A1. Appendix 1: Background

A 1.1 GDE Biodiversity

Diverse species are supported by groundwater dependent ecosystems (GDEs) in Kona (A1 Table 1). Native wetland birds rely on *loko wai kai* (anchialine pools) and *loko iʻa* (Indigenous aquaculture systems) for nesting habitat, including the endemic *ʻalae* (*Fulica alai*) and endangered *aeʻo* (*Himantopus mexicanus*; Christen et al. 2005). GDEs broadly, from anchialine pools to *loko iʻa*, *muliwai* on nearshore reefs influenced by submarine groundwater discharge springs, and subterranean aquifers themselves, support diverse native and introduced organisms. This includes terrestrial plants with water and nutrient sources, such as trees like the Polynesian introduced *hau* (*Hibiscus tiliaceus*), endemic *loʻulu* (*Pritchardia spp.*), grasses (*Ruppia maritima* and others)*,* sedges including *makaloa* (*Cyperus laevigatus*), and succulents like indigenous *ʻākulikuli* (*Sesuvium portulacas*). GDEs also broadly support vertebrate and invertebrate species; for instance, some species of fish and invertebrates have GDE-dependent larval stages that move across salinity gradients into various GDEs to complete their life history, while other euryhaline species opportunistically use GDEs to gain refuge from predation, and still others move into GDEs to feed on GDE species (Titcomb et al. 1978, Havird et al. 2015, Marrack et al. 2015, Peyton et al. 2016, Smith and Parrish 2002). Low-salinity tolerant macro and microalgae grow in exclusion from grazers in geologically protected GDEs (Littler and Littler 2006), while taking advantage of groundwater derived nutrients (Abbott 1947). The habitat range of some invertebrates, including endemic shrimp species, spans nearshore, estuarine, and anchialine systems (Titcomb et al. 1978, Yamamoto et al. 2015). See A1 Table 3 for examples of GDE species salinity tolerances. Surprisingly few Hawaiian species have published salinity tolerances and defined groundwater chemistry and quantity needs.

A1.1.1. *Loko wai kai* (anchialine pool) biological diversity:

Diverse assemblages of organisms are found in anchialine pools, including crustaceans, fishes, mollusks, isopods, amphipods, decapod crabs and alpheids, a hydroid, sponges, polychaetes, tunicates, insects, algae, and aquatic macrophytes (Brock 1977, Brock and Kam 1997, Yamamoto et al. 2015). Eight species of anchialine pool shrimps are found in Hawaiʻi's anchialine pools, all of which are listed as endangered species candidates except *ʻōpae ʻula* (*Halocaridina rubra*), and five of which are endemic (*Halocaridina rubra*, *Halocardidina palahemo*, *Procaris hawaiana*, *Palaemonella burnsi*, and *Vetericaris chaceoru*; Christen et al. 2005, Yamamoto et al. 2015). Of the five endemics, *V. chaceorum* and *H. palahemo* are recorded to exist in a single pool each, both of which lie outside the southern boundary of the study site for this research (Christen et al. 2005). Of the eight anchialine pool shrimp species found in Hawaiʻi, four are recorded for the Kona region (Christen et al. 2005). The endemic *ʻʻōpae ʻula*, *Halocaridina rubra*, are the most abundant in Kona's anchialine pool systems and play a key role in ecological functioning by consuming algae and detritus (Seidel et al. 2016). *ʻʻōpae ʻula* have been recorded in the stomach contents of nearshore fish species including *ʻuʻu* (*Myripristis spp.*), suggesting that *ʻuʻu* travel into groundwater-fed spaces to feed on *ʻʻōpae ʻula* which are swept out by outgoing tides (Yamamoto et al. 2015). The indigenous *Metabetaeus lohena* is a predator of *H. rubra*, and the indigenous *ʻōpaeʻhuna* (*Palaemon debilis)*, all of which are found in anchialine pools (Brock and Kam 1997). The rare endemic, *Palaemonella burnsi* is found in this region, within Kaloko Pond in Kaloko-Honōkohau National Historic Park (Brock and Kam 1997).

