the modern era were translated using the Hawaiian Dictionary (Pukui and Elbert 1986) and www.wehewehe.org.

Relating to this work specifically, while I have completed 300-level ʻŌlelo Hawaiʻi classes and have gained additional fluency in reading and writing through this research, I have also been studying with Kumu Hula Kekuhi Keliikanakaoleohaililani for nearly two years beginning with Hālau ʻŌhiʻa in May 2021, Oli Honua starting in Fall of 2021, and Ulu ka ʻŌhiʻa starting in Fall of 2022. I have been attending Kānaenae Together with Kalei Nuʻuhiwa regularly since Fall of 2020. That said, the research presented here is not an exhaustive analysis of IK on Pueo, which would require a level of fluency in ʻŌlelo Hawaiʻi that I do not currently possess. Following Au (2018), I have worked within a recognition of my own limitations. I focused my analysis on information that was accessible at my level of ʻŌlelo Hawaiʻi fluency, and my understanding of the information as it relates to ecology and cultural knowledge passed down to me by my teachers. As a believer in the akua kahiko (ancient gods), my own worldview and experience as a Kanaka ʻŌiwi scholar informed my interpretations and perception (Au 2018). Additionally, two of my committee members, and my kumu ʻōlelo (Hawaiian language teacher) who have been instrumental in my understanding of these articles are fluent in ʻŌlelo Hawaiʻi. I have consulted with them regarding meaning and palapala (adding diacriticals—ʻokina and kahakō).

Archival Search

I searched the Papakilo Database in the years 2020 and 2021 (Chinn *et al.* 2014, Sato *et al.* 2018, Luat-Hūʻeu *et al.* 2021) for articles relating to Pueo. Because the word "pueo" can also refer to things other than a bird species such as a person or place, kalo (taro) varieties (papapueo, pueo hālenalena and pueo keʻokeʻo), and the lashing on the main beam of a house (ʻaho pueo), a more refined word search was used to narrow the search to articles relevant to the Hawaiian owl. The word combinations used were "pueo", "manu pueo", "pueo akua", and "pueo aumakua". In addition, I searched māhele (land claim) records on Papakilo Database for place-names that included Pueo.

Once I identified relevant articles using the process outlined above, they were imported into a file. Then, I read the entire article in ʻŌlelo Hawaiʻi, and added ʻokina and kahakō. Finally, I wrote down a summary of the article, and translated relevant pieces of each article into English to reference during analyses and in the presentation of results.

Analysis

Each article was categorized as kaʻao/moʻolelo, oli/mele, kanikau (funeral dirge), or opinion piece/article (Sato *et al.* 2018; Figure 1). Following this, once relevant articles were identified, after palapala each article was imported into NVivo software to organize and analyze quantitative data obtained from Hawaiian language archives (QSR International 2020). I identified the source of the article and the author when possible, and key themes associated with cultural keystone species and conservation caretaking (hōʻailona (omens), ʻaumakua, kinolau, kupua (shapeshifters), akua, allegory, ecology). Ecology was further divided into habitat, diet, physical description, atmospheric phenomena, timing, associated species, and behavior. Information within articles were coded according to which key themes they fit into, with some articles having multiple codes across key themes. This software facilitated the identification of common terms and themes associated with the research subject, and organization of codes so that themes could be easily identified and understood in relation to each other.

RESULTS

I found 495 articles containing the term "manu pueo", occurring between the years 1837 and 1941 (Table 2.2). There were 92 results for the term "pueo aumakua", occurring between the years 1858 and 1932. I identified 565 articles for the term "pueo akua", occurring between the years 1835 and 1935. Of the 495 articles identified as containing the term "manu pueo" (Table 1.2), I read over 300 ʻōlelo Hawaiʻi articles in the Papakilo Database. A few of these articles were serials, which were treated as individual articles in analysis since each article in the series potentially contained new and relevant information. I also read all English language sources which referenced Pueo from the Papakilo online database, such as the Hawaiian Almanac and Annuals, which contained statistical reports, articles in a broad range of topics including biology, and essays. I excluded articles from my analysis that were irrelevant, or were repeats of previously read articles (including transcribed or repeated moʻolelo). Multiple articles only contained the phrase "malu ke kula ʻaʻohe keʻu Pueo[6]" (the plain was calm, there was no Pueo calling), and all but one of these was also excluded from analysis. There were also variations on this ʻōlelo noʻeau, one of which used lele (fly) instead of keʻu. I stopped reading articles when the majority of information contained within articles were repeats of previously read information; thus, not all articles found were relevant for analysis. A total of 117 primary ʻŌlelo Hawaiʻi articles were ultimately used in my analysis. The broader themes I identified within articles were coded in NVivo (Figure 2.2).

Table 2.2 Number of hits per search term returned from searching the Papakilo Database between 8/2020–12/2021.

Keyword	Number of articles	First mention (year)	Last mention (year)
pueo	1345	1835	1944
manu pueo	495	1837	1941
pueo akua	565	1835	1935
pueo aumakua	92	1858	1932

[6] ʻŌlelo noʻeau 2130: "there was perfect peace" (Pukui 1983).

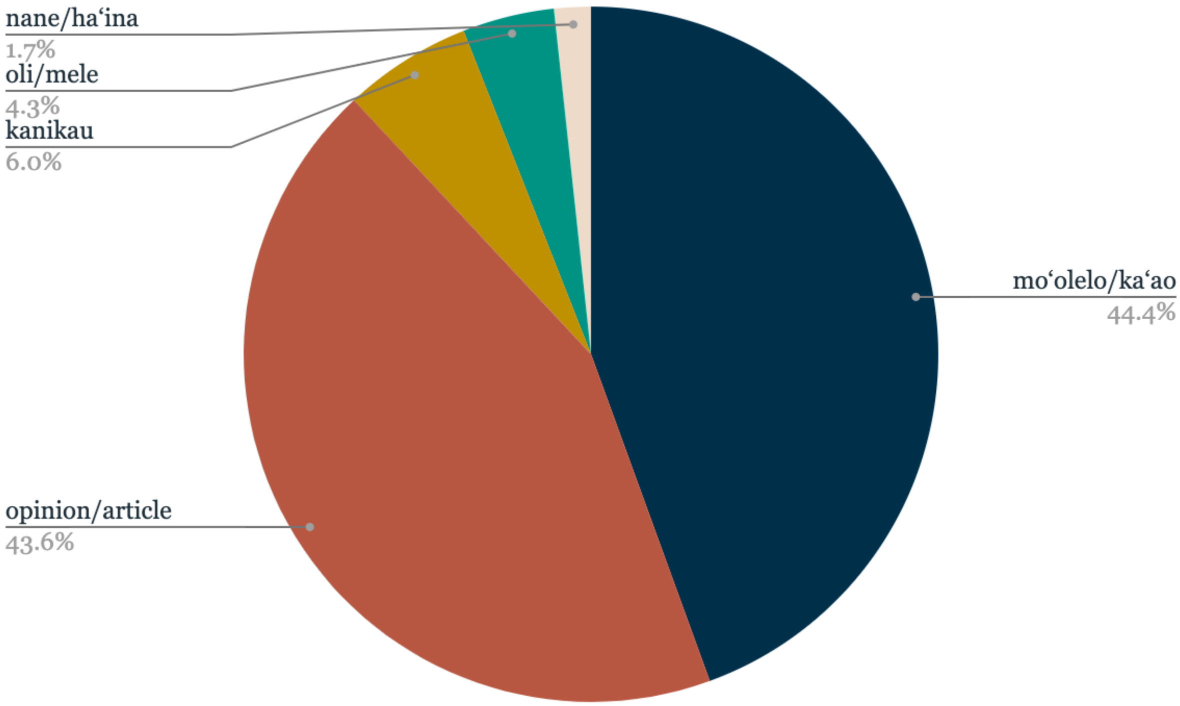

Figure 2.1 Percentages of total articles (n = 116) in each thematic category of primary ʻŌlelo Hawaiʻi article analyzed from Papakilo Database.

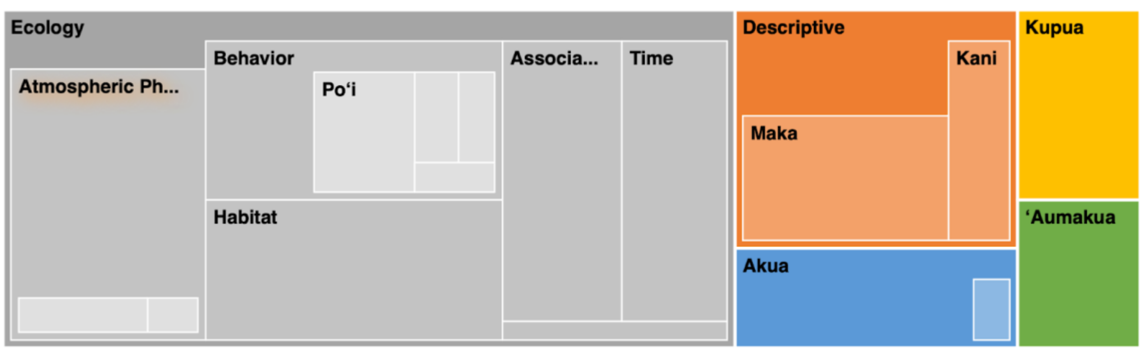

Figure 2.2 Hierarchy chart of codes from NVivo illustrating frequency of coding references for each thematic category.

Mo‘okū‘auhau & ‘aumakua

Nā Pueo lani ho‘oku‘i (Kaiakea 1922).

Pueo in the highest heavens.

The majority of articles were categorized as mo‘olelo/ka‘ao followed by opinion/article (Figure 2.1). Three articles were found relevant to mo‘okū‘auhau and eight in regards to Pueo as ‘aumakua[7]. In one mo‘olelo, Pueo is the mother of Hina, and the grandmother of Laukiamanuikahiki, whom she comes to kill (Kumalae (Ed.) 1935), while in another mo‘olelo, Pueo is the child of Hina and Hinalaua‘e, and the younger sibling of Māui (Maunupau 1922). Pueo are related to ali‘i in multiple articles. They appear in Mele a Pāku‘i, which connects the genealogies of ‘Umi-a-Līloa to Wākea (Kumalae (Ed.) 1933), as well as in a kanikau for Kalaniana‘ole (Kaiakea 1922), and Ruth Ke‘elikolani (Anonymous 1883). An ali‘i of Ka‘alaea is a kupua with a Pueo body (Poepoe 1909). Pueonuihō‘ano‘ano was the kia‘i (guard) of the feather house of Kauakahiali‘i (Ho‘oulumāhiehie 1912). Pueo is also the thing that catches the lineage of the heavens, or lofty genealogies (Manu 1895). Pueonuiokona was a makāula, or a seer (Kiliona 1930).

In order to deify a loved one into a Pueo ‘aumakua, the bones of the loved one would be ritualistically fed to the akua kumupa‘a (ancient family god) Kūkauakahi in kākū‘ai[8] ceremonies. Kūkauakahi is the child of Haumea and Kanaloa (Kalākaua 1889); he has the body of a Pueo (Kawainui (Ed.) 1893). If the ‘uhane (spirit) was accepted by Kūkauakahi, they would enter into kekahi mau ‘ōuli o ka lani (the nature of the heavens) and fly in the sky as a Pueo (Kamakau 1870).

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[7] When spirits were transfigured into ‘aumākua they would take care of the family, give orders about the things that are necessary to live, and provide protection from misfortune (Kawainui (Ed.) 1893). However, if things were not cared for, such as food, ipu paka (two gourd drums tied together), calabashes, water gourds, beds, and such, people would get sick or have problems that were caused by the ‘aumakua (Kawainui (Ed.) 1893).

[8] Dead loved ones were deified to akua kumupa‘a (ancient family gods) to become ‘aumakua in ceremonies called kākū‘ai (ritualistic feeding). Kākū‘ai involved wrapping iwi (bones) into a kuolo (bundle) made of coconut-dyed kapa, and offering ‘awa (kava, *Piper methysticum* root) and specific mea ‘ai (food items) to an akua kumupa‘a, all of which were dependent on which ‘aumakua form was desired, or appropriate given the family mo‘okū‘auhau. More information can be found in Nānā i ke Kumu and Ka Po‘e Kahiko.

Pueo were famous in the ancient times for their power, and for saving their kahu (keepers) from imminent demise (Kamakau 1870). Pueo ʻaumakua were known to hoʻopakele (free) their kahu if they were hopu pio (taken prisoner), or if their life was threatened. It was also said that it was a normal occurrence for a Pueo to strike their wings calmly and open the door to slowly guide young female prisoners to their escape (Kawainui (Ed.) 1893). For example, a girl on Kauaʻi named Wainiha was arrested when riding her horse from Wailua to town. While she slept, she heard a Pueo slap their wings on the door and looked to see that it was open; the Pueo led her past the sleeping guards and back to her horse (Kamakau 1870). Additionally, if a kahu of the Pueo was killed and buried in the dirt, the Pueo would fetch them by digging in the dirt with their wings, restoring life, and the kahu would live again (Kaawa 1865). In the famous moʻolelo of Kahalaopuna, from Mānoa, Oʻahu, her Pueo ʻaumakua restored her life multiple times after her jealous husband Kauhi murdered her and buried her body near a pōhaku (boulder). This continued until he covered her grave with pōhaku too large for her Pueo ʻaumakua to move (Kaao 1932). There are other examples of Pueo saving people, restoring their life, or acting as alakaʻi (leaders; *n* = 4). If a person was shipwrecked, they would perhaps be saved and brought back to land by a manō (shark), puhi (eel), or Pueo (Iosepa (Ed.) 1893). One example is when Napaepae's waʻa (ship) capsized at sea, he swam all day and all night, then early in the morning a Pueo clapped their wings in front of him, and led him to shore at Kaunakakai, Molokaʻi (Kamakau 1870). A woman named Kahulunuikaʻaumoku was killed in the battle of Kukiʻiahu; a Pueo slapped her face with their wings and her corpse was restored to life as if being awakened; the Pueo then led her to Aiea (Kamakau 1867).

<u>Akua, kupua & kino lau</u>

Pueo are an akua of our kūpuna (ancestors; *n* = 16). When all the heiau were still standing on all the islands, many akua were worshiped, including Pueo (Anonymous 1893). However, I found evidence of the shifting attitude toward akua during this time period of the late 1800's. For example, Kamakau said that the Pueo was not an akua, but "he haili o ke akua ka pueo", (the pueo is the spirit of god), similar to a dove (Kamakau 1870). In the same article, two kahuna find a Pueo dead in the street, and while one of them wailed day and night over the death thinking that he had forsaken the Pueo, the other said "ʻaʻole he mau akua liʻiliʻi lapuwale" (there are no small worthless gods), and Jehovah is the only god (Kamakau 1870). An article from 1919 pleaded with people to stop worshiping the akua of their "poʻe kūpuna naʻaupō" (ignorant ancestors) and become servants of Jehovah (Mahuka 1919). Further, Kalua (1870) wrote that when ka lāhui (the people) turned towards the truth about akua, all the heiau were destroyed and the akua moʻo, lāʻau, Pueo, and manō left.

Pueo were also kinolau of multiple akua, including Kū in the form of the aforementioned Kūkauakahi (Kamakau 1870). Lilinoe took the form of a Pueo to lead people out of the mist at Haleakalā, Mauna Kea, and Mauna Loa (Hood *et al.* 1976). The moʻo akua Waka took the form of a Pueo at Kapueokahi, Māui, and appeared to Kapōʻulakinaʻu in dreams for seven nights, enchanting her (Manu 1899). Additionally, there was a moʻo akua (lizard deity) named Mukuhinia on Maui whose hair swaying was one indication that there was a Pueo above (Nailiili 1868). Pueo are also one of Kamapuaʻa's manu (Kahiolo 1891) as well as one of Laka's manu (Kanepuu 1868). Further, the aforementioned Kapōʻulakinaʻu had relations with Pueo in two moʻolelo across three articles.