Some of Kona's pools contain characteristic cyanobacterial carbonate producing mats or crusts comprised of a matrix of living organisms including; cyanobacteria (including *Lyngbya, Schizothrix, Scytonema* and *Oscillatoria spp.*), chlorophytes (*Rhizoclonium sp*. and *Cladophora spp.*), the marine plant *Ruppia maritima,* bacteria, diatoms, and protozoans (Brock and Kam 1997). West Hawai‘i anchialine pools are known for characteristic orange to yellow cyano-bacterial mats which form a white precipitate of silicon, magnesium, calcium and phosphorus on the pond floor (Brock and Kam 1997). Common molluscs found in Kona's anchialine pools include *Theodoxus cariosa*, *Melania sp.*, and *Assiminea nitida* (Brock and Kam 1997). The macroalgae, *Ahnfeltiopsis concinna*, has also been recorded within anchialine pools (Brock and Kam 1997).

A few endemic damselfly species, including the endangered species candidate *Megalagrion xanthomelas,* rely on anchialine pools for specific salinities for reproduction (Seidel et al. 2016). The indigenous dragonfly *Pantala flavescens* is also present in Kona's anchialine pools (Seidel et al. 2016). The endemic, brackish water tolerant, *‘o‘opu ‘akupa*, or sandwich island sleeper goby (*Elotris sandwichensis*) are found in Kona's anchialine pools (Brock 1977). Common anchialine pool fish species include *āholehole* (*Kuhlia sandvicensis*), *‘ama‘ama* (*Mugil cephalus*), *uouoa* (*Neomyxus chaptalii*), *‘o‘opu* (*Eleotris sandwichensis*), ‘o‘opu nākea (*Awaous stamineus*), *kūpīpī* (*Abdeufduf sordidus*), *manini* (*Acanthrurus trigostegus*), and *weke‘ā* (*Mulloidichthys flavolineatus*; Brock 1977).

A1.1.2. *Muliwai* (nearshore reefs) biological diversity

SGD seeps in nearshore ecosystems deliver cool, fresh, nutrient rich fluxes of water to nearshore reefs and create zones of high productivity as phytoplankton (Delevaux et al. 2018) and macroalgae (Amato et al. 2016) acquire otherwise limiting nutrients from groundwater sources. Some euryhaline fish species require fresh or brackish water to complete their life histories, while others are tolerant of brackish water and benefit from predation and protection in these productive, turbid, and, often, calmer, nearshore ecosystems which provide food and protection from wave action and larger predators (Smith and Parrish 2002). As the Kona coast is devoid of riverine inputs these species must rely on SGD for habitat in this region. A survey of juvenile fish and larvae often associated with these kinds of estuarine regions in Hawai‘i found fish species associated with estuarine waters include; *weke* (*Mulloidichthys flavolineatus)*, *‘oi‘o* (*Albula virgata)*, *moi* (*Polydactylus sexfilis*), *uouoa* (*Neomyxus leuciscus*), *manini* (*Acanthurus trigostegus*), *mā‘i‘i‘i* (*Acanthurus nigrofuscus*), *kala* (*Naso unicornis*), *‘iao* (*Atherinomorus insularum*), *‘Ulua* (*Caranx ignobilis, C. melampygus, and C. sexfasciatus*), *lai* (*Scomberoides lysan*), *awa‘awa* (*Chanos chanos*), *kākū* (*Sphyraena barracuda*) introduced sardine (*Herklot sichthys quadrimaculatus*), *‘o‘opu* (*Eleotris sandwicensis*), *nehu* (*Encrasicholina purpurea*), *iheihe* (*Hemiramphus depauperatus* and *Hyporhampus acutus*), *āholehole* (*Kuhlia xenura* and *K. sandvicensis*), and *‘o‘opu hue* (*Arothron hispidus*); shrimp species (*Macrobrachium grandimanus*, *Palaemon pacificus*, and *Palaemon debilis*) and one crab species (*Portunus sanguinolentus*; Peyton et al. 2016). *‘Ulua* (*Caranx ignobilis* and *Caranx melamypygus*) opportunistically inhabit Hawaiian estuarine regions as nursery and hunting habitat (Smith and Parrish 2002). Sediment and low salinity in estuarine regions can prevent coral growth and lead to proliferation of sediment and low salinity adapted species, such as worms and shelled animals, and fish that feed in soft sediment such as rays and flatfishes (Christen et al. 2005), as well as sediment- adapted marine plant species, such as the indigenous seagrass, *Halophila decipiens* (Fonesca 1989) and proliferation and even blooms of macroalgal species including *Gracilaria spp.*, *Hypnea spp.*, *Cladophora spp.*, and *Ulva spp.* (Abbott 1947, Amato et al. 2016).