Twelve Pueo kupua (supernatural beings) were identified across articles. In the epic tale of Hiʻiakaikapoliopele, Hiʻiaka and Wahineʻōmaʻo met with two different Pueo kupua, both of whom were also kinolau, aliʻi (chief, royalty), and akua, one at Waiāhole, Oʻahu and the other at Puʻueo above Hilo (Poepoe 1909). KawailoaikapolioLokoea is a Pueo kupua who is eventually captured in the magical net of Niuloahiki, a kumu niu (coconut tree) kupua and loses his powers (Olopana-Nui-Akea 1914). In "He Moʻolelo no Hiakaloka", there are two wāhine (women) hoʻokalakupua (magicians/enchanters; shapeshifters) at Hālaʻi, Hilo. The people in the moʻolelo are saved from these two wāhine ʻeʻepa (women with miraculous powers) by Kaihe who is also a niu (coconut) kupua. The first of these kupua is a woman with red hair who can become a manō in the sea, an ʻIʻiwi (Scarlet Honeycreeper; *Drepanis coccinea*) in the mountains, an ʻoʻopu hiʻu kole (red-tailed goby; *Sicyopterus lagocephalus*) in freshwater. She can reach the uplands by flying in the form of a Pueo and is seen entering the ocean as a Pueo at Makahanaloa (near Honomū, Hāmākua, Hawaiʻi), which is an ancient leaping place for souls (Uluihi (Ed.) 1916; Pukui *et al.* 1976). The other wahine ʻeʻepa in this moʻolelo has black hair and can become an ʻIo (Hawaiian Hawk, *Buteo solitarius*), hīhīmanu (spotted eagle ray; *Aetobatus narinari*), and ʻApapane (*Himatione sanguinea*). A tale of kupua from Kōhala describes a conflict between a Pueo mahiʻai (farmer) and an ʻiole ʻaihue (rat thief) who is stealing Pueo mahiʻai's ʻuala (sweet potato, *Ipomoea batatas*); Pueo eventually seeks the help of an ʻAlalā (Hawaiian Crow; *Corvus* *hawaiiensis*) kupua named Pīkoi from Oʻahu to come and kill the rat with his arrows (Kumalae (Ed.) 1934).

Ecology

> He kohu Pueo ka ʻaʻā o kona mau maka, e haka pono iho ana i ka honua… mai ʻo nā piko mauna; a he hiona hoʻi kona o ka ʻIo, e kau aheahe mālie ana i ka makani; ʻaʻohe āna lālā kau ʻole (Kaunamano (Ed.) July 6, 1893).
>
> The Pueo looks like their eyes are staring, gazing directly at the world, from the summits of the mountains; and has the appearance of an ʻIo perching calmly in the wind; there is no branch where they don't perch.

A total of 53 articles articulated information related to Pueo ecology. Pueo were once abundant (n = 5). Ahia (1885) states that Pueo in Puna, Hawaiʻi were "ma ʻō a maʻaneʻi mai mauka makai" (here and there from mountain to sea). In the time of Hiʻakaikapoliopele, Pueo were abundant across the pae ʻāina (islands):

> "He pueo ko nā wahi āpau. Mai Hawaiʻi aku nei ia mea he pueo, a hōʻea i Kauaʻi. ʻAʻohe ʻāina pueo ʻole" (Poepoe 1909).
>
> There are Pueo in every place. From Hawaiʻi to Kauaʻi there are Pueo. There is no land without Pueo.

In two iterations of the moʻolelo of Kapoʻi, the number of Pueo flying blackened the sky (Kamakau 1865, Uaua 1871). Additionally, Henshaw (1903) states that Pueo were "formerly numerous in the lowlands of all the island", but that sugarcane production caused a decline by destroying nesting sites. Further, Pueo were being "ruthlessly killed" because they are owls, and that the species had already become rare (Henshaw 1903).

Pueo were described as the size of a mother hen, with broad wings about the length of an iwilei (length from collar to fingertip), hidden ears, long claws, and a strong, sharp-curved beak like a spear tip (Keauokalani 1863). They were described as ikaika (strong; n = 7), kupanaha/kupaianaha (wonderful, amazing, strange; n = 7), hoʻānoano (sacred; n = 6), and akamai (intelligent; n = 3). The most commonly mentioned trait of Pueo was their eyes (n = 19). Their eyes were described as large (nui/nunui; n = 5). Many terms illustrated how radiant their eyes were, including uwila/huila (lightning/flashing), ʻaʻā (glazing, glowing), and ʻālohilohi (sparkling/radiant), and they glanced about this way and that. In contrast, their eyes were also described as lulu (calm), hāloʻiloʻi (tearful), as well as obscure (pōwehiwehi and pōaʻeaʻe). The kani (call or voice) of Pueo was described in nine articles:

> Kona kani me he hāwanawana lā akā inā naʻe e hakakā ʻo ia, alaila he keʻu ke kani, keʻukeʻu (Keauokalani 1863).
>
> Their voice is like a whisper, but if they are fighting their call is keʻu, keʻukeʻu.

In moʻolelo, Pueo were described in direct relationship with other species (Figure 2.3). Pueo were said to look like ʻIo (Hawaiian Hawk; *Buteo solitarius*) and ʻIwa (Great Frigatebird; *Fregata minor*), but their behavior was like the ʻIo (Keauokalani 1863, Keawehaku 1893). These three species were considered manu ʻaihue, and Pueo was "ke aliʻi o nā manu ʻaihue" (chief of the thief birds; Keauokalani 1863). Pueo was said to "hoʻokolo ʻia i ka nui manu o kākou[9]" in two articles.

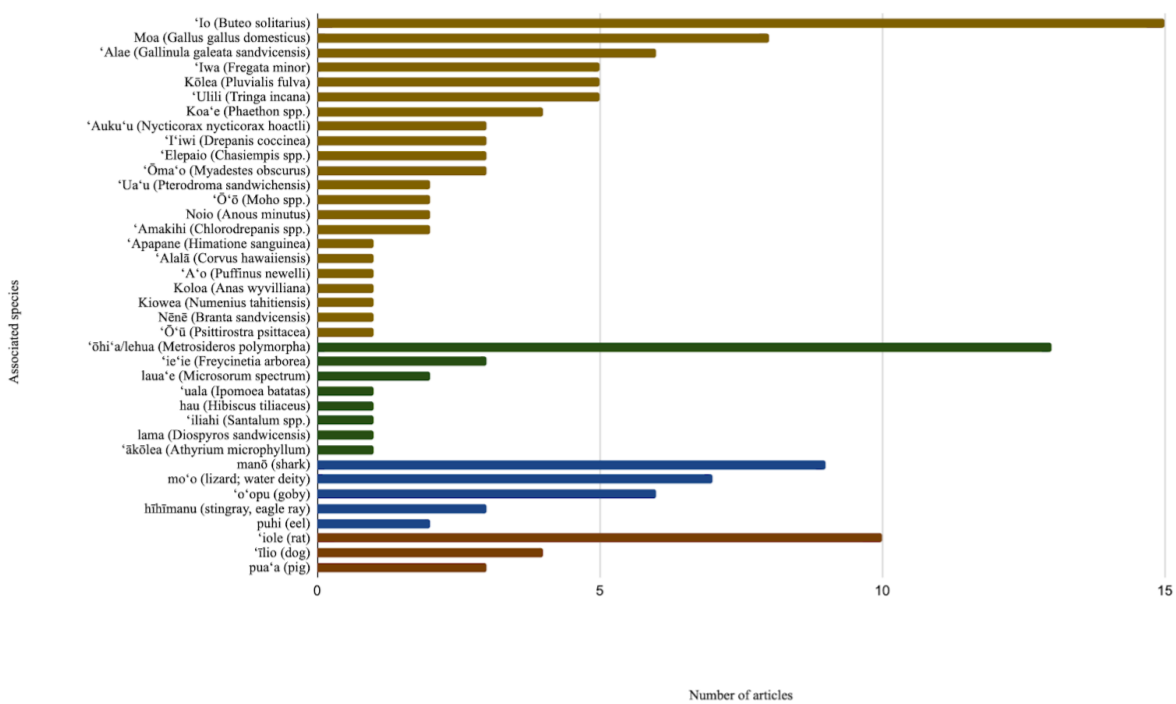

Figure 2.3 Associated species and number of articles each species was mentioned in.

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9 ʻŌlelo noʻeau 1086: "go and consult others" (Pukui 1983).

Na ka Pueo o ka Wao akua i paikau hele aʻe iā lākou. (Kapu (Ed.) 1893).

It was the Pueo of the realm of the gods who went to and fro to them.

Pueo appeared in a multitude of habitats across moʻolelo (Figure 2.4). Additionally, Pueo were found in the following wao (social-ecological zones; Winter *et al.* 2018a): wao akua (cloud forest where sacred elements left undisturbed; n=1), wao nāhele (remote forest, rarely accessed; n=1) and wao kele (forested uplands; n=1).

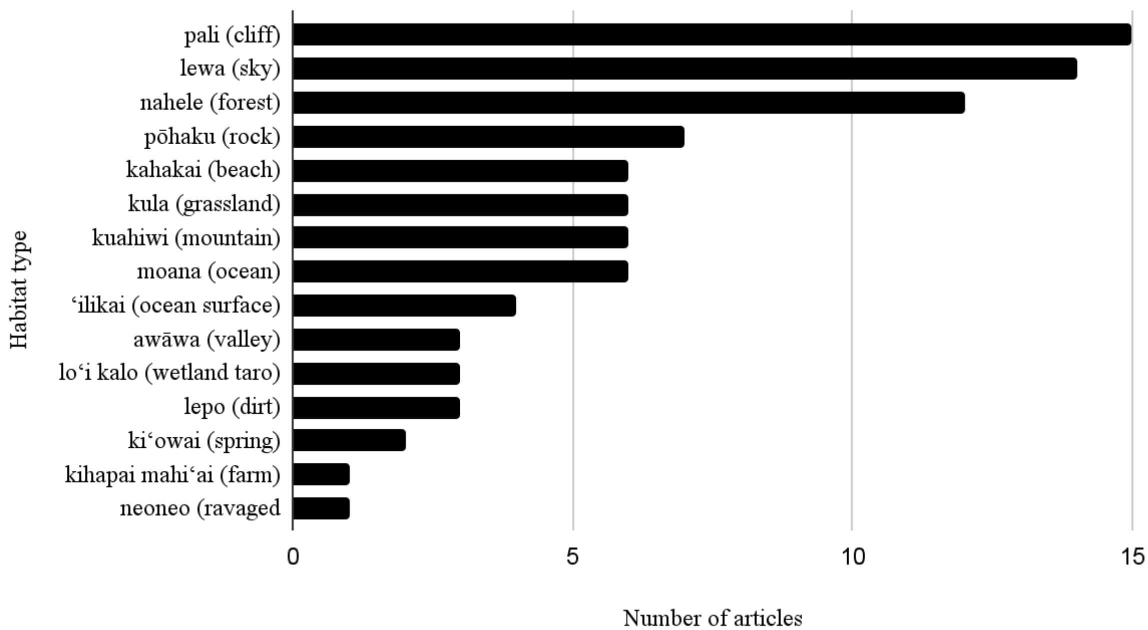

Figure 2.4 Number of mentions of Pueo habitat by type identified across articles.

In addition to their habitat, specific Pueo behaviors were mentioned in 35 articles. Pueo flew from the mountains to the sea (n = 2), they flew between islands (n = 4), and they gathered en masse (n = 2). In the Maui version of the moʻolelo of Kapoʻi, Pueo from Hilo, Kāʻu and Puna gathered at Kapueokahi in Hana; Pueo from Kona, Kōhala and Hāmākua gathered at Kīpahulu. The Pueo from Kauaʻi and Oʻahu gathered at Kaulanaakapueo at Makapuʻu (Waimānalo, Oʻahu) then met with Pueo from Molokaʻi, Lānaʻi, Kahoʻolawe and the Pueo from west Māui at Mānawaipueo, and then followed the alanui pali (cliff trail) ʻAʻalaloloa to Wailuku to meet with the Pueo of east Māui (Uaua 1871). In the Oʻahu version of the moʻolelo of Kapoʻi, Pueo from the islands of Hawaiʻi, Lanaʻi, Māui and Molokaʻi gathered at Kalapueo in Waimānalo, Pueo from Koʻolau and Kahikikū gathered at Kanoniakapueo, and Pueo from Niʻihau, Kauaʻi and the east gathered at Pueohulunui to battle Kakuhihewa (Kamakau 1865).

Pueo behavior also related to time (Figure 2.5). Pueo appeared in moʻolelo on the moon phases of Hoaka (n =1), Mahealani (n =1), Kāne (n =2) and Lono (n =2). In the month of Welo all things grow, and the Pueo mistook the new growth of yams (uhi, pia, hoi) for rat tails, and pounced mistakenly (Kaleinuipaoaikeala 1891; Poepoe 1906). One article described how hot it was at Makahūʻena, Kauaʻi, and that there were no Pueo flying in unison (Kaunamano (Ed.) 1893). There were also mentions of Pueo activity in relation to time of day (Figure 1.3). Pueo were described as not being able to see clearly during the day, and were mostly active at night (n =2). In the day, Pueo rested or roosted in the forest, and in the pō (night), they puka (emerged):

> ʻAʻole e hiki i ka pueo ke ʻike mōakāka i ka mālamalama o ka lā, he pōwehiwehi kona mau maka; no laila, e peʻe ana ia i loko o ka ulu lāʻau i ke ao, a pō puka mai (Makua *et al.* 1877).
>
> The Pueo cannot see clearly in the light of the day, their vision is obscured; therefore, they rest in the forest during the day, and at night, they emerge.

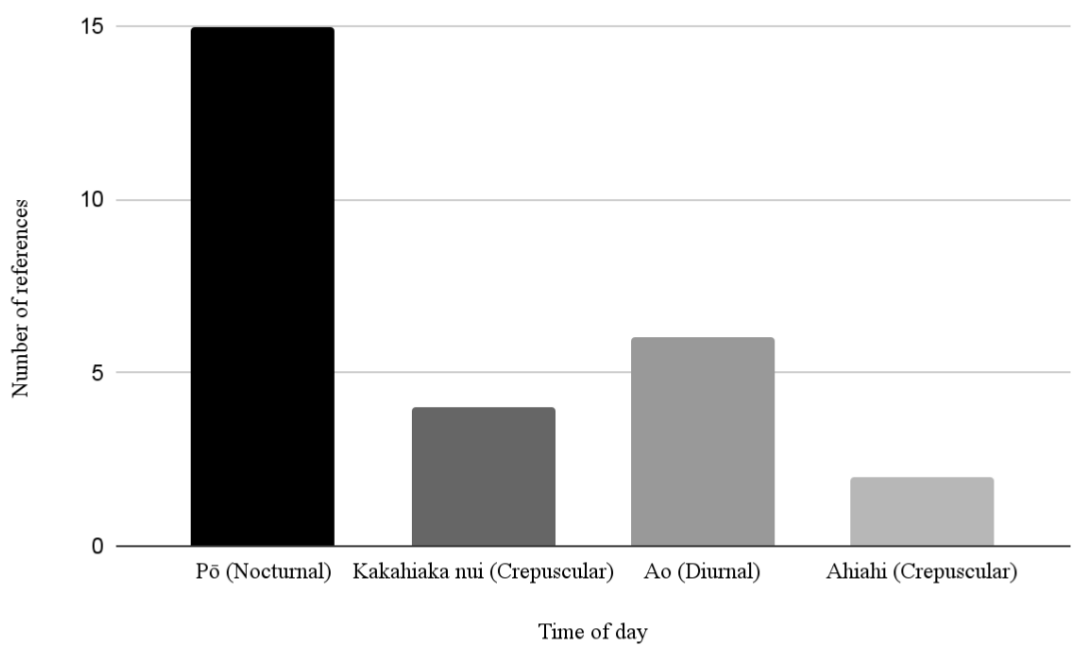

Figure 2.5 Number of references of Pueo activity across articles in regards to time.

Pueo were associated with a number of atmospheric phenomena (Table 2.6). Pueo were the reason or source of ua (rain; *n* = 2), and the cause of uwila (lightning; Kahoewaa 1882). The term mānowai (*n* = 1) was used in relation to Pueo, which is the heart and circulatory system, or figuratively the source of water and of life. In addition to rain, Pueo were related to waimaka (tears; *n* = 5), and appeared in hihiʻo (visions, dreams; *n* = 3).

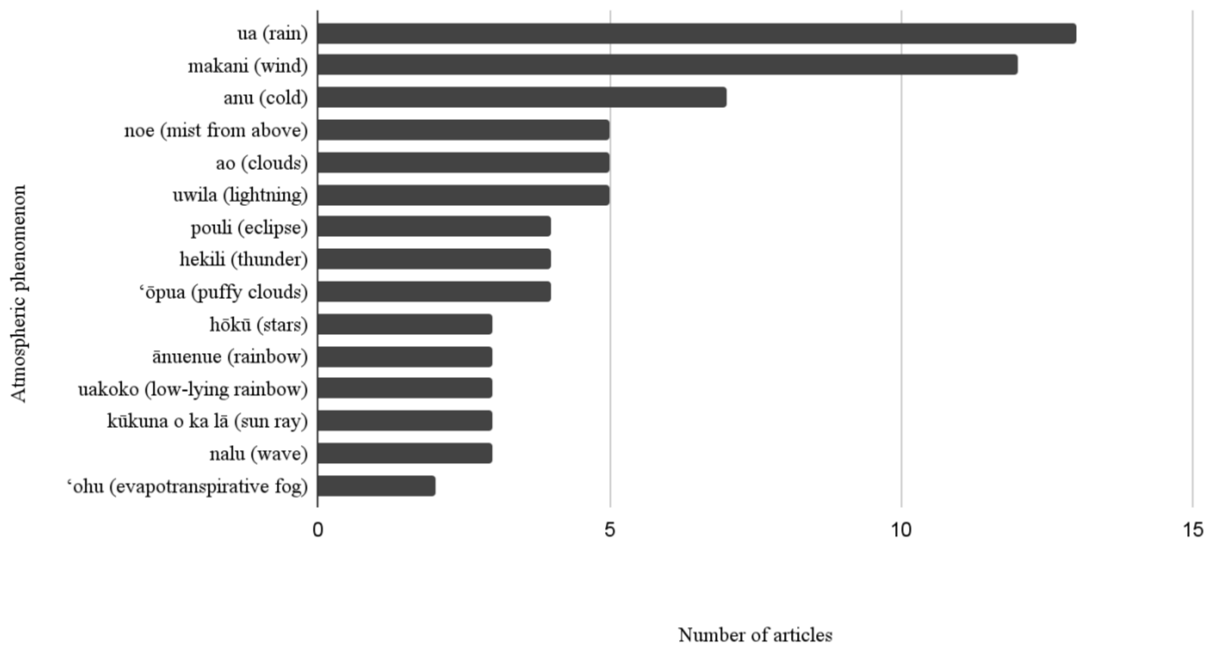

Figure 2.6 Atmospheric phenomena that occur in relation to Pueo.

> He ʻūpoʻipoʻi pinepine ka pueo i ka wā e lele ai, a no laila ua hoʻohalike ia me nā wāhine loea ʻakuku (Keawehaku 1893).
>
> The Pueo repeatedly slaps their wings together while they fly, and therefore they are making like the women who are expert kapa beaters

Pueo are related to Hina (*n* = 4), who is an expert kapa beater (Maunupau 1922). Pueo are compared to and have relations with women who beat kapa (*n* = 3). After seeing a group of Pueo circling overhead, a wahine kukukapa (woman who beat kapa) stated that her kūpuna (elders) said it was a hōʻailona (sign) of good fortune to see this bird, and then the appearance of multiple Pueo guided her to Waipahu (Pooloa 1919). Two articles mention Pueo being a positive hōʻailona (sign) specifically of being on the right path.

> Nānā mai ia Pueo a ʻōili aku me ka ʻiole i ka nuku, manaʻo aʻe ʻoe ua waiwai kamahele, ola nā noho hale (Kawainui (Ed.) 1883).
>
> A Pueo is seen appearing with a rat in their beak, you know the main importance, the houses thrive.

The way Pueo catch their prey was described across articles with the term poʻi, which means to cover or catch between cupped hands, pounce, or snatch (Pukui and Elbert 1986). This term is also reduplicated: popoʻi, poʻipoʻi and ʻūpoʻipoʻi. The prey for which Pueo utilize this skill were ʻiole (rats; $n = 6$), moa liʻiliʻi (small chickens; $n = 5$), or other birds ($n = 2$). Kaikuahineole (1862) described two men finding a Pueo eating the eyes of a dead old woman. S.M. Kamakau (1849) states that Pueo were given by god as protectors against ʻiole. There is a man named Kapoʻi in two separate moʻolelo who found seven Pueo eggs. Pueo dig in the dirt to build their nests ($n = 3$); which were at times found next to pōhaku ($n = 2$).

While it does not appear to have been a common practice, some kānaka ate Pueo. Pueo were famous in the old days in Kula, Māui because of how delicious they were (Keauokalani 1863). Kamakau (1870) states that Pueo were food for people in Naʻalehu, Kaʻū. However, Keauokalani (1863) said Pueo were not eaten on the islands of Oʻahu or Hawaiʻi. Another article goes on to say that those who ate Pueo were teased (Keawehaku 1893).

Pueo feathers were used for pāpale (hats; Nailiili 1868), and to decorate owl idols (Henshaw 1903). Pueo may have also been kept as captive birds at heiau (Henshaw 1903). Kānaka caught Pueo using either a pehe or peheapueo (Henshaw 1903), or a kīpuka, which consisted of a net fastened between short sticks. Between them was a long-pointed stick with a rat tied to it beneath the net called an ʻolokaʻa, which would pierce the stomach of the Pueo when the Pueo pounced on the rat or chicken tied to the ʻolokaʻa (Keauokalani 1863).

<u>Allegory</u>

> Heaha ka manu e kiaʻi mau la i ko hale? He Pueo.
>
> Who is the bird who continually guards the house? Pueo.

Pueo were also used as allegory (*n* = 20). Pueo were called thieves (*n* = 3), liars (*n* = 2), and were mentioned in regards to land theft or land loss (*n* = 4)—more specifically Pueo and ʻIo debated who was responsible for the land theft or loss. For example, ʻIo asked Pueo "Na wai ka hala?" (Whose fault is it) and Pueo responded: "Naʻu ka hala" (it is my fault; Kanealiʻi 1883). One writer inquired: "Pehea lā e loaʻa hou ai ka hanohano i ko kākou ʻāina?" (How do we restore glory to our land)—and pleaded for Pueo to consult with others (Kamaliikane (Ed.) 1898). Dimerata (1896) in a political allegory asked the reader to contemplate who was the Pueo, who were the rats, and who were the small chickens. Another article argued that Pueo and ʻIo could be tamed and live with rats and small birds peacefully, as a happy family, like enlightened (i.e., Christian) people (Gibson (Ed.) 1880).

Inoa ʻĀina (Place names)

I identified 61 Pueo place names in the māhele records. Of these, 21 were on Hawaiʻi Island, followed by 14 on Māui and Oʻahu. The most common place name was Pueo, followed by Puʻu Pueo and Poʻo Pueo. There is a place named Kalehuapueo, makai (ocean side) of Kaluapele (Pele's pit; Kaui 1866). Kapueokahi ("the single owl" Pukui, Elbert & Mookini 1976) is a lae (cape or point) on Māui where Kapōʻulakinaʻu was enchanted by Waka in the form of a Pueo. Kapueokahi, Kaulanaakapueo, and Mānawaipueo (see Ecology) were three places where Pueo gathered on Māui to destroy the people of Wailuku, which was named Wailuku because all the people and aliʻi were destroyed in that battle (Uaua 1871). Kalapueo, Kanoniakapueo, and Pueohulunui were where Pueo gathered to battle Kakuhihewa in the Oʻahu version of the Kapoʻi story (Kamakau 1865). Further, Pueo were in the description for the lunar month of Welo:

> Welo—ʻO huli ke au i ʻo welo; ʻo welo kīhei a ke aʻe loa; a ʻo ke aho loa hoʻi a ka lawaiʻa. ʻO ka malama kēia e kōwelowelo ai ka huelo o ka hoi a me ke piʻa; a kuhihewa ka pueo, he huelo ʻiole, ʻo ka lele nō ia a poʻi (Poepoe 1906).
>
> Welo (April/May)—The time turns to Welo; in Welo the kīhei blows up; and fishing is good. During this month the new growth on the yams wave; and the Pueo mistakenly thinks (they are) the tail of a rat, and then flies and pounces.

DISCUSSION

Due to their cultural and ecological importance, their function as akua, as well as their relationship to multiple akua, the body of Hawaiian knowledge encapsulated in Nūpepa demonstrates that Pueo are a Cultural Keystone Species. Data from Nūpepa show that Pueo meet all but one of the criteria to designate a species as a Cultural Keysone Species (Table 2.1). Pueo are kinolau of akua that play important roles in ecosystem functioning (i.e., water cycles and forest health). The akua that Pueo are genealogically related to are foundational in nutrient cycling through ecosystems, demonstrating that our kūpuna understood Pueo's ecological importance. Pueo are also associated with atmospheric phenomena that are indicators of ecosystem health such as fog, mist, clouds, and rain, which are particularly important as we consider ecological shifts happening due to climate change. In the next few sections I will go through each of the criteria for Cultural Keystone Species, and the ways in which Pueo meet those criteria.

Naming and terminology

Pueo were also foundational to naming at multiple scales. For example, the main purlins in traditional house construction are called ʻaho pueo. Pueo are related to the Hawaiian ancestor and staple crop, kalo, in naming terminology (Winter 2012). Numerous place names included Pueo or were named due to incidents that occurred involving Pueo. For example, Wailuku, Māui was so named because Pueo killed all the aliʻi and makaʻāinana there (Uaua 1871).

Pueo were described as phenological indicators of season. Young fledgling Pueo would pounce on growing yams in the lunar months of Welo (April to May) as they learned to hunt (Poepoe 1906), perhaps because the new growth of these plants resembles rat tails. Atmospheric phenomena that occur in moʻolelo about Pueo indicate seasonality and are indicative of behavioral changes throughout the year. Many of the atmospheric phenomena—ua, ānuenue and uakoko, makani, hekili, uila—all occur during Lono season, which starts with the rising of Makaliʻi (Pleiades) in our night sky which occurs around October or November (Nuʻuhiwa 2018). Pueo breeding season also begins around this time (Wang 2022). Therefore, Pueo are likely to be more active and visible, performing aerial displays such as sky dances and wing claps as a part of their mating dance (Wiggins *et al.* 2020). In contrast, certain types of thunder, and lightning that strikes the earth are indicators of the initiation of Kū season (Nuʻuhiwa 2022).

Additionally, environmental indicators of the return of the koholā and Ke Ala Polohiwa a Kanaloa (winter solstice), such as the return of Kōlea, also show up in moʻolelo about Pueo (n = 5; Keliʻikipikāneokolohaka 2021).

Intensity, type, multiplicity of use

Pueo parts were utilized for multiple purposes, including food and cultural items, according to Nūpepa, and multiple trapping methods were described for the capture of Pueo (Keawehaku 1893). Keauokalani (1863) said that Pueo were eaten on Māui and Kamakau (1870) said they were eaten in Nāʻalehu, Kaʻū, but Pukui disputes this claim in her translation of Kamakau (1968). Feathers were used in the highest quality kahili (Malo 1951), pāpale (Nailiili 1868), and to decorate Pueo kiʻi (idols; Henshaw 1903). Pueo were potentially even kept at heiau (Henshaw 1903).

Irreplaceability, unique position in culture

Pueo hold an irreplaceable and unique position in Hawaiian culture as akua, ʻaumakua, and kinolau. Before Christianity, Pueo were considered akua by some of our kūpuna. In addition to being ancestors (Kalākaua 1889), Pueo are also ʻaumakua and had pilina with aliʻi lines, warriors, and mahiʻai. Articles showed that they had relationships to a multitude of akua who represented ecosystem functionality. Further, it is important to mention that “all of these relationships exist simultaneously; there are no ‘bold lines’ between akua” (Kealiʻikanakaʻoleohaililani, personal communication).

Psycho-socio-cultural function

Cultural Keystone Species whose existence and symbolic value play an important role in the stability of a culture over time, and who are featured prominently in narrative, ceremony, dances, and symbolism are said to have psycho-socio-cultural function (Cristancho and Vining 2004). Pueo are prominent in moʻolelo, kaʻao, hula, koʻihonua, oli, and kanikau. Pueo, like all akua, have important ceremonial, as well as symbolic value. Discerning which akua are associated with which elements helps us understand their function. In the articles, the central role of Pueo as ecosystem indicators was demonstrated in that they were associated with circular rhythms in nature such as seasons and moon cycles, as well as with ecosystem dynamics such as predator-prey cycles.

Pueo are genealogically related to Hina, the moon, who plays an important role in keeping time, and planting crops because she pulls liquid such as water, sap, lava, and blood like a magnet and causes ebb and flow (Nuʻuhiwa 2022). Further, Hina and Uli both appear in multiple moʻolelo (Kalua and McCormack 2022); Hina gave birth to many kupua and then their grandmother, often Uli, would come to hānai (raise) them. In one moʻokūʻauhau Uli (Ulikahulipāpākini) and Lono (Lonoikapukolikoliko) give birth to four daughters named Hina: Hinamakakai, Hinamalule, Hinaanaiamea, and Hinakeka (Kalai 1896):

> Lonoikapukolikoliko (k) iā Ulikahulipāpākini (w),
> Hānau ʻo Kānelūhonua (k), ʻo Kumulipo (k), ʻo ʻŌpuʻukahonua (k), ʻo Kumuhonua (k), ʻo Hinamakakai (w), ʻo Hinamalule (w), ʻo Hinaanaiamea (w), ʻo Hinakeka (w), ʻo Pōʻele (w), ʻo Pōwehiwehi (w), ʻo Lalohana (w), ʻo Kūkūʻena (w), ʻo Nuakea (w), ʻo Kapauonuiākea (w), ʻo Nihoaikaulu (w), ʻo Kaiona (w), ʻo Puanui, ʻo Pualoa, ʻo Puaiki, ʻo Puapoko he poʻe wāhine wale nō ia; ʻo Hanalaʻaiki (w), Kahailiopua (w), ʻo Laea (w), ʻo Kaiona (w), ʻo Waiololī (k), ʻo Waiololā (w), Kānewahilani (k), Kapaialani (k).

Uli is potentiality; her sacred power is homeostasis, harmonic balance and synchronicity, which depends on things getting knocked out of balance (Kealiikanakaoleohaililani 2022).

The relationship of Pueo to water cycles are exemplified by their positionality as kinolau to Kāne, moʻo akua, and Lilinoe. Kāne is the heat of the earth in the atmosphere, fresh water, evapotranspiration, and growth (Kanahele 2011, Kanahele 2021). Moʻo akua are pili to fresh-water bodies (e.g., rivers, lakes, ponds, and streams; Brown 2022). They represent the life-sustaining and destructive forces of water and water cycles, and the ability to shapeshift (Brown 2022). Lilinoe is the akua of mist, fires and desolation, the daughter of Kāne and sister to Poliʻahu (Yuen 2016). She takes the form of a Pueo to lead people out of thick mist at Haleakalā, Mauna Kea, and Mauna Loa (Hood *et al.* 1976). Further, Pueo were considered the source of rain and lighting, and referred to as mānowai: the source of water and life. These pilina are indicative of the atmospheric phenomena that appeared in relation to Pueo, as well as their relationship to the ʻōhia lehua (*Metrosideros polymorpha*) who play important roles in water cycling through ecosystems (Giambelluca *et al.* 2009; Bright *et al.*, 2015; DLNR 2016; Teuling *et al.* 2017), and are also kinolau of Kāne (Kanahele 2011), and moʻo akua (Brown 2022).