Speciation within Hawaiian GDEs has led to the evolution of endemic species which rely on groundwater inputs for survival, for example, the endemic *āholehole* species, *Kuhlia xenura,* is a nocturnal planktivore whose young are found in shallow coastal estuarine waters and tide pools (Christen et al. 2005, Yamamoto et al. 2015). This differentiates the endemic *K. xenura* from the indigenous *K. sandvichensis*, which prefers higher salinity (Christen et al. 2005). The authors expect this is true for more endemic Hawaiian species and varieties of vertebrates, invertebrates, and macroalgae, as the topic has not been thoroughly examined.

A1.1.3 *Loko iʻa* (indigenous aquaculture system) biological diversity

Under Kānaka ʻŌiwi (Native Hawaiian) management, *loko iʻa* aquaculture was carried out in virtually any sizeable body of water, including naturally occurring anchialine pools and modified natural embayments, as these were stocked, collected from, and maintained with desirable species specific to each *loko iʻa (*Kikuchi 1976). *Loko iʻa kuapā*, or walled aquaculture systems, have a permeable barrier made of stone to impound water from springs as well as the nearshore (Kikuchi, 1976). *Loko iʻa kuapā* walls were built to be permeable to allow water flow and tidal exchange while dampening wave action, thereby creating large areas of calm, shallow, water with ample sunlight for algal growth (Kikuchi, 1976). Intentionally positioned *mākāhā* (sluice gates) allowed for tidal exchange and control of the movement of fish in and out of the pond (Kikuchi, 1976, Winter et al. 2020a).

Other groundwater dependent components of *loko iʻa* aquaculture systems included stocked anchialine pools, including *kiʻo pua*, small fingerling holding ponds, *loko wai kai*, anchialine pools (often stocked with *ʻoʻopu* and *ʻōpae*), and *wai ʻōpae*, pools that were important habitat for *ʻʻōpae ʻula* (Kikuchi 1976, Maly and Maly 2003, Mackenzie 2015). *Loko wai kai* were used as *loko iʻa* to grow *āholehole*, Hawaiian flagtail (*Kuhlia xenura*) and big eyed mullet (*Kuhlia xenura*), *'o'opu* (various gobies including *Elotris sandwichensis*), *amaʻama* (*Mugil cephalus*), *awa* (*Elops machnata*), and *awa'awa* (*Chanos chanos;* Kikuchi 1976). *Loko puʻuone* are natural estuarine habitats that have no surface connection to the sea due to formation of a sand and loose coral berm (the *puʻuone,* or sand berm), formed from either sea level changes or wave action, fish grown in puʻuone were considered a savory, highly prized delicacy (Kikuchi 1976). *Loko kuapā*, walled fishponds, were purposefully engineered to be permeable to allow water flow while dampening wave action and allowing control of fish movement in and out of the pond through the *mākāhā*, or sluice gates (Kikuchi 1976).

Kānaka ʻŌiwi observed that freshwater associated species thrive naturally in SGD and riverine influenced *muliwai*, and engineered *loko iʻa* to enhance productivity in these natural systems. The foundation for this productivity is the growth of algae and microbenthos, with most algae growing in the more marine influenced region (*limu pālahalaha*, or *Ulva lactuca*, *Erythrotrichia carnea*, *Centroceras clavulatum*, and *Ceramium spp.*), while some fresh-water species are restricted to spring fed inlets (*Spirogyra* and desmids), brackish tolerant species are found throughout the aquaculture system (*Cladophora spp., Polysiphonia spp.* and *limu ʻeleʻele*, *Ulva prolifera*) and abundant epiphytic diatoms which form a thick mat mixed with small algae and animal larval stages (Abbott 1947). A study of *loko iʻa* food chains for key harvested species (*amaʻama* and *awa*) found that *amaʻama* feed primarily on littoral diatoms and cyanobacteria, while *ʻawaʻawa* feed on unicellular algae as juveniles and filamentous algae as they mature (Hiatt 1947). Overall, both species subsist largely on diatoms (including *Navicula*, Cymbella*,* *Pleurosigma*, *Amphora*, *Melosira*, *Mastogloia*, *Coscinodiscus*, *Nitzchia*, *Surirella*, and *Hyalodiscus*) and blue green algae (*Oscillatoria*, *Merismopedia*, and *Microcystis*), with smaller portions of the diet comprised of filamentous algae (*Cladophora spp., Ulva prolifera, Vaucheria,* *Spirogyra, Polysiphonia, Acrochaetium*), plant fragments (*Batis maritima*), and other microorganisms (Hiatt 1947).