The akua kumupaʻa Kūkauakahi represents Kū, the akua that rules over growth, the sky and earth together, the works of man, and war (Kanahele 2021). Pueo are protectors in war, as noted in the saying ka pueo kani kaua, "the owl who sings of war, the owl as a protector in battle" (Beckwith 1970). Beckwith (1970) also asserts that Kūkauakahi is associated with Kāne worship and Handy and Pukui (1998) state that he associated with "Kāne of the Pele clan" (potentially Kānehekili, Kānemilohaʻi and/or Kānehoalani; Keliikanakaoleohaililani, personal communication). Kūkauakahi is the son of Haumea and Kanaloa in the Kumulipo and of Wākea and Papa in another moʻokūʻauhau (Poepoe 1906).

> Hānau ʻo Haumea he wahine, noho iā Kanaloa he kāne
> Hānau ʻo Kukauakahi he kāne, i noho iā Kuaimehani he wahine…
> ʻO Haumea ʻo ua wahine la nō ia
> Noho iā Kanaloa akua
> ʻO Kauakahi akua no a ka lolo (Kalākaua 1889).

The relationship of Pueo to Haumea and Kanaloa through moʻokūʻauhau personifies the function of this apex predator in ensuring nutrient cycling through ecosystems. Haumea is the top of the earth where there is fertilizer and all things that grow on earth (Kanahele 2022). Kanaloa is the ocean akua and is related to "foundational knowledge, ancestral continuum, and environmental balance" (Nuʻuhiwa 2022). Further, everything that dies eventually ends up in the ocean (Kanahele 2022). The heat of Kāne works with Kanaloa to cause decomposition and these two akua work together to ensure the health of the earth, and that nothing goes to waste (Kanahele 2021, Kanahele 2022). Thus, a relationship exists for the utilization of the benefits of death that make everything living healthy, which reflects the roles of apex predators in ecosystem health.

Pueo's relationship to Kapōʻulakinaʻu and Uli, who live in Keʻalohilani, and are associated with learning whilst in a dream state (Kanahele 2011). Kapōʻulakinaʻu, another child of Haumea, is associated with Laka, and has the power to take or restore life (Kanahele 2011). Pueo has the markings or physical traits of Kapō, (i.e., mottling, dark streaks; Kealiikanakaoleohaililani, personal communication). Like Kapōʻulakinaʻu and Uli, Pueo show up in dreams, and have the power to restore life. Kapō is also silent, and Pueo's voice is described as "me he hāwanawana lā", like a whisper (Kahiolo 1863; like all owls they have specialized feathers that make their flight almost completely silent (Wagner *et al.* 2017).

Pueo are totems in the form of ‘aumakua and kinolau. By Platten & Henfrey’s (2009) definition, all ‘aumākua would be considered Cultural Keystone Species because these species support system complexity and have essential functions in our culture concerning social identity, cultural practices, and beliefs. Indeed, some of the sayings about Pueo also indicate a much deeper cultural importance than what is currently understood. Pueo are in the highest heavens (Kaiakea 1922). Pueo ascends through Nu‘umealani to Ke‘alohilani (Manu 1895), which are the realms of the gods (Handy and Pukui 1998; Kanahele 2011).

Interaction with other species

In Nūpepa, Pueo interacted with multiple species including ‘Io and manō, other endemic apex predators who are also ‘aumākua, as well as the foundational forest tree ‘ōhi‘a lehua, and two social-ecological keystones, kalo and ‘uala (Winter *et al.* 2018b). Pueo and ‘Io are the only two native raptors to fill the terrestrial apex predator niche in Hawai‘i. The number of species that Pueo have relationships with indicate that our kūpuna understood the relationality between apex predators and other species that indicated ecosystem health. Further, these relationships are reflected in apex predators’ pilina to kānaka, in particular, to ali‘i as ‘aumākua, and the functionality of this relationship. Our kūpuna understood that ecosystem health was necessary for kānaka to thrive in the pae ‘āina, thus venerating apex predators who play a critical role in ecosystem function and act as indicators of ecosystem health suggests that ali‘i knew if they maintained pilina with these species they would be informed of ecosystem health decline.

Further, the plants that Pueo are associated with also have important ecological functions. ‘Ōhi‘a lehua are the most common tree in Hawaiian forests, are primary habitat for endemic honeycreepers, and play an important role in watershed health by collecting water (DLNR 2016). ‘Ōhi‘a are one of the first plants to colonize new earth after a lava flow (DLNR 2016). ‘Ōhi‘a also play important roles in the evapotranspirative process (Giambelluca *et al.* 2009), and cloud formation (Bright *et al.*, 2015, Teuling *et al.* 2017). ‘Ōhi‘a are kinolau of Laka, Kāne (Kanahele 2011), Hi‘iaka, and Kū (Gon 2013); the relationships to these akua are shared by Pueo. Further, ‘ie‘ie (*Freycinetia arborea)* was the second most common plant species that Pueo are pili to—another kinolau of Kāne and Laka (Kanahele 2011). ‘Ie‘ie are sprawling vines common in wet to mesic forests (Gustafson *et al.* 2014), on middle-aged substrates (Dupuis 2012). They are kinolau of Kāne due to the way they feed large amounts of rain back into forest systems (Kurashima *et* *al.* 2018). Pukui and Elbert (1986) state that ‘ie‘ie are one of five kinolau placed on hula altars, which also include lama (*Diospyros* spp.), and ‘ōhi‘a. Kanahele (2011) elaborates that Kāne and Laka are the male and female counterparts of each of these plants. Further, the aforementioned Kapō is the dark side of Laka. In addition to being called one of Laka’s manu (Kānepu‘u 1868), Pueo’s relationship to these plants reinforces their relationship to the aforementioned akua.

Persistence and memory of use in relationship to cultural change

Through the use of Pueo as allegory it is clear that kānaka blamed the ali‘i for the loss of land and water to foreign interests. Some of the relationships of Pueo to ali‘i were discussed above. Ali‘i were responsible for maintaining water cycles (EKF 2011), as well as for maintaining the abundance that the land provided, and ecosystem functionality (Kurashima *et al.* 2018). This kuleana is why kānāwai and kapu were traditionally enforced by ali‘i (Kurashima *et al.* 2018). Kapu is the level of sacredness; kānāwai are laws or edicts that are enacted to preserve the kapu through certain behaviors (Kanahele *et al.* 2017). The metaphor of Pueo being tamed so they can live peacefully together with rats as “enlightened people” is a metaphor for the forced assimilation of kānaka to Christianity. The degradation of religious systems such as ho‘omana were harbingers of the change in land tenure and stewardship which centered foreign interests and capital (Kame‘elehiwa 1994). This type of narrative is part of a larger settler-colonial project which seeks to erase the native and remove them/us from the land (Tuck and Yang 2012). Some of the ways in which this shift in religious ideologies affected kānaka who still desired to practice ho‘omana can be seen in this quote from Thurston (1882):

> Religion-related structures and objects were destroyed throughout the islands, and anyone who refused to comply with the edict was persecuted and even killed.

A look across the literature hints at intentional violence done to Pueo due to colonialism. People were killing Pueo “for no reason other than” that they were owls, and the species was becoming increasingly rare (Henshaw 1903). That Pueo were being intentionally shot indicates the intentionality of this violence. Pueo were a part of ho‘omana rituals and are considered akua as well as ‘aumakua, and were perhaps also kept as captive birds in heiau (Henshaw 1903). However, Kalua (1870) said that when the heiau were toppled, Pueo akua left.

Similar acts of colonial violence were waged upon other species that held cultural or spiritual significance to Indigenous Peoples. The most well-known examples of this are the North American bison (*Bison bison*) and the wolf (*Canis lupus*). Starting in the 1860's the American armed forces intentionally waged a war on bison in order to snuff out the food source for plains tribes and end their "nomadic" way of life (Sheridan 1868; Sherman 1875). Indeed, following the route of colonization, settlers systematically hunted bison, and by the 1830's this iconic species was nearly extirpated east of the Mississippi (White 2009). Similarly, as the wave of settlers moved west across the continent, wolves were also targeted because settlers feared them—an attitude that was brought from Europe. Wolves are sacred to many Indigenous Peoples, playing prominent roles in creation stories, and were hunted to the brink of extinction by 1926 in what is now known as North America after systematic hunting, and a large-scale strychnine poisoning of baited carcasses (Allen 1874; Lopez 1978). In 1630, the first bounty was placed on wolves in Massachusetts (Young 1944), which continued until 1965 and had increased to $20-$50 per wolf (USFWS 2007, cited in PBS 2008). A parallel can be drawn between this and a similar bounty placed on ʻIo. Despite how rare ʻIo had become by 1889, Dr. V. Knudsen of Waiawa offered $10 for one ʻIo, $15 for two, and $20 for three (Anonymous 1889). ʻIo are the ʻaumakua of many high-ranking chiefs (thus the naming of ʻIolani Palace) and hold similar cultural importance to Pueo. Systematically removing sacred creatures is a tool of colonization that further separates Indigenous peoples from our lands and ancestral practices to force assimilation. This is part of a larger cultural genocide that demonized other ceremonial practices such as drinking ʻawa (Winter 2004) and dancing hula, which was banned by Kaʻahumanu in 1830 along with the worship of our ancient gods (Kamakau 1961, Silva 2000).

Degradation of hoʻomana due to Christianity is clearly illustrated across the literature when our kūpuna turned away from our akua and ʻaumākua, and towards Jehovah. In hoʻomana rituals, akua are given mana through ritual, creating a reciprocal relationship that ensures the health of both akua and kānaka (Brown 2016). Thus, the health of our akua ensures our health and vice-versa. This is reflected in the fact that as Indigenous people our health is directly related to ecosystem health, and we ensure ecosystem health by protecting biodiversity. Currently, 80% of the world's biodiversity is being conserved by Indigenous peoples (World Bank 2003, World Bank 2008). Perhaps, then, the intentional destruction of Pueo and lack of information on Pueo ecology is due to a rift in our religious system that caused certain cultural knowledge to be forgotten.

Presence/abundance in the human community

While Pueo still persist in low numbers across the islands, they were historically abundant. In the moʻolelo of Hiʻiakaikapoliopele it was said that from Hawaiʻi to Kauaʻi there was no place without a Pueo (Poepoe 1909). Pueo had, indeed, once been "very numerous in the lowlands of all the islands", but sugarcane fields had destroyed lowland Pueo breeding habitat (Henshaw 1903). In 1902 a man named Dr. George Huddy found a nest of four Pueo in Kalihi Valley, Oʻahu, and took them home (Williams 1902). No one in Huddy's family recalls having seen Pueo in Kalihi Valley for the past 40 years (1860's), although they were "at one time plentiful" in the valley (Anonymous 1902).

Despite the intentional destruction of Pueo across the islands after the illegal overthrow of the Hawaiian Kingdom, and a systematic destruction of our ritual practices, Pueo have persisted. They are the only raptor known to breed on all islands (DLNR 2005; Cotin and Price 2018). Despite their historical abundance, they are currently believed to be in decline (DLNR 2005), and were recently listed as a species of concern by USFWS (USFWS 2021). Modern day moʻolelo about Pueo are still told today by people who have interactions with them, and they are still considered kupaianaha by many kānaka including myself. Their continued persistence indicates their resilience as a species and reflects the resilience of Kānaka in the face of large-scale cultural change and a deliberate attempt to erase us.

IK reflected in research

IK of Pueo is supported by studies on Short-eared Owls globally. For instance, Makua *et al.* (1877) said that Pueo roost in the forest during the day, and at night they emerge. Tseng *et al.* (2017) confirmed that Short-eared Owls in Taiwan left their preferred day-roosting sites in grasslands or woodlands at dusk to hunt over agricultural lands at night. Wilhite (2021) found that Pueo on Oʻahu almost exclusively perched in woodlands during the day when they were least active, and that they were most active during nocturnal and crepuscular periods, emerging from the forest to hunt preferentially over open grasslands.

Pueo use of edge habitat—the transition between two habitat types—where a variety prey is available and abundant (Šálek *et al.* 2010) is represented by a Kāne kinolau named Kāneikapahuʻa, a war god with a Pueo body who stands at the edge of the forest (Emory 1942). Pueo have been observed using a variety of habitats including wetlands, high-elevation native forests, agricultural lands and developed areas (Wilhite 2021, Cotin *et al.* 2018), which was reflected in the variety of habitats Pueo occupied in moʻolelo. Indeed, the term "peʻepeʻe pueo" means to hide in the forest like an owl (Pukui and Elbert 1986). Similarly, these observations can further deepen our understanding of Kānekūpahuʻa (the man with the Pueo body standing at the forest edge), as IK about species behavior and distribution.

Across moʻolelo, Pueo are mentioned most often at night, which is consistent with global research on Short-eared Owls (Craighead and Craighead 1956; Clark 1975; Clark 1983; Reynolds & Gorman 1999; Calladine *et al.* 2010; Calladine & Morrison 2013; Larson & Holt 2016; Johnson *et al.* 2017; Tseng *et al.* 2017; Wilhite 2021). Furthermore, Clark (1983) asserted that Short-eared Owl hunting effectiveness increases with lunar illumination, reinforcing IK that Hawaiians hold reflected in Pueo's relationships to Hina. During dark nights, when the moon is not illuminated, Pueo may shift their behavior to be more crepuscular to take advantage of the light of the sun in the evening or early morning when the moon is dark, more research is needed to elucidate this relationship.

Pueo appeared in articles in concurrence with atmospheric phenomena such as fog, mist, clouds, and rain, which are also closely tied to forest health. This IK is reflected in the following ʻōlelo noʻeau:

> Hahai nō ka ua i ka ulu lā'au.
>
> Rain always follows the forest (Pukui 1983).

Indeed, this IK has been validated. Scholl *et al.* (2007) confirmed that fog and clouds are important water sources in forest ecosystems. Dawson (1998) affirmed that the presence of trees influences the amount of fog in the forest. Further, deforestation changes hydrology by decreasing the amount of water in the degraded systems (Ingwerson 1985, Lawton *et al.* 2001). The relationship between Pueo and these atmospheric phenomena and as manōwai are other examples of how our kūpuna understood their importance in forest and ecosystem health—that all of the aforementioned variables were indicators of a healthy ecosystem. However, the relationship of Pueo to clouds can also be interpreted as an elevational. Pueo occupy the space where the clouds rest on the mauna (mountain), which is also exemplified in Pueo being found in the wao akua (Kapu (Ed.) 1893).

Pueo are also less specialized in their diets than continental Short-eared Owls. In addition to rodents, Pueo eat birds, insects, and lizards (Henshaw 1903; Mostello and Conant 2018, Luther 2020). These differential preferences between individuals for habitat type and prey indicate that Pueo are generalists, although more research is needed to determine whether they are generalists at the individual, population, or regional level. Further, a quote indicates that from an IK perspective Pueo have the largest home range of any of our native manu:

> ʻAʻohe a mākou ʻōlelo ʻē aʻe nou e Pueo, eia wale nō, he keiki kamaʻāina nō o no ka ʻāina nei, no laila, ua ʻike nō ʻoe i nā kauauna nihomole āpau o ka ʻāina iho nei. (Poepoe (Ed.) 1896).
>
> We have no place to refute you, Pueo, for you are the child born of this place and you know the lay of the land in this entire region as a man knows the berms of his taro field.

This utterance could be classified as an ʻōlelo noʻeau, but it is one that was not previously documented by Pukui (1983).

While more research is needed to fully understand the depths of the relationships between Pueo and other species, as well as their relationship to the multitude of akua, the relationships between these akua, and all the implications of these relationships, this research is a starting point. Realizing the depths of IK through nuance and multiple layers of meaning is also difficult due to the lapse of time, and our current context as well as loss of certain aspects of ʻŌlelo Hawaiʻi through colonization and the nearly 100-year ban on ʻŌlelo Hawaiʻi. Others may be able to delve deeper into some of these phenomena, and uncover even more pertinent information. Like any Indigenous group, Hawaiian culture is not a monolith, therefore others may read or translate differently, or notice additional layers of meaning. I chose to focus my research on the breadth of knowledge held in Nūpepa articles by looking across articles instead of deep diving into a specific moʻolelo. Bringing together different streams of information in a coherent way takes expertise, focus, and a breadth of knowledge. A team of people with different areas of expertise could pull even more out of these articles. Additionally, Pueo is one of my

ʻaumakua. Therefore, my personal relationship with Pueo and my aloha and reverence for them may have influenced the way I interpreted the articles. I tried to channel my ancestors as much as possible while conducting this research to guide my interpretation.

Restoration of ʻŌiwi land stewardship practices has the potential to increase Pueo abundance, since Pueo were historically abundant in agro-ecological systems stewarded by kānaka. For example, Hawaiian land stewardship practices and biocultural restoration have already been shown to increase habitat for endemic waterbirds (Winter *et al.* 2018a, Opie 2022). Since Pueo and ʻAlae appear together in moʻolelo these restoration practices may similarly benefit Pueo. Further, Harmon *et al.* (2021) predict that restoration of loʻi kalo would significantly increase habitat for endangered endemic waterbirds, more than making up for losses due to sea level rise. Biocultural restoration has been shown to meet conservation goals for rare and endangered species (Winter *et al.* 2020a), as well as preserve functionality of ecosystems and maintain biodiversity (Winter *et al.* 2020b). Lastly, restoration of hoʻomana practices and the reciprocal energy exchange between kānaka and Pueo is likely to have a positive impact on the species.

Kuʻu wahi ʻaumakua Pueo
E lele ana i ka lewa nuʻu i ka lewa lani
Ma luna o ka ʻāina āpau
Mai ke kualono a hiki i ka moana hohonu
Ka mea e poʻi nei i ka ʻiole a me nā manu liʻiliʻi
Na Pueo lani hoʻokuʻi
Nāna e popoʻi i ka aewa o ka lani
ʻEliʻeli kau mai
(Stormcrow 2023).

My beloved Pueo ancestor
Flying in the highest heavens
Over all the land
From the mountain top to the deep ocean
The one who pounces on rats and small birds
It is Pueo in the highest heavens
Looking to cover up the lofty genealogies
Possess me with awe

CHAPTER 3: FACTORS INFLUENCING DETECTABILITY OF PUEO

ABSTRACT

Species who are perceived as specialists can become generalists in island ecosystems due to release from inter-specific competition. Indeed, species who colonize islands tend to be far-ranging generalist species capable of utilizing multiple habitats and ecosystems. Short-eared Owls (*Asio flammeus flammeus*) are a globally distributed species who are often referred to as grassland specialists. However, island endemic subspecies of Short-eared Owl tend to utilize a broader range of habitats and food sources. Hawai‘i has a suite of three resident raptors: Pueo (*Asio flammeus sandwichensis*), ‘Io (*Buteo solitarius*) and Barn Owl (*Tyto alba*). Pueo are the only remaining raptor to breed across all islands, and utilize every available terrestrial habitat type. ‘Io are presently only on Hawai‘i Island, with occasional sightings on Māui. Barn Owls were introduced in 1958 to control rats and are now present on all islands. In this study I sought to understand the factors influencing Pueo occupancy and detectability on Hawai‘i Island. We conducted audio broadcast surveys utilizing the calls of these three raptor species in multiple ecosystems. Results indicated that temperature and elevation were the two most important factors influencing Pueo distribution. Pueo were detected in nearly every habitat type that we surveyed, but were more likely to occupy higher elevation habitats. ‘Io, on the other hand, were detected more frequently in low to mid-elevation habitats. Our study provides evidence that Pueo are generalists and Short-eared Owls may be globally distributed because of their ecological flexibility.

INTRODUCTION

Species who are perceived as specialists in continental systems can function as generalists in island ecosystems due to release from interspecific competition and niche expansion (Crowell 1962; Van Valen 1965; Abbott 1980; Baker-Gabb 1985; Olesen *et al.* 2002). Specialists are typically restricted to a narrow subset of resources or habitats (McKinney 1997; Colles *et al.* 2009), constrained by smaller range sizes (Brown 1995) and have low dispersal capability (Williams *et al.* 2006). In instances when a specialist has a large range size, their exposure to a variety of habitat types and resources can cause them to act as generalists, becoming more flexible in resource use (Colles *et al.* 2009). In contrast, species may be generalists due to a set of morphological and physiological characteristics that lend themselves to behavioral flexibility. As a result, they may tend to be opportunists using diverse habitats for foraging and breeding (Cooper *et al.* 2002) causing them to potentially be less threatened by habitat alteration or disturbance due to diverse use of resources (Büchi and Vuilleumier 2013). Most species who colonize islands are highly mobile generalist species who are flexible in habitat selection and resource use (Blondel 2000). As a result of this adaptability, generalists play important roles in ecosystem function (Palacio *et al.* 2016). For example, apex predators who act as generalists by consuming multiple species provide more system stability than specialist counterparts (Brechtel *et al.* 2019).

Apex predators such as raptors (e.g., hawks and owls), are indicators of ecosystem health (Kovács *et al.* 2008, Movalli *et al.* 2017, Natsukawa *et al.* 2021) and biodiversity (Sergio *et al.* 2008) and are particularly sensitive to anthropogenic changes on the landscape (Sergio *et al.* 2008). However, one-third of global raptor research is focused on only 10 species, and research remains a global priority (Buechley *et al.* 2019; McClure *et al.* 2023). Island-endemic and tropical raptor species have a larger proportion of threatened species and remain understudied (McClure *et al.* 2018). Island endemics are range-restricted by the size of the island they live on (Anderson 1994; Blondel 2000) and may be further constrained in the coming decades due to climate change (Jansson 2003; Smeraldo *et al.* 2020).

Short-eared Owls (*Asio flammeus*) are a globally distributed species, often described as grassland-dependent specialists (Machniak and Feldhamer 1993; Stone *et al.* 1994; Wiggins *et al.* 2006; Figueroa *et al.* 2009; Booms *et al.* 2014; Tseng *et al.* 2017) who preferentially utilize heterogeneous habitats with structural complexity (Miller *et al.* 2016). In continental systems they are considered nomadic and undertake large seasonal movements in search of prey (Calladine *et al.* 2012; Johnson *et al.* 2017; Tseng *et al.* 2017). Short-eared Owls are most active nocturnally (Craighead and Craighead 1956; Clark 1975; Clark 1983; Reynolds & Gorman 1999; Calladine *et al.* 2010; Calladine & Morrison 2013; Larson & Holt 2016; Johnson *et al.* 2017; Tseng *et al.* 2017) and are diurnally active only during the breeding season (Reynolds & Gorman 1999; Calladine *et al.* 2010). Due to evidence of range-wide population decline over the last few decades, Short-eared Owls are a species of conservation concern (Holt 1986; Wiggins *et al.* 2006; Booms *et al.* 2014). Thus, developing robust survey methods remains a global priority.

Short-eared Owls are a good candidate for understanding functional differences within generalist species given that there are six range-restricted island subspecies, and nine subspecies that utilize tropical latitudes (Wiggins *et al.* 2020). Island-endemic Short-eared Owls may differ functionally in behavior due to constrained ranges and prey preferences. In Hawaiʻi, Scotland, and the Galapagos, Short-eared Owls behave as residents with high site fidelity relative to continental systems (Village 1987; Schulwitz *et al.* 2018, Wilhite 2021). In the Caribbean, Short-eared Owls (*A. f. domingensis*) occupy open woodlands, forest edges, and mangroves (Wiley 1986, Wiley *et al.* 2010, Thorstrom and Gallardo 2017). Galápagos Short-eared Owls (*A. f. galapagoensis*) prefer the wettest high elevation habitats, and their distribution, abundance, and behavior is affected by co-existence with the Galápagos Hawk (*Buteo galapagoensis*) and Barn Owl (*Tyto alba*) (deGroot 1983). On islands where the Galápagos Hawk and Galápagos Short-eared Owl co-exist, the Short-eared Owl is present in comparatively smaller numbers and is either completely nocturnal or rarely seen diurnally; where all three are present the Short-eared Owl is crepuscular (deGroot 1983). A similar suite of raptors exists in Hawaiʻi: Pueo (Hawaiian Short-eared Owl; *A. f. sandwichensis*), ʻIo (Hawaiian Hawk; *Buteo solitarius*), and Barn Owl (*Tyto alba*). Formerly resident on Oʻahu, Kauaʻi, Molokaʻi, and Māui, ʻIo occurs today primarily on Hawaiʻi island (Clarkson and Laniawe 2020). The Barn Owl was introduced in 1958 to control rats and is found on all main Hawaiian Islands (Mostello and Conant 2018). Thus, Pueo are the only remaining native raptor to breed on all islands (DLNR 2005), and are therefore the only native apex predator filling the critical role of top-down trophic control in most systems.

Pueo are endemic and appear in the subfossil record after the arrival of Kānaka ʻŌiwi (Native Hawaiians; Olson and James 1991) to the islands, perhaps due to the introduction of the Pacific rat (*Rattus exulans*; Burney *et al.* 2001) and the transformation of lowland areas to Hawaiian agroecology systems such as loʻi kalo (wetland taro fields). They are thought to have arrived here from Alaska (Wiggins *et al.* 2020). In Hawaiian culture, Pueo are valued as ʻaumakua (deified ancestors, ancestral guardians), akua (deities, elemental forces), and kinolau (physical manifestations) of the akua Kāne (this thesis; Handy and Pukui 1998), Kū (Gon *et al.* 2021), Lilinoe (Hood *et al.* 1976), and moʻo akua (water deities; Brown 2022). They are nocturnal, crepuscular, and diurnal (Henshaw 1903; Berger 1981), and have been observed using every terrestrial habitat in Hawaiʻi for hunting, nesting, or roosting (DLNR 2005; Cotin and Price 2018; Wilhite 2021; Luther 2020). Their diet is more flexible than the North American subspecies and prey consists of rodents, birds, insects, and lizards (Henshaw 1903; Mostello and Conant 2018; Wang 2022). On the island of Oʻahu, Pueo are state-listed as endangered due to habitat loss and threats from vehicle collisions, rodenticide poisoning, and introduced mammalian predators such as cats (*Felis domesticus*), dogs (*Canis lupus familiaris*) and mongoose (*Herpestes auropunctatus*; DLNR 2005). However, there are no state-wide population estimates for Pueo. Occupancy estimates from eBird data have shown that Pueo have lower occupancy on Hawaiʻi Island than Oʻahu despite having a seven times larger land mass (Wilhite 2021).

In this study we sought to understand factors influencing Pueo detectability, and develop robust survey methodology applicable to the multitude of habitat types Pueo are known to utilize. We also sought to identify potential interspecific interactions between Pueo, ʻIo, and Barn Owl. We surveyed for Pueo, ʻIo and Barn Owls in a variety of habitat types using audio broadcast surveys, which have been shown to increase detection probabilities for rare species such as owls (Mosher *et al.* 1990; Kissling *et al.* 2010; Ibarra *et al.* 2014). We used multi-species occupancy models (MSOM) to assess pairwise covariance (likelihood of one species being present given another is present; Rota *et al.* 2016), and single-season occupancy models (SSOM) to assess factors influencing detectability Pueo.

METHODS

Study Area

The Island of Hawai‘i (Figure 3.1) is the largest and youngest of the Hawaiian Islands with an area of 10,433 km^2 (Juvik & Juvik 1998). It is composed of five shield volcanoes, including Kohala, Mauna Kea, Hualālai, Mauna Loa, and Kīlauea, of which Mauna Loa and Kīlauea are still active (Armstrong 1973). Mauna Kea reaches a height of 4207 m from sea level (USGS 1977), with a total height over 10,000 m when measured from the sea floor (Ireton and Schaumann 2012). Mean annual precipitation ranges from 204 mm to 10,271 mm, resulting in diverse vegetation types and microecosystems (Giambelluca *et al.* 2014). The largest percentage of remaining native-dominated forests (38.1%) are on Hawai‘i Island, with ‘ōhi‘a (*Metrosideros polymorpha*) dominant in both dry and wet forests (Jacobi *et al.* 2017).

Study site selection

We selected study sites from areas where Pueo were previously observed, which was informed by the eBird data from the years 2019 and 2020, and from additional data points from Hāloa ‘Āina and Three Mountain Alliance where Pueo have been observed. Sites were selected on state, federal, and private lands where access was obtained. Observations of Pueo from eBird were turned into polygons with an 8 km radius, corresponding to the larger end of the home range size of Pueo (Wilhite 2021). Polygons were merged and put onto a vegetation raster in ArcGIS. Eighty points were randomly selected and 30 survey routes were selected from initial sites by ease of access on roads, which were preferentially not heavily trafficked (Figure 3.1; Takats *et al.* 2001).

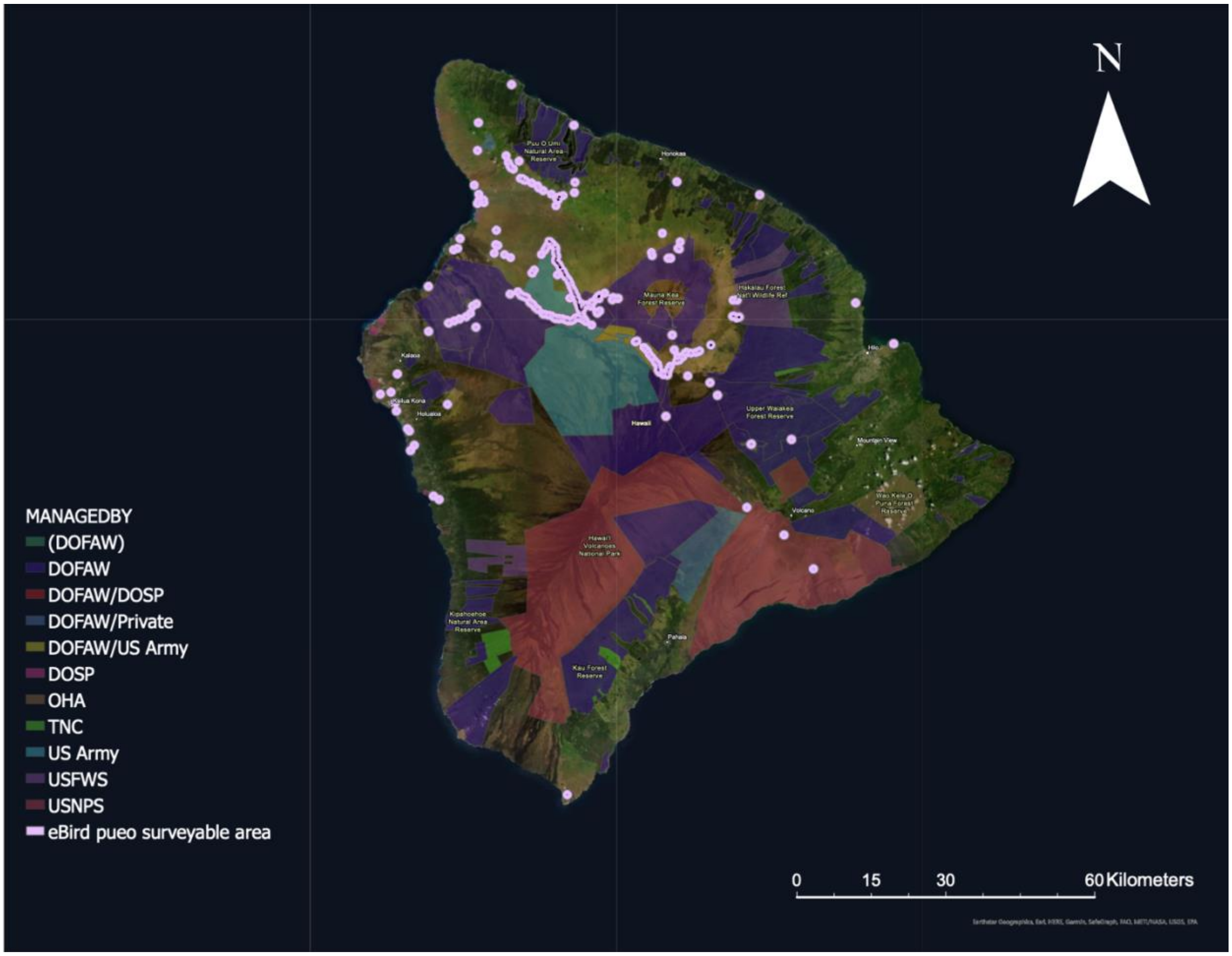

Figure 3.1 Map of sites selected from eBird data for Pueo survey routes.