A1.2 Invasive species and GDEs

Within anchialine pools, invasive guppies or poeciliids (*Gambusia affinis* and *Poecilia reticulata*) are a primary cause of declining water quality and dramatic decreases in *ʻōpae ʻula* populations (Havird et al. 2013, Marrack et al. 2015), tilapia also impact a number of anchialine pools and *loko iʻa* by predating native species and increasing nutrient concentrations (Adler and Ranney 2018). Tilapia can also become invasive in nearshore regions, so special care has been taken not to release this species from *loko iʻa* to adjacent nearshore systems ("Adler and Ranney 2018," http://files.hawaii.gov/dlnr/cwrm/activity/keauhou/20181108-GDE_Symposium_Final.pdf).

GDEs can become dominated and overgrown by invasive terrestrial plants such as seashore paspalum (*Paspalum vaginatum*), mangrove species (*Rhizophora mangle*, *Bruguiera gymnorrhi* and *Conocarpus erectus*), and water hyacinth (*Eichornia crassipes*; Allen 1998). Even the Polynesian introduction, *hau*, (*Hibiscus tiliaceus*), can become weedy and require removal from anchialine pools and *loko iʻa* (Allen 1998). If left unmaintained, *Hau* and mangrove act as invasive species, grow rapidly and reduce open water and overgrow mudflats and shallow coastal waters (Allen 1998). *Kūpuna* (elders) of the Kekaha region in interviews by Maly and Maly (2003) identified invasive mangrove growing in fishponds and anchialine pools that elder generations used to collect *ʻōpae ʻula* for *ʻōpelu* fishing.

In the nearshore region, invasive macroalgal species can form bloom conditions where SGD becomes elevated in nutrients, and where herbivorous fish populations are low (Littler and Littler 2006, Dulai 2021). While the only instance recorded in the literature for Kona is *Acanthophora spicifera* in the Kaloko fishpond of Kaloko Honōkohau (Weijerman et al. 2008), the introduction of alien species and pollution of nearshore groundwater are a primary concern for GDEs in Kona, with problematic blooms occurring on the nearby islands of Maui and Oʻahu (Smith et al. 2005, Vermeij et al. 2009, Dailer 2012b, Amato et al. 2016, Dulai 2021). See A1 Table 2 for a summary of invasive species recorded in Kona GDEs.

A1.3. GDE historical context

Prior to Western contact in 1778, a from mountain to sea, *ahupuaʻa* , were held in trust by *aliʻi* (ruling class), who extended rights to use these resources to the *hoaʻāina* (tenants of the land) either themselves or through their *konohiki* (McGregor 1996, Maly and Maly 2003). The *konohiki* system was based on an intimate understanding of interconnected land and ocean resources , and the ecology and practices associated with these systems (Costa-Pierce 1987, Jokiel et al. 2011, Friedlander et al. 2013, Mackenzie 2015, Vaughan 2018).

The Hawaiian Kingdom, established in 1795 by Kamehameha I, was illegally overthrown by the United States of America in 1893. Under Hawaiian Kingdom law, private ownership and commodification of land began following the Land Commission of 1845, the Māhele (division of lands) of 1848, and the Kuleana act of 1850, which contributed to shifts in access and rights to land, including to GDEs, across Hawaiʻi (McGregor 1996, Osorio 2004, Friedlander et al. 2013, Mackenzie 2015, Vaughan and Caldwell 2015, Beamer and Tong 2016). In the case of *loko iʻa* and *loko wai kai*, the Māhele designated both as private property of the individual or corporate land owners (Mackenzie 2015). In the case of nearshore fisheries following the Māhele, *konohiki* fishing rights designated the land owner as the *konohiki* and gave the *konohiki* and *hoaʻāina* (tenants) rights to fisheries associated with their *ahupuaʻa* (Mackenzie 2015). Later, after the illegal overthrow, the Organic Act of 1900 that established Hawaiʻi as a territory of the United States: "specifically sought to terminate exclusive fishing rights and open the fisheries to all, and thus required all konohiki and hoaʻāina to register their rights to preserve them as 'vested." (Mackenzie 2015: p.7). Many fisheries were not registered leading to a loss of traditional fishing and management rights (Mackenzie 2015).