Kilo

Kilo means to watch, observe or forecast (Pukui and Elbert 1986). We arrived 120 minutes before the end of civil twilight, and I offered my leo (voice) in oli (chant) to ask permission to enter. We recorded kilo data with survey data in Survey123. These observations included flowers blooming, plants seeding or fruiting, and native forest birds (passerines and Nēnē) were present.

Surveys

Audio, or broadcast surveys, use pre-recorded vocalizations of either the target species or one of their predators to elicit a vocalization from any individuals present (Takats et al. 2001). We used roadside surveys consisting of three to five survey sites per route, spaced between 800 m (0.5 miles) and 1.6 km (1 mile) apart (Takats *et al.* 2001; Norambuena and

Muñoz-Pedreros 2018; Wingert and Benson 2018). Each survey site along the route was treated as an independent survey (Takats *et al.* 2001; Larson & Holt 2016). We started surveys 90 minutes before the end of civil twilight, and ended at civil twilight or when five surveys had been completed.

Pueo and ʻIo calls were obtained from the Lohe Lab at UH Hilo, and Barn Owl calls were downloaded from xeno-canto (www.xeno-canto.org/; Zubergoitia *et al.* 2020). The Pueo recording consisted of a variety of calls including alarm calls and bark but did not include hoots. Surveys began with a one minute passively listening period (Norambuena and Muñoz-Pedreros 2018). We then broadcast a digital recording of each species at full volume using a FoxPro Inferno Predator Call Speaker with a FoxPro XP-70 external speaker for one min—consisting of 15 seconds in each cardinal direction followed by five minutes of listening for a total observation period of 19 minutes per survey point (Norambuena and Muñoz-Pedreros 2018). Calls were played in a randomized order (Norambuena and Muñoz-Pedreros 2018). Playback was stopped when a raptor was detected and we observed each individual detected for five minutes following detection. Audio surveys were not conducted if wind speed was above 32 km/h or if there was heavy precipitation (Takats *et al.* 2001).

Most sites were visited three times to increase the likelihood of reaching maximum detection probability for occupancy modeling. Each site was visited once per anahulu, or 10-day lunar period: (1) hoʻonui (growing), (2) poepoe (round/full), and (3) hoʻēmi (waning). One site (Puʻu ʻŌʻō) was hike-in and we only completed one survey at that site. Three survey routes (Hāloa ʻĀina 1 and 2, and Kālopa State Park) were treated as single surveys for analysis due to spatial constraints, with each survey site along those routes treated as replicates instead of independent as the sites along these routes were spaced 250 m apart.

Environmental and Survey Covariates

At each site we recorded route, GPS coordinates for each survey site, Julian date of survey (January 1 = 1), visit number (1, 2 or 3), average wind speed (over a three minute period; measured with a Kestrel 5000) and direction, sky condition (cloud cover), temperature (degrees celsius; measured with a Kestrel 5000), moonrise time, sunset time, pō mahina (moon phase) from the 30-day Hawaiian moon cycle, anahulu, habitat type, and dominant vegetation type.

Raptor-specific information recorded included: species (Pueo, ‘Io, or Barn Owl), number of individuals, time detected, and type of response (bark, hoot, flight toward observer, flight away from observer).

Elevation was determined using GPS data. We used habitat type recorded during surveys to classify habitat using IUCN habitat classification schemes version 3.1 for analysis (IUCN 2023). Predator control (i.e. cat trapping) was informed by Mossman (personal communication).

Pō Mahina (Moon phase)

Pō mahina (moon phase from the Hawaiian moon calendar) are not determined by the Gregorian calendar, but rather each named moon phase starts with the rising of that named moon. For example, the day following a moonrise is named for the previous moon. Therefore, moon phase was determined by the timing of moonrise, zenith, and moonset and in relation to other moon phases, marked by four moon phases: Hilo, Olekulua (hoʻonui), Hoku, ʻOlekūlua (hoʻonui), Hoku, and ʻOlekūlua (hoʻēmi). Hilo rises at sunrise, is at the zenith at midday, and sets at sunset, ʻOlekūlua in the hoʻonui anahulu rises at midday, is at the zenith at sunset and sets at midnight, Hoku rises in opposition to the sun, is at the zenith at midnight and sets at sunrise, and ʻOlekūlua in the hoʻēmi anahulu rises at midnight, is at the zenith at sunrise and sets at midday (Nu’uhiwa, personal communication). Moonrise and sunset times as well as lunar illumination (%) were obtained from www.timeanddate.com.

Statistical Analysis

We used single-season single-species occupancy models and multi-species occupancy models using ‘unmarked’ and ‘AICcmodavg’ packages in the statistical programming software R (MacKenzie *et al.* 2006; Fiske and Chandler 2011; Ibarra *et al.* 2014; Rota *et al.* 2016; R Core Team 2022). When calculating detection probability and occupancy, ‘unmarked’ accounts for imperfect detection and false absences (MacKenzie *et al.* 2006; Fiske and Chandler 2011), which are common in studies of rare species such as owls (Kissling *et al.* 2010; Regan *et al.* 2018). Multi-species occupancy models were used to assess pairwise covariance for Pueo, ‘Io, and native passerines, which is the probability of the occurrence of one species given the presence of another (Rota *et al.* 2016). Following Fuller *et al.* (2016), we used single-season occupancy models instead of dynamic occupancy models, despite surveying for multiple seasons, because we were not interested in the processes that dynamic occupancy models explain (i.e., extinction, colonization, and were not trying to estimate abundance. Pō mahina was input into our models as percent lunar illumination, informed by www.timeanddate.com.

We assessed and compared model fit using Akaike information criterion (AIC; Akaike, 1974), the lowest score indicating best fit. We used AIC_c to assess the relationships between Pueo detection probability and survey-level covariates: julian date (seasonality), anahulu, moon phase, quarter, sky (cloud cover), windspeed, and temperature. AIC was also used to distinguish the importance of occupancy level covariates: elevation (m), and habitat type (IUCN classification).

RESULTS

We completed 175 surveys at 89 survey sites along 22 routes between June 2021 and January 2023. We detected a total of 31 individual Pueo on 26 surveys at 25 sites (Figure 3.2) for a naïve occupancy estimate of 28%. Only four detections (15%) totaling six individuals occurred during the passive listening period; 85% of the detections occurred after playing audio broadcast. Twelve detections (45%) were on DLNR-managed lands, and 36 of the survey sites (40%; *n* =89) along seven routes were on DLNR-managed lands. Twenty-three detections were on the first visit (88%), and three were on the second visit (12%); we had no detections of Pueo on the third visit to any site. We detected a total of 11 individual Pueo at ten sites in March 2022 (35%) and 11 Pueo at seven sites in February 2022 (35%; Figure 3.5); during this time there was also evidence of breeding; we sighted three pairs of Pueo along Waikiʻi Road and one pair at Puʻu Waʻawaʻa. We detected Pueo in every habitat type we surveyed, except developed areas (Figure 3.6). A total of 21 detections were visual (68%), and 10 were auditory (32%; Figure 3.7). Most of the detections in grassland, shrubland, and dry forest were visual. Conversely, in lava field and in closed canopy habitats such as mesic or non-native forests most detections were auditory.

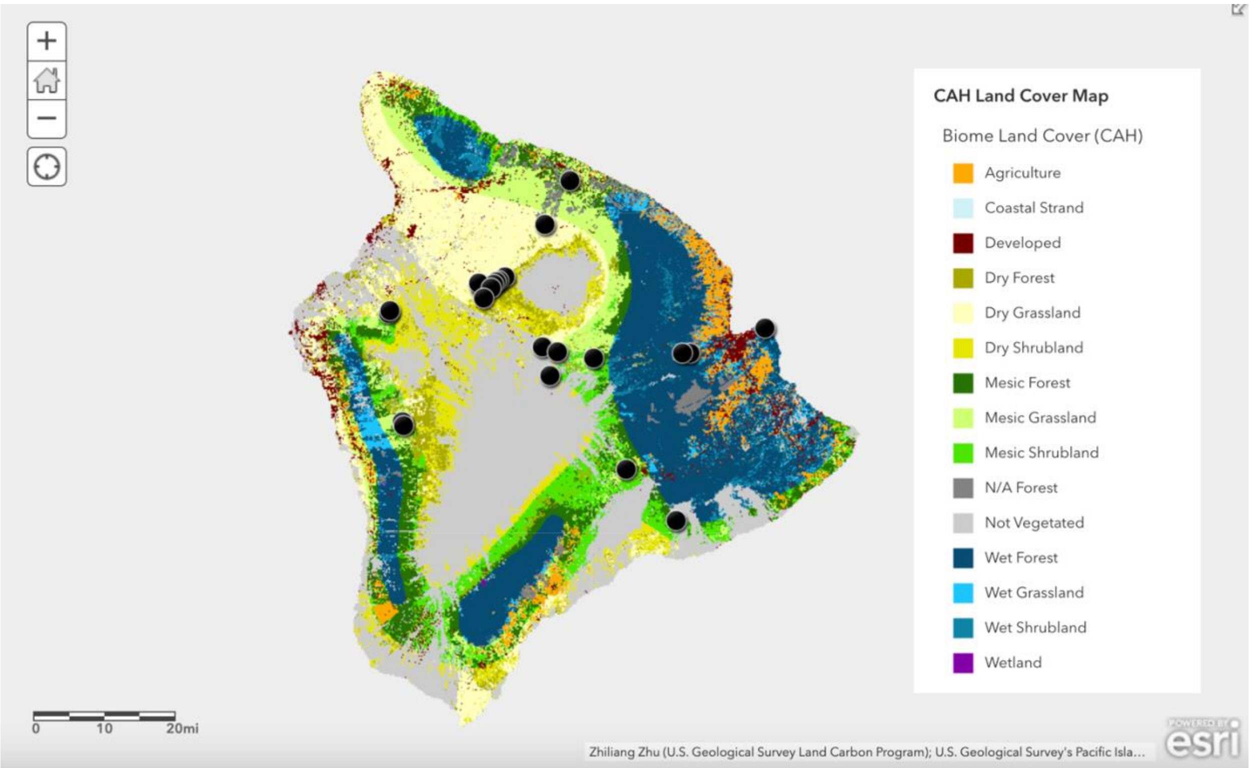

Figure 3.2 Map of survey sites where Pueo were detected (*n* = 25).

We detected a total of 18 ‘Io at 13 survey sites (Figure 3.3) for a naïve occupancy estimate of 20%. All detections of ‘Io were visual. Pueo and ‘Io were detected along the same survey route five times, and at the same site three times. Barn Owls were only detected at two survey sites (Figure 3.4), so this species was not included in further analysis. However, both detections were along routes where we also detected ‘Io; no Pueo were detected along either survey route. At least one endemic passerine was detected at 55 sites during 123 surveys for a naïve occupancy estimate of 62%. The majority of endemic passerine detections were either of the species ‘Apapane or ‘Amakihi. Further, Pueo and ‘Io only responded to their own calls and not to the calls of the other species.

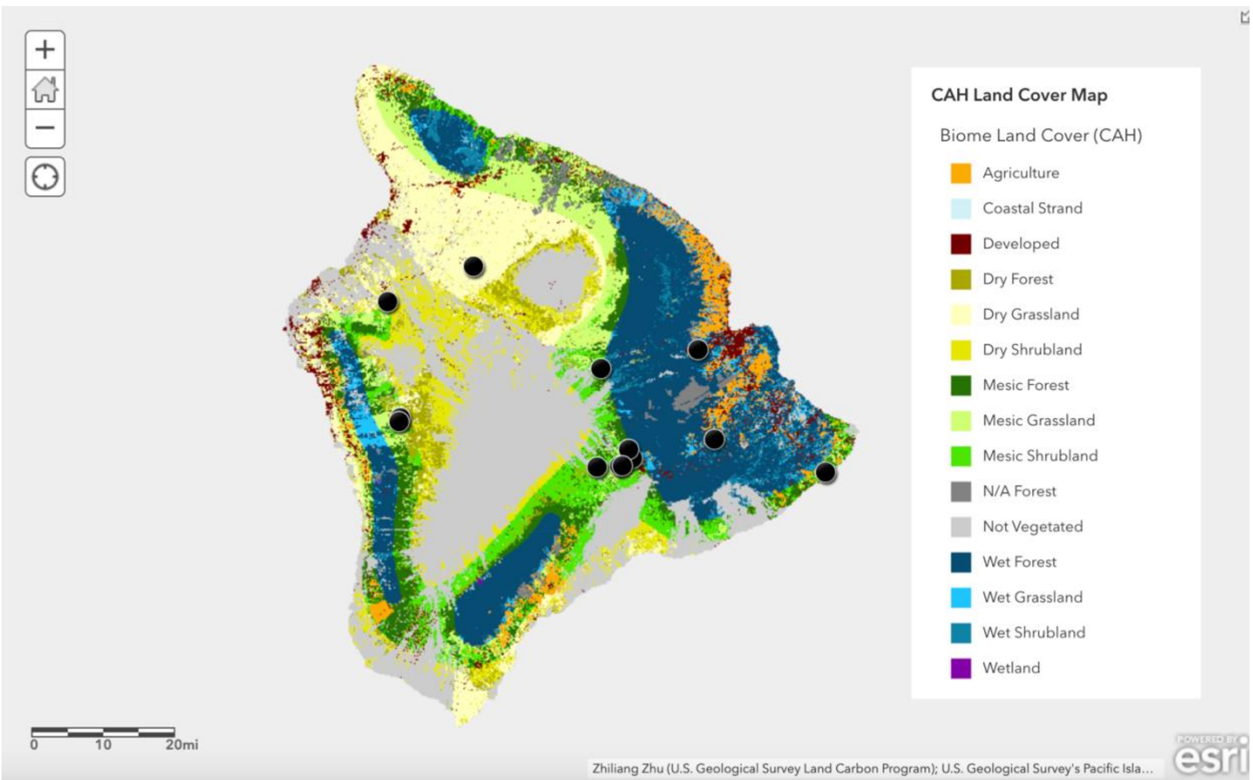

Figure 3.3 Map of survey sites where ‘Io were detected.

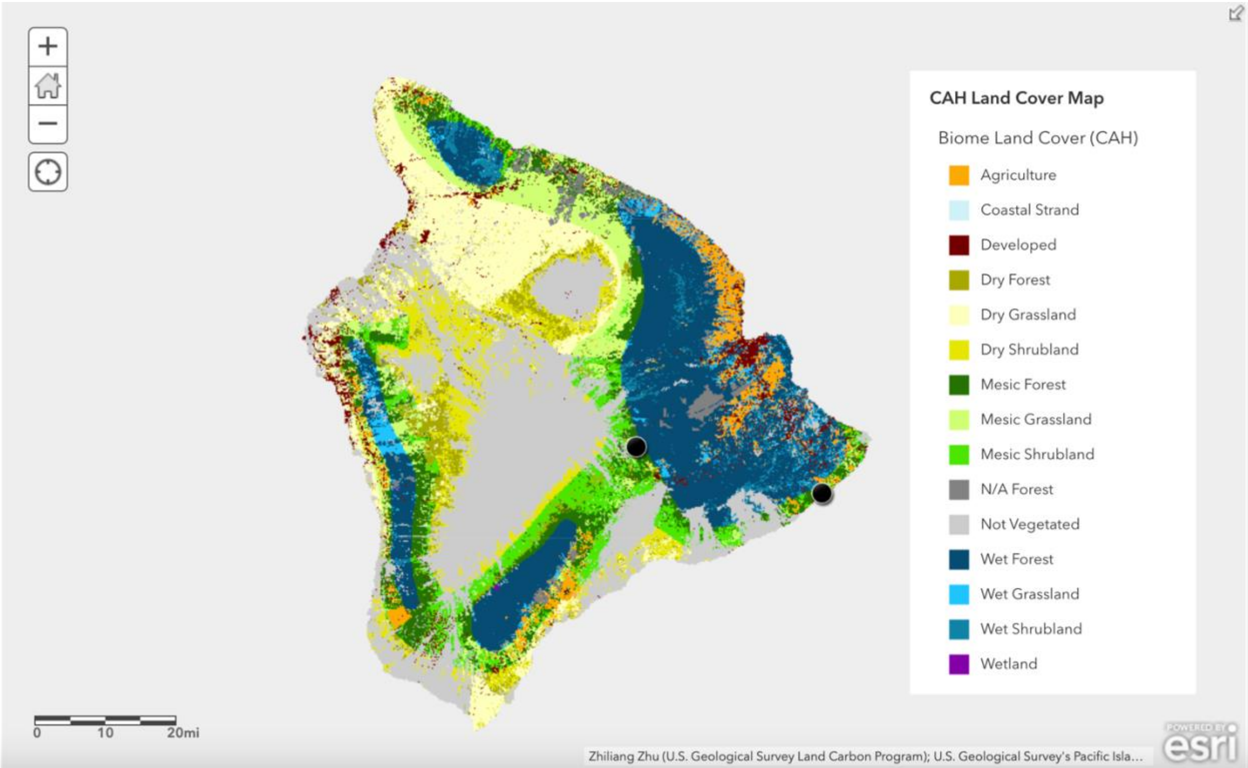

Figure 3.4 Map of survey sites where Barn Owl were detected.