The impacts of colonization and associated economic and political changes that occurred post-Western contact led to decreased cultural practice, management, and decreased perpetuation of knowledge related to GDEs, as generational knowledge of language and practice, and Kānaka ʻŌiwi populations themselves declined, primarily from introduced diseases (Osorio 2002, Jokiel et al. 2011, Friedlander et al. 2013, Mackenzie 2015, Vaughan and Caldwell 2015). However, *kūpuna* recall abundant and productive fisheries throughout the islands and point to declines in resource abundance. For example, Maly and Maly (2003: p. 19) interviewed *kūpuna* about Hawaiʻi and concludes that "fisheries throughout the islands from Hawaiʻi to Niʻihau and the Moku Manamana [Necker Island of Papahānaumokuākea] (Moku ʻAha [the archipelago as a whole]) were rich and sustained all the families who fished."

In recent decades there has been resurgence in advocacy for protection of GDEs and associated cultural practices, and a movement for biocultural restoration. In 1994 subsistence fishing communities throughout Hawaiʻi advocated for the development of Community-Based Subsistence Fishing Areas (CBSFAs), and in 1994 the Hawaiʻi Revised Statutes §188-22.6 was passed by the legislature, which gave the Department of Land and Natural Resources the authority to create CBFSAs "to protect and reaffirm fishing practices customarily and traditionally exercised for purposes of native Hawaiian subsistence, culture, and religion," (Vaughan 2018). Today the vested rights associated with *konohiki* fisheries remain uncertain, and could play an important role in the future of Hawaiʻi's nearshore fisheries, especially as they relate to constitutional protections of Hawaiian traditional practices and legal provisions for CBFSAs (Mackenzie 2015).

An interviewee from our current study describes the resurgence in GDE management in recent decades at Kīholo:

> *"Before us there was a private landowner, nothing was happening down here. And that was the time when [lineal descendent members of today's community management groups were] here in the 1970's, [their] family were the caretakers...It was a smaller community then, but during the decades when it was neglected from the 1980s on there was a disconnect, right. There was a time when no one was here being active stewards. So I think we're trying to rebuild those connections again."*

Several legal battles in the past few decades have highlighted continued interest to maintain GDEs and associated cultural practices, and set the precedent for the current legal protections surrounding GDEs (Public Access Shoreline Hawaii, by Jerry Rothstien and Angel Pilago, v. Hawaiʻi County Planning Commission and Nansay Hawaii, Inc. 1995 County of Maui v. Hawaii Wildlife Fund 2019, Ka Paʻakai o Kaʻaina, Kona Hawaiian Civic Club, and Protect Kohanaiki Ohana v. Land use commission, State of Hawaiʻi 2000). The entire island of Molokaʻi was designated as a groundwater management area (GMA) by CWRM in 1992 in response to concerns over water resources (Oki 2006). For instance, at least one contested case hearing ruling limited the pumping of the groundwater by Molokaʻi ranches to a suitable limit to sustain groundwater flow to GDEs used for gathering of of fish (mullet, *ʻholeʻhole*, milkfish), and limu (*ogo*, *manauea*, *ʻeleʻele*, and *huluhuluwaena*; IN RE: the Contested Case Hearing on Water Use, Well Construction, and Pump Installation Permit Applications, Filed By Waiʻola O Molokaʻi, Inc. and Moloka‘i Ranch, Limited. 2004). During this hearing, the right to *malama ‘aina* (care for the land) was also testified as being sustained by “protecting the natural ecosystems from desecration and deprivation of its natural freshwater resources" (IN RE: the Contested Case Hearing on Water Use, Well Construction, and Pump Installation Permit Applications, Filed By Wai‘ola O Moloka‘i, Inc. and Moloka‘i Ranch, Limited. 2004).

A petition to designate Kona’s Kaloko Honōkohau, a site with numerous *loko wai kai*, three *loko i‘a*, and large regions of *muliwai*, as a GMA was denied by CWRM in 2017 (Christian 2017). The criteria for designating a GMA under CWRM require a significant impact to GDEs and cultural practice be seen prior to designation, thus Kaloko Honōkohau could not be listed as a preventative measure. Finally, in 2012 a lawsuit on the neighboring island of Maui was brought by the community and the Sierra Club for violation of the clean water act by Lahaina wastewater treatment plant and the US supreme court ruled to maintain the Clean Water Act in the Maui case in 2019 (County of Maui v. Hawaii Wildlife Fund 2019).

A1: Table 1, GDE species

Category	Species	Hawaiian name	Common name	Status	Loko wai kai	Muliwai	Loko iʻa	GDE resources	Associated values
Bird	*Fulica alai*	ʻalae keʻokeʻo	hawaiian coot	endemic	x		x	nesting habitat; water	
Bird	*Himantopus mexicanus knudseni*	aeʻo	hawaiian stilt	Endemic; endangered	x		x	nesting habitat; water	
Bird	*Branta sandvicensis*	nēnē	goose	endemic	x		x	nesting habitat; water	
Bird	*Anas wyviliana*	Koloa maoli	hawaiian duck		x		x	nesting habitat; water	
Bird	*Pterodroma sandwichensis*	ʻuaʻu	hawaiian petrel		x		x	nesting habitat; water	
Bird	*Nycticorax nycticorax hoactli*	ʻaukuʻu	black crowned night heron		x	x	x	habitat	
Bird	*Anas clypeata*	koloa mōhā	northern shoveler	Indigenous; migratory	x		x	habitat	
Bird	*Ayatha affinis*		lesser caup	migratory	x		x	habitat	
Bird	*Arenaria interpres*	ʻakekeke	ruddy turnstone	migratory	x		x	habitat	
Plant	*Bacopa monnieri*	ʻaeʻae	bakopa	indigenous	x		x	water; nutrient source	
Plant; palm	*Pritchardia spp.*	loʻulu		Endemic and indigenous	x		x	water source	
Plant	*Cyperus laevigatus*				x		x	water source	
Plant; palm	*Cocos nucifera*	Niu	coconut palm	indigenous	x		x	water source	food; weaving; building
Plant; succulent	*Sesuvium portulacastrum*	ʻākulikuli		indigenous	x		x	water; nutrient source	food; medicine
Plant; succulent	*Lycium sandwichensse*	ʻōhelo kai			x		x	water source	
Plant; sedge	*Bolboschoenus maritimus*	kaluhā			x		x	water	
Plant; sedge	*Cyperus laevigatus*	makaloa			x		x	water; nutrients	weaving
Aquatic plant	*Ruppia maritima*		Widgeon grass	indigenous	x	x		water; nutrients	
Eel	*Gymnothorax pictus*	puhi kāpʻā	Moray eel	indigenous	x	x	x	habitat	
Shrimp	*Palaemon debilis*	ʻōpae huna	Feeble shrimp	indigenous	x	x	x	habitat	food; fishing
Shrimp	*Machrobrachium grandimanus*	ʻōpae ʻoehaʻa	Hawaiian prawn	endemic	x	x	x	habitat	
Shrimp	*Halocardinia rubra*	ʻōpaeʻula	Anchialine pool shrimp	endemic	x	x	x	salinity- specific reproductive needs; habitat	fishing; environmental indicator
Shrimp	*Procaris hawaiana*			endemic	x			habitat	
Shrimp	*Palaemonella burnsi*			endemic	x			habitat	
Shrimp	*Metabetaues lohena*			indigenous	x			habitat	fishing
Dragonfly	*Pantala flavescens*		globe skimmer	indigenous				habitat; reproduction	
Damselfly	*Megalagrion xanthomelas*		orangeback hawaiian damselfly	endemic	x			salinity- specific reproductive needs	
Crab	*Portunus sanguinolentus*		three spot swimming crab	endemic subspecies		x		nursery habitat	
Fish	*Kuhlia sandvicensis and Kuhlia xenura*	āholehole	flagtail	endemic	x	x	x	salinity-specific reproductive needs; nursery habitat	food; spirituality