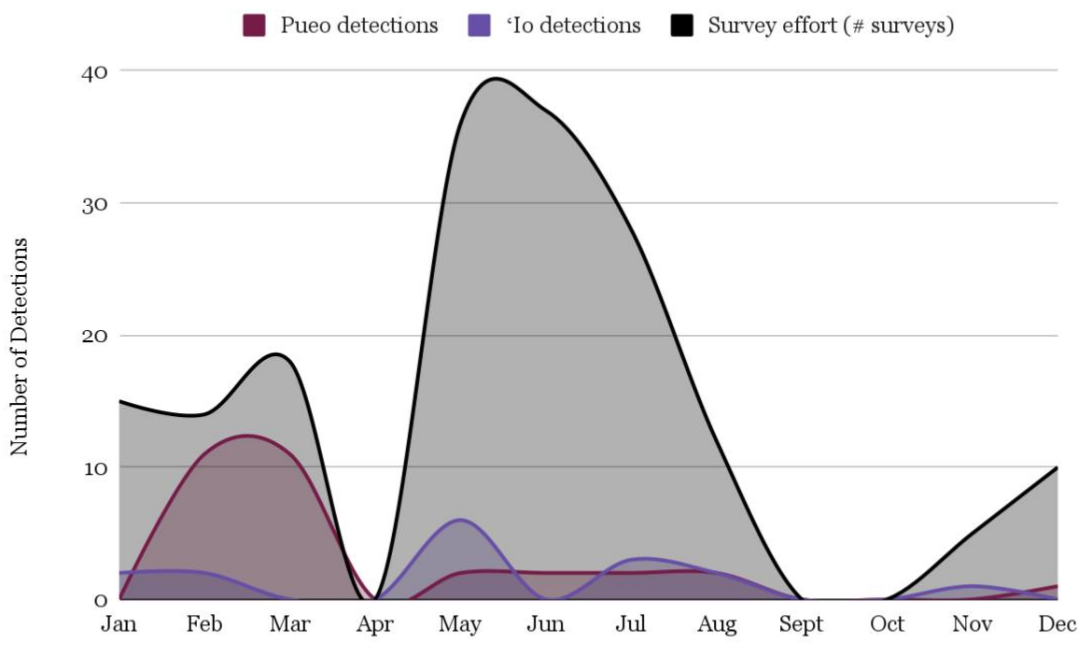

Figure 3.5 Survey effort and number of detections per month. No surveys were conducted in April, September, or October due to logistical issues and coordination of field crew.

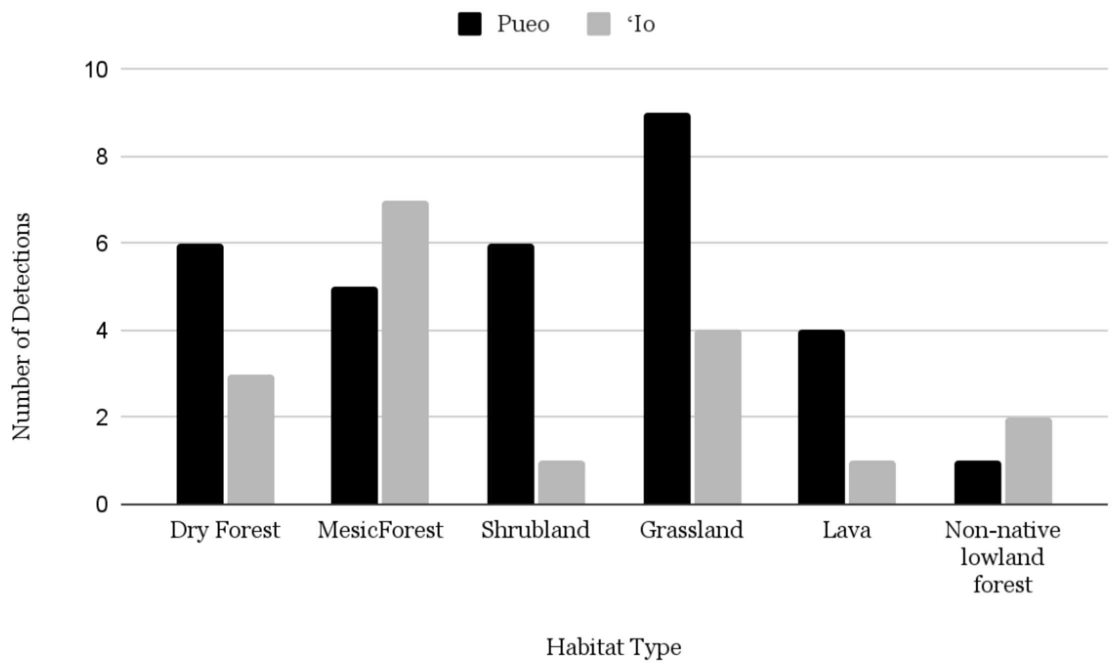

Figure 3.6 Number of Pueo (*n* =31) and 'Io (*n* =18) detected in each ecosystem type.

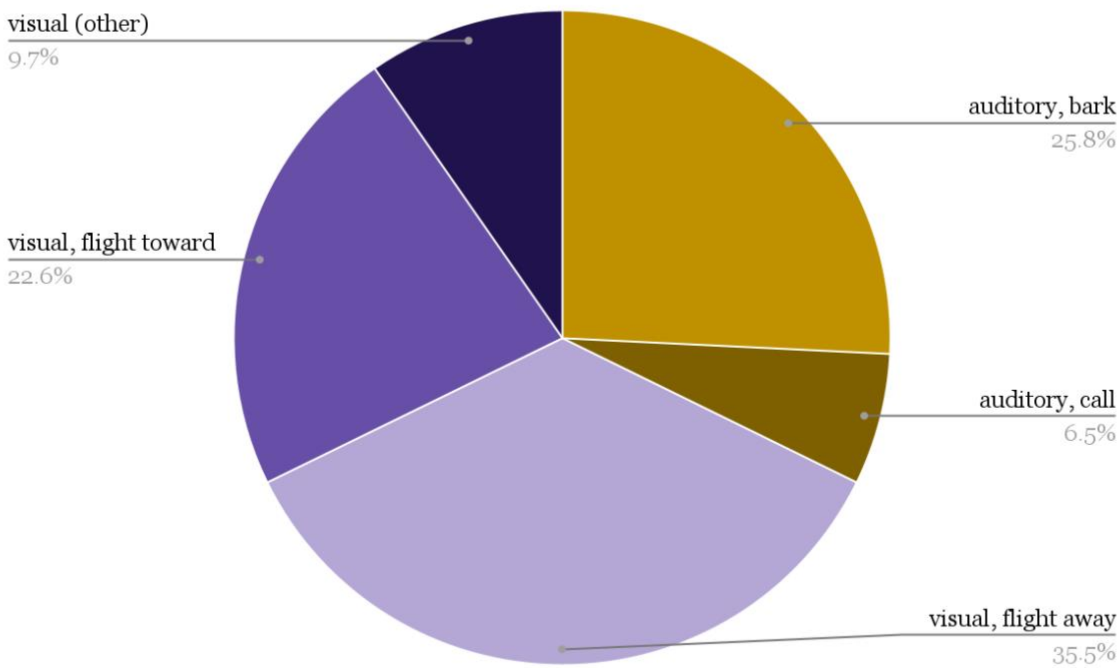

Figure 3.7 Percentages of each Pueo response type to audio broadcast calls.

Our multi-species occupancy model indicated that Pueo were more likely to occupy a site if ‘Io were present, and less likely to occupy a site if native forest birds were present. However, at least one native passerine was detected at 64% of the sites (n = 25) where Pueo were detected. ‘Io are more likely to occupy a site if native Passerines are present (AICc: 432.9). However, the interactions between species were not statistically significant and the top model assumed independence among species (AICc: 427.3).

Detection Probability

Pueo detection probability was between 10% and 21% (95% CI: 0.101, 0.206; Table 3.1). The best predictor for Pueo detection was temperature (ºC), with nearly all the weight on that model (Table 3.2; Figure 3.8). Confidence intervals did not overlap with zero indicating this is a strong predictor (Table 3.1). Date, wind, and sky (cloud cover) were all better predictors of Pueo detection probability than the null model (Table 3.2). However, AICc indicated weak support for date, and no support for the other variables.

Table 3.1 Pueo beta coefficient estimates (β), standard errors (SE), and p-values {P(>|z|)} for detectability covariates and occupancy (ψ) estimates with highest support (ΔAIC_c) from single season occupancy models.

	β	SE	P(>|z|)
Detection probability (*p*)			
Intercept	0.146*	0.267	<0.001
Temp (ºC)	-0.366*	0.116	0.002
Day of year (season)	-0.011*	0.003	<0.001
Windspeed (km/h)	-0.167	0.092	0.07
Sky (% cloud cover)	0.011	0.06	0.06
Occupancy (ψ)			
Intercept	0.99*	0.23	0.826
Elevation (m)	0.005*	0.001	0.001
Habitat Type (IUCN classification)	-5.7	7.5	0.448

*95% confidence intervals do not overlap with zero.

Table 3.2 Model selection table for factors affecting Pueo detection probability (p) where occupancy (ψ) is held constant, and occupancy (ψ) parameterized by temperature. K= number of parameters.

Model	**Δ AIC$_c$**	**AIC$_c$ weight**	**LogL (LL)**	***K***
p(temp)	0.00	0.99	-62.92	3
p(date)	9.06	0.01	-67.45	3
p(wind)	15.90	0.00	-70.87	3
p(sky)	18.32	0.00	-72.08	3
p(null)	20.05	0.00	-74.02	2
p(lunar illumination)	21.13	0.00	-73.49	3
ψ(elevation), *p*(temperature)	0.00	0.50	-61.24	4
ψ.(null), *p*(temperature)	1.17	0.28	-62.92	3
ψ.(habitat), *p*(temperature),	1.69	0.22	-62.08	4
ψ.(predatorcontrol), *p*(temperature)	3.37	0.09	-62.98	4

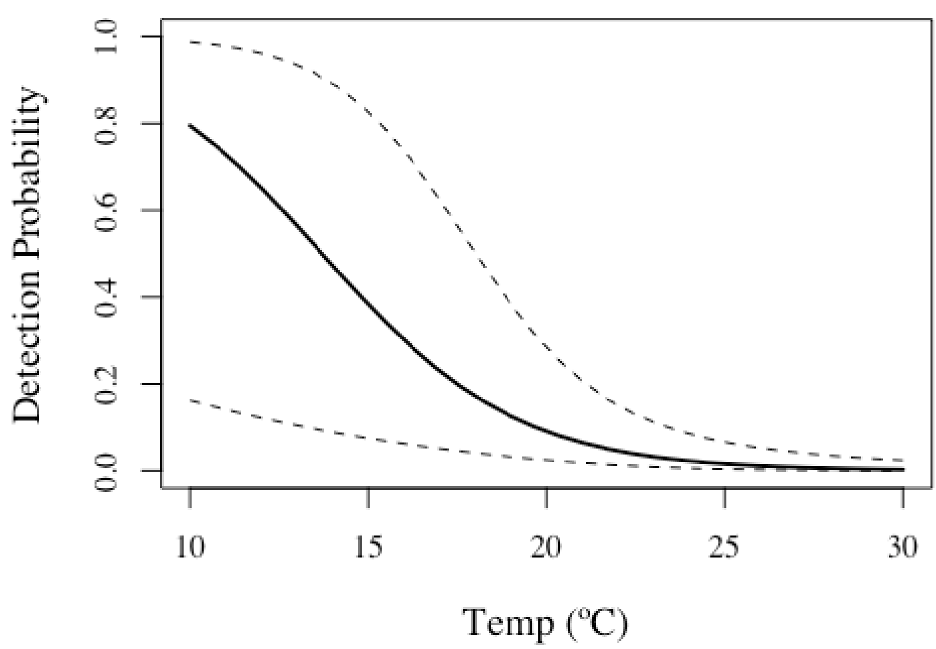

Figure 3.8 Pueo detection probability in relation to survey covariates that had support from AICc with 95% confidence intervals non-overlapping with zero.

Occupancy

Elevation had a significant effect on occupancy ($p < 0.01$), as well as on detection probability ($p < 0.01$). Confidence intervals for elevation were non-overlapping with zero indicating that it is a strong predictor. AICc weight was nearly half for elevation, nearly twice the power of the null model. There is a strong increase in occupancy probability at higher elevations and very low occupancy probability at low elevations (Figure 3.9).

While predator control (i.e., cat trapping) did not perform as well as the null model, an AIC score of 3.37 indicates there is some support for this model. Of the sites where we detected Pueo, 27% (*n* = 26) were in Ka‘ohe Game Management Area where they have a cat-trapping grid (Mossman, personal communication). An additional 26% (*n* = 31) of the Pueo we detected were in the areas directly adjacent to Ka‘ohe—Waiki‘i Rd. to the West and Mana Rd. to the North.

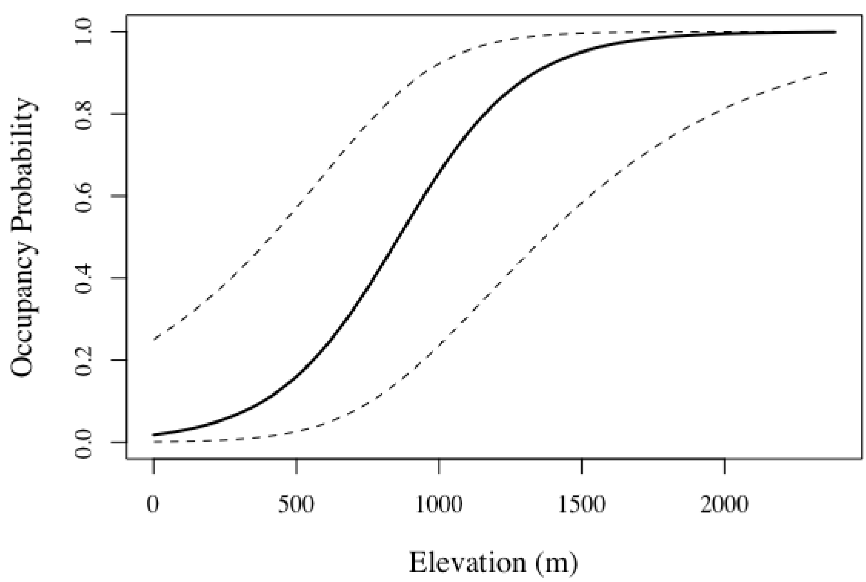

Figure 3.9 Pueo occupancy probability in relation to elevation, after accounting for detectability {ψ(elevation), p(temp)} with 95% confidence intervals.