A1: Table 1, GDE species

Category	Species	Hawaiian name	Common name	Status	Loko wai kai	Muliwai	Loko iʻa	GDE resources	Associated values
Fish	*Chanos chanos*	ʻawa	milkfish	indigenous	x	x	x	nursery habitat	food; spirituality
Fish	*Eleotridae; Gobiidae; and Blennidae*	ʻoʻopu	general term for gobies		x		x	nursery habitat	food; stocked in loko wai
Fish	*Elotris sandwichensis*	ʻoʻopu akupa		endemic	x			habitat; nursery habitat	
Fish	*Awaous stamineous*	ʻoʻopu nākea	stream goby	endemic	x			habitat	
Fish	*Arothron hispidus*	ʻoʻopu hue	white spotted puffer	indigenous		x		nursery habitat	
Fish	*Abudefduf sordidus*	kūpīpī	blackspot sergeant	indigenous	x			habitat	
Fish	*Acanthurus trigostegus*	manini	convict tang	indigenous	x			habitat	food
Fish	*Acanthurus nigrofuscus*	māʻiʻiʻi	brown surgeonfish	indigenous		x		juvenile habitat	
Fish	*Mulloidichthys flavolineatus*	wekeʻā	square spot goatfish	indigenous	x	x		habitat; soft sediment feeding; juvenile habitat	food
Fish	*Albula virgata and Albula glossodonta*	ʻoiʻo	bonefish	Endemic (*A. virgata*) and indigenous (*A. glossodonta*)		x	x	hunting; shelter; juvenile habitat	food
Fish	*Mugil cephalus*	ʻamaʻama	mullet			x	x	anadroumous; salinity specific reproduction	food; spiritual practice
Fish	*Polydactylus sexfilis*	moi	six finger threadfin	indigenous		x	x	anadroumous; salinity specific reproduction; juvenile habitat	food
Fish	*Caranx ignobilis; C. melampygus; C. sexfasciatus*	ʻUlua; papio (juvenile)	jacks			x	x	opportunistic hunting; shelter; juvenile habitat	food
Fish	*Selar crumenophthalmus*	ʻakule	big eyed scad	indigenous		x	x	nursery habitat	food
Fish	*Myripristis berndti and Myripristis amoena*	ʻuʻu	mempachi; squirrelfish	indigenous		x		opportunistic hunting; shelter	food
Fish	*Mulloidichthys spp.*	weke	goatfish	indigenous		x	x	nursery habitat	food
Fish	*Elops hawaiensis*	awaʻawa	ladyfish	indigenous		x	x	nursery habitat	food
Fish	*Neomyxus leucisus*	uouoa	sharpnose mullet	indigenous		x		nursery habitat	food; spirituality
Fish	*Naso unicornis*	kala	bluespine unicornfish	indigenous		x		nursery habitat	food
Fish	*Atherinomorus insularum*	ʻiao	hawaiian silverside	endemic		x		nursery habitat	spirituality
Fish	*Scomberoides lysan*	lai	leatherback	indigenous		x		nursery habitat	food; drum making
Fish	*Sphyraena barracuda*	kākū	great barracuda	indigenous		x		nursery habitat	
Fish	*Encrasicholina purpurea*	nehu	hawaiian anchovy	endemic		x	x	nursery habitat	bait fish
Fish	*Hemiramphus depauperatus; H. acutus*	iheihe	polynesian halfbeak; acute halfbeak	indigenous		x		nursery habitat	
Macroalgae	*Gracilaria coronopifolia*	Limu manauea	ogo	indigenous		x	x	salinity specific growth needs; nutrients; shelter	food; medicine
Macroalgae	*Gracilaria parvispora*	Limu manauea loloa	ogo			x		salinity specific growth needs; nutrients; shelter	food; medicine

A1: Table 1, GDE species

Category	Species	Hawaiian name	Common name	Status	Loko wai kai	Muliwai	Loko iʻa	GDE resources	Associated values
Macroalgae	*Ulva prolifera*	Limu ʻeleʻele		indigenous		x	x	salinity specific growth needs; nutrients; shelter	food; medicine; groundwater indicator; cultured fish food
Macroalgae	*Ulva lactuca*	Limu pālahalaha	Sea lettuce	indigenous		x	x	salinity specific growth needs; nutrients; shelter	food; medicine; groundwater indicator
Macroalgae	*Erythrotrichia carnea*			indigenous			x	habitat	
Macroalgae	*Centroceras clavulatum*			indigenous			x	habitat	
Macroalgae	*Ceramium spp.*			indigenous			x	habitat	
Macroalgae	*Phycocalidia vietnamensis*	Limu paheʻe	Slippery algae	indigenous		x		associated with SGD habitat	food
Maroalgae	*Grateloupia filicina*	Limu huluhuluwaena		indigenous			x	grow on the seaward side of loko iʻa	food; medicine
Macroalgae	*Hypnea spp.*			indigenous		x		brackish tolerant; nutrients	
Macroalgae	*Spirogyra spp.*			indigenous			x	habitat at spring fed inlets	cultured fish food
Macroalgae	*Vaucheria spp.*						x	habitat	cultured fish food
Macroalgae	*Cladophora spp.*			indigenous	x	x	x	brackish tolerant; nutrients	groundwater indicator; cultured fish food
Macroalgae	*Polysiphonia spp.*			indigenous			x	habitat	cultured fish food
Macroalgae	*Acrochaetium sp.*						x	habitat	cultured fish food
Cyanobacteria	*Lyngbya*			indigenous	x			habitat	
Cyanobacteria	*Schizothrix*			indigenous	x			habitat	
Cyanobacteria	*Scytonema*			indigenous	x			habitat	
Cyanobacteria	*Oscillatoria*			indigenous	x		x	habitat	cultured fish food
Cyanobacteria	*Merismopedia*						x	habitat	cultured fish food
Cyanobacteria	*Microcystis*						x	habitat	cultured fish food
Diatoms	*Navicula; Cymbella; Pleurosigma; Amphora; Melosira; Mastogloia; Coscinodiscus; Nitzchia; Surirella; and Hyalodiscus*						x	habitat; calm water; nutrients	cultured fish food

Appendix 1, Table 1: GDE species that were mentioned in our literature review or in interviews. This table is not an extensive list of GDE associated species or GDE species relevant to cultural practice in Kona; nor are the species-specific associated cultural practices extensive.

A1 Table 2 GDE invasive species

Category	Species	Common name	Status	Loko wai kai	Muliwai	Loko i'a	Impacts
Macroalgae	*Acanthophora spicifera*	Spiny seaweed	introduced	x	x	x	Overgrowth and displacement of native macroalgae; coral
Macroalgae	*Claophora spp.*		native	x	x	x	Bloom forming with excess nutrients and/or sunlight; reduced herbivory
Plant	*Batis maritima*	Pickleweed	introduced	x		x	Overgrowth of GDE systems; displacement of natives; sedimentation
Plant, grass	*Paspalum vaginatum*	Seashore paspalum grass	introduced	x		x	Overgrowth of GDE systems; displacement of natives; sedimentation
Plant, Tree	*Prosopis pallida*	Kiawe	introduced	x	x	x	Increased nitrogen delivery; leaf litter leads to sedimentation
Plant, tree	*Hibiscus tiliaceus*	Hau	polynesian introduction	x		x	Overgrowth of GDEs; shading of GDes
Fish	*Gambusia affinis and Poecilia reticulata*	Guppies	alien invasive	x			Predation of native shrimp; sedimentation of pools; displacement of native species
Fish	*Tilapia spp.*	Tilapia	alien invasive			x	Increased sedimentation; predation of native fish and insect larvae
Jellyfish	*Cassiopea spp.*	Upside down jelly fish	alien, invasive			x	Displacement of native species; stinging cells released into water; stinging of volunteers and caretakers

Appendix 1 Table 2: A list of some invasive species found in Kona's GDEs

A1 Table 3 GDE salinity tolerance

Species	Organism	Hawaiian Name	Salinity Tolerance	Value
Gracilaria coronopifolia	Macroalgae	Limu manauea	Maximum growth at 27‰; minimum 35‰	Food; medicine; primary productivity
Ulva prolifera	Macroalgae	Limu ʻeleʻele	Maximum growth at 10 ‰	Food; medicine; primary productivity
Mugil cephalus	Fish	ʻAmaʻama	Maximum survival eggs: 30-32‰; Larvae: 26-28‰; larvae higher growth at 22-23‰; Juveniles <15‰	Food; spiritual practice
Kuhlia xenura, Kuhlia sandvicensis	Fish	Āholehole, āhole	Similar to ʻamaʻama	Food; spiritual practice
Caranx ignobilis	Fish, Jacks	ʻUlua, Papio	Wide, rely on GDE to prey on *M. cephalus* and *Kuhlia spp.*	Food
Megalagrion xanthomelas	Damselfly		Maximum 15‰	Endemic; endangered species

Appendix 1 Table 3: Salinity tolerance of some GDE associated species.

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