DISCUSSION

Pueo were not significantly associated with any particular ecosystem, suggesting they are a generalist species that utilize multiple vegetation types. Our study, which took place in a highly diverse island system with multiple ecosystem types across a 2500 m (8,200 ft) elevational gradient suggests that Short-eared Owls are globally distributed because of their ecological flexibility. This plasticity in behavior is consistent with ʻŌiwi (Native Hawaiian) Indigenous Knowledge of Pueo (Chapter 2), and studies of other island endemic subspecies (Crowell 1962; MacArthur *et al.* 1972). We observed Pueo foraging in grasslands and shrublands, and flying from higher to lower elevations at dusk in lava fields. We also observed breeding behaviors in grasslands, shrublands, dry forest, and high elevation mesic forest. Nesting and hunting behaviors have been observed in wetlands, grasslands, agricultural lands, and high-elevation native forests (Cotin and Price 2018; Wang 2022). Similarly, continental Short-eared Owls may also prefer heterogeneous habitat with structural complexity (Miller *et al.* 2016). A recent study provided evidence that Short-eared Owls overwinter in young forests in Northeastern Algeria (Menaa *et al.* 2021). Similarly, other island endemic Short-eared Owls have also been seen using a variety of forested habitats (Wiley 1986; Village 1987; Wiley *et al.* 2010; Thorstrom and Gallardo 2017; Schulwitz *et al.* 2018).

Similar to continental Short-eared Owls who undertake large seasonal shifts in latitude due to shifting abundance of food resources and temperature (Wiggins *et al.* 2020), Pueo appear to be shifting activity temporally and in elevation to meet thermoregulatory or foraging needs. These shifts upward in elevation due to warmer temperatures may occur for a longer period of time as climate change makes lower elevations hotter and drier throughout more of the year (Smeraldo *et al.* 2020). These patterns are consistent with continental Short-eared Owls that are active diurnally only during the breeding season (Reynolds & Gorman 1999; Calladine *et al.* 2010).

As temperature and elevation are correlated, there may be other explanations for these shifts in activity patterns. A previous study that largely detected Pueo above 700 m elevation on Māui noted relatively intact habitat at higher elevations, less development, and thus less use of rodenticides as potential explanations (Luther 2021). Development, habitat loss and rodenticide use are considered threats to Pueo and have resulted in the species being state-listed as endangered on Oʻahu (DLNR 2005). In contrast, Pueo were once abundant in the lowlands of all the islands, but plantation agriculture such as sugarcane production, with seasonal burning and monoculture approaches likely reduced nesting success in lowland areas, and by the early 20th century Pueo were observed to be sparse in the lowlands (Henshaw 1903). Further, colonial settlers intentionally killed Pueo at low elevations in the late 1800s (Henshaw 1903).

We found evidence that ʻIo are likely influencing Pueo distribution. Corresponding with the peak of the ʻIo breeding season that runs from April through June (Clarkson and Laniawe 2020), in the month of May, we saw an increase in ʻIo activity with evidence of breeding pairs, and a simultaneous decrease in Pueo detections. Pueo likely have a longer breeding season than ʻIo and have been observed breeding November through May throughout the Hawaiian Islands (Wang 2022), but more research is needed to determine whether competition and interactions with ʻIo constrain the Pueo breeding season on Hawaiʻi Island. Pueo and ʻIo both use a variety of ecosystems, and may be preferentially utilizing edge habitat. ʻIo were present at more low and mid elevations sites. However, this observed pattern may be due to their responsiveness to audio broadcast calls, which have previously been utilized to survey for ʻIo (Hall *et al.* 1997). While not statistically significant due small sample size of detected ʻIo, we observed inverse trends for the two species in regards to elevation and temperature, and ʻIo were seen mostly in forest ecosystems. This could be a result of niche partitioning similar to what has been documented in the Galapagos subspecies (deGroot 1983). Further, ʻIo have been observed chasing Pueo from nesting territories (Griffin 1985).

We expected lunar illumination to have more of an effect on Pueo detectability, like other owl species (Takats and Holroyd 1997; Hardy & Morrison 2000; Rocha and Salazar 2001; Kissling *et al.* 2010; Ibarra *et al.* 2014). However, since our surveys took place during civil twilight, and Pueo are most active nocturnally, future studies should further examine the potential relationship between Pueo activity and moon cycles.

Despite inconsistent survey efforts throughout the year due to time constraints and coordination of the field crew, we note that during the time of highest effort few Pueo were detected during the surveys (Figure 3.5). However, this may have been due to limitations in the survey design, in which surveys ended after civil twilight, as previous studies have suggested a shift in Pueo activity toward nighttime during warmer months. Four Pueo were observed in the summer of 2022 once it was dark and after the survey period. Only three Pueo were detected at higher elevations during surveys in the summer of 2021, and two of these detections were within ten minutes of sunset. Future studies of movement ecology are needed to definitively determine whether Pueo undertake seasonal movements to higher elevations, or shift activity toward nocturnal hours during periods of higher daytime temperatures.

Optimizing survey methods for Short-eared Owls remains a global priority (Booms *et al.* 2014). Our study shows that using audio broadcast calls increases the likelihood of detecting Pueo in contrast to a previous study which found the use of callback to be ineffective (Larson and Holt 2016). We note a few differences between our studies. First, Larson and Holt (2016) used hoots in their survey protocol, which was potentially ineffective compared to visual surveys due to low site fidelity and the nomadic nature of the continental subspecies (Calladine *et al.* 2012; Johnson *et al.* 2017; Tseng *et al.* 2017). Further, our study used alarm calls, which may be more effective at eliciting a response. Further we note this method may have higher utility for island endemic Short-eared Owls due to increased site fidelity on islands compared with continental populations (Village 1987; Schulwitz *et al.* 2018, Wilhite 2021).

Generally, raptor surveys are most effective at detecting birds when conducted during the breeding season as they are more active and more responsive to playback (Larson and Holt 2016; Miller *et al.* 2016, 2022). This is consistent with our study results, and we suggest surveys for Pueo should be conducted between the months of January through May (Wang 2022). Despite a relatively lower number of surveys in February and March, more individuals were detected and many of them exhibited breeding behaviors. Generally, raptor surveys are optimized during breeding season due to increased detectability (Larson and Holt 2016; Miller *et al.* 2016, 2022). Our study indicates that the months of January to May may be the most ideal time to survey for Pueo, which is consistent with a peak in breeding activity during this time (Wang 2022).

Despite a much larger land mass, Pueo occupancy was observed to be lower on Hawaiʻi Island than previously found in a study of the population on Oʻahu (Wilhite 2021), which may be a result of interspecific competition with ʻIo like patterns observed in the Galapagos where

Galapagos Hawks and Galapagos Short-eared Owls coexist (deGroot 1983). However, we note low sample sizes in both studies, and more surveys are necessary to determine whether the species should be state-listed on Hawaiʻi Island as well.

Pueo are a ground-nesting species (Wiggins *et al*. 2020), and mammalian predators have been documented predating nests (Northwood 1940; Snetsinger 1995; Wang 2022). Thus, nesting success may be higher in places with invasive predator control conducted to benefit other Endangered species. Our study found that areas with invasive predator control appeared to have a higher number of detections, although we were not able to statistically test this difference due to a low sample size. Similarly, Pueo have been observed nesting in areas that are fenced to exclude invasive ground-based predators for the protection of Nēnē (Hawaiian Goose; *Branta sandvichensis*).

RECOMMENDATIONS

Increased agency and private landowner collaboration is critical to conserve our native raptors, to inform population trends for Pueo, and interspecies dynamics between Pueo, ‘Io, and Barn Owl. Raptors are difficult to monitor due to their large range sizes and low densities (Newton 1979; Fuller and Mosher 1981). Thus, collaboration across land boundaries will be necessary to infer population dynamics and monitor raptor species (McClure *et al.* 2022). Our study suggests that the minimum number of site visits to accurately detect Pueo on Hawai‘i Island is five due to the higher end of detection probability on Hawai‘i Island being estimated at 20% in our study, in contrast to previous studies which suggested three visits was adequate to detect Pueo if they were present (Cotin and Price 2018). This may differ between islands due to population trends and behavioral differences between individual birds, but we also note a difference in methodology, given the focus on call playback in this study. Use of audio broadcast surveys was successful to help us detect Pueo in closed-canopy habitats where visual detection declines (Fuller and Mosher 1981). Pueo and ‘Io only responded to their own calls, so use of Pueo calls in surveys for Pueo is likely to be effective throughout the islands.

Use of audio broadcast surveys was successful to help us detect Pueo in closed-canopy habitats where visual detection declines (Fuller and Mosher 1981). Pueo and ‘Io only responded to their own calls, so use of Pueo calls in surveys for Pueo is likely to be effective throughout the islands.

Predator control such as trapping of cats (*Felis cattus*), dogs (*Canis lupis familiaris*) and small Indian mongoose (*Herpestes auropunctatus*) is likely to have a positive effect on Pueo nesting success. Wang (2022) found that nest failure for Pueo was directly linked to predation by introduced mammals. We saw an increase of detections, and a higher number of individuals in areas within and directly adjacent to where there are active cat trapping grids to protect Palila on Mauna Kea. This indicates these areas may be acting as source populations for adjacent areas, but more research is needed to determine how significant these effects are as we had low overall detections. Other island subspecies of Short-eared Owls have also been seen to be sensitive to predation by mammalian predators including rats.

CHAPTER 4: SYNTHESIS

This thesis consists of a chapter that highlights the rich and diverse Indigenous Knowledge documented in primary ʻŌlelo Hawaiʻi (Hawaiian language) sources, and a chapter studying modern populations of Pueo using conventional field methodology synthesized with Indigenous practices and Knowledge. In this section, I will discuss the synergy and interconnectedness of these approaches, and identify knowledge gaps and potential future pathways for Pueo studies.

Pueo are genealogically related to Hina, the moon. Across moʻolelo Pueo show up most frequently at night. This is reflected in moʻolelo from Aotearoa, where Hineruru is an owl woman (Schwimmer 1963). Short-eared Owl hunting effectiveness is known to increase with lunar illumination (Clark 1983). Further, Global research on Short-eared Owls showed that they are mostly nocturnal, being active diurnally only during the breeding season (Craighead and Craighead 1956; Clark 1975; Clark 1983; Reynolds & Gorman 1999; Calladine *et al.* 2010; Calladine & Morrison 2013; Larson & Holt 2016; Johnson *et al*. 2017; Tseng *et al*. 2017; Wilhite 2021). However, Pueo also show up in moʻolelo during crepuscular periods (morning and evening), and during the day. Galápagos Short-eared Owl (*A. f. galapagoensis*) utilize temporal niche partitioning to co-exist with the Galapagos Hawk (*Buteo galapagoensis*) and Barn Owl (*Tyto alba*), and can be diurnal, crepuscual or nocturnal depending on the presence of other raptors (deGroot 1983). Similar patterns are likely to occur across Short-eared Owl's range.

The main factor influencing Pueo detectability was temperature, with lower chances of detecting Pueo as temperature rises. This was reflected in ʻIke Kuʻuna or Indigenous Knowledge of Pueo. In Mahuʻena, Kauaʻi, it was noted that there were no Pueo flying in unison (likely referring to their sky dance) when it was hot (Kaunamano (Ed.) 1893). Another iteration of the ʻōlelo noʻeau "Malu ke kula ʻaʻohe lele/keʻu Pueo[10]" specifically mentions the month of August (Kealoha 1892). Pueo were observed to be less diurnally active during the heat of the summer during field studies on Hawaiʻi Island, where they were observed exclusively after the end of civil twilight or in high elevation mesic forest over 1200 m, and all but one of the detections during surveys was in the 10 minutes surrounding sunset. Further, summer is Kū season (Kirch

[10] ʻŌlelo noʻeau 2130: "there was perfect peace" (Pukui 1983).

2014), and the ʻōlelo noʻeau "Malu ke kula, ʻaʻohe keʻu Pueo" (Pukui 1983) which means "there is perfect peace" was also linked to an ideal time to make offerings to Kū:

> Ua malu ka ʻaha, he ʻaha kēia noʻu e Kū, e Kūmakaiki, e Kūmakanui, he malu, ʻaʻohe kānaka hele, ʻaʻole waʻa holo, ʻaʻole manu e lele, ʻaʻole pueo keʻu, ʻaʻole ʻalae kani, ʻaʻole ʻīlio aoa, aʻole puaʻa ʻalalā, aʻole paka ua e kulu, he malu no Kū, no Kūkaʻilimoku, Kūnuiākea (Kapu (Ed.) 1896).
>
> The ceremony was tranquil, this was my ceremony to Kū, to Kūmakaiki (Kū with small eyes), to Kūmakanui (Kū with big eyes), it was serene, there were no people wandering, no ships sailing, no birds flying, no Pueo hooting, no ʻAlae (Hawaiian Moorhen; *Gallinula galeata sandvicensis*) calling, no dogs barking, no pigs whining, no raindrops dripping, it is peaceful for Kū, for Kūkaʻilimoku, for Kūnuiākea.

Similarly, Pueo appear with fog and clouds in moʻolelo, which can be interpreted as the elevational gradient where the clouds rest on the mauna. Elevation was the most important factor influencing Pueo occupancy in our field study on Hawaiʻi Island, and has been observed on Maui (Luther 2020) and in occupancy models that used eBird data (Wilhite 2021). This is also reflected in Pueo occupying the wao akua and wao maʻukele, which are upland forested areas which were rarely accessed.

Pueo were not particularly associated with any specific ecosystem in our field study, and also appeared across a broad range of ecosystem types across moʻolelo, including Hawaiian agroecological systems. Other studies have also observed Pueo in various habitat types (Wilhite 2021, Cotin and Price 2018). The Pueo kinolau of Kāne in the form of Kāneikapahuʻa who stands at the edge of the forest is representative of Pueo use of edge habitat. Edge habitat is often a resource-rich area with high prey density (Šálek *et al*. 2010). Further, it was noted that Pueo would roost in the forest during the day and emerge at night, which has been echoed by transmitter studies on Short-eared Owls in Taiwan (Tseng et al. 2017) and Pueo at Lualualei on Oʻahu (Wilhite 2021).

Further, Pueo were indicators for certain seasonal phenomena. Pueo are in the description for the lunar month of Welo (April/May), where they mistakenly pounce on the growing tails of yams thinking they are rat tails (Kaleinuipaoaikeala 1891; Poepoe 1906). During this time, young Pueo are learning to hunt, and may be learning to differentiate new growth from rat tails. Further, other atmospheric phenomena that Pueo show up in tandem with i.e., rains, wind, cold, thunder, lighting, and rainbows are all indicators of Lono season, which begins with the rise of

Makaliʻi (Pleiades) in the night sky (Nuʻuhiwa 2019). This happens around October or November, which is also the beginning of Pueo breeding season (Wang 2022), when they are likely to be more active. Further, the majority of our Pueo detections in the field were during Lono season in February and March.

Moving forward, there are several areas of research that would be exciting to pursue. Determining which factors are most heavily contributing to Pueo mortality is important in long-term species conservation planning. Some of the more prominent threats to Pueo include habitat loss, collisions with vehicles, rodenticide poisoning, and predation by introduced mammals (DLNR 2005). Climate change is also emerging as a potential threat to Pueo, so I suggest further research into their temperature tolerance range (Freitas *et al.* 2010). Determining to what extent predator control benefits Pueo breeding success would help with conservation planning for the species. Further, monitoring Pueo presence in biocultural restoration projects before and after restoration to determine whether Pueo are able to move back into lands once restored to ʻŌiwi stewardship practices would be interesting. Nocturnal studies or transmitter studies that can monitor Pueo movement and temporal behavior can inform biological understanding and inform conservation efforts for the species, and could help parse out interactions between Pueo and ʻIo. Further, by elucidating these interactions we can gain insights into the ecological processes that shape biodiversity in Hawaiʻi, which can inform conservation strategies that promote the health and resilience of Hawaiian ecosystems. Using ʻŌiwi Indigenous science in tandem with conventional science can help us reach the apotheosis of knowledge acquisition. Conservation strategies developed through the utilization of both of these knowledge systems synchronously offers a unique opportunity to explore the intersections of ecology, culture, and conservation, and to develop innovative strategies for protecting Pueo and other iconic species.

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