5-YEAR STATUS REVIEW

Species Reviewed: *Drosophila mulli* (Mull's picture-wing fly)
Current Classification: Threatened

Federal Register Notice announcing initiation of this review:
[USFWS] U.S. Fish and Wildlife Service. 2018. Endangered and threatened wildlife and plants; initiation of 5-year status reviews for 156 species in Oregon, Washington, Hawai'i, Palau, Guam, and the Northern Mariana Islands. Federal Register 83(88): 20088–20092, May 7, 2018.

Lead Region/Field Office:
Interior Region 12, Portland Regional Office/Pacific Islands Fish and Wildlife Office (PIFWO), Honolulu, Hawai'i

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Methodology used to complete this 5-year status review:
This review was conducted by U.S. Fish and Wildlife Service (Service) staff working in the PIFWO beginning in October 2019. The review was based on a review of current, available information since the last 5-year status review for *Drosophila mulli* (USFWS 2012). The evaluation by Diane Sether, Lead Invertebrate and Wildlife Biologist, was reviewed by John Vetter, Animal Recovery Coordinator, and Megan Laut, Conservation and Restoration Team Manager. As this review results in recommended reclassification of the taxon, RO review was also conducted as noted above.

Background:
For information regarding the species' listing history and other facts, please refer to the species' profile page on the Service's Environmental Conservation Online System (ECOS) database for threatened and endangered species at *https://ecos.fws.gov/ecp0/profile/speciesProfile.action?spcode=I0R1*.

Review Analysis:
The previous 5-year status review for *Drosophila mulli* dated August 28, 2012 is available at https://ecos.fws.gov/docs/five_year_review/doc4098.pdf and includes the then-current species' status, threats, management efforts, and references cited (USFWS 2012). Critical habitat for the species was designated in 2008 (USFWS 2008). The Recovery Outline for Hawaiian Multi-Island Species, including *D. mulli*, was completed on July 30, 2020 and is available at https://ecos.fws.gov/docs/recovery_plan/SIGNED_Multi-Island_recovery_outline_07-30-

2020_1.pdf (USFWS 2020). The associated Draft Recovery Plan for 50 Hawaiian Archipelago Species is scheduled to be completed in 2021.

Drosophila mulli, in the family Drosophilidae, is a picture-wing fly endemic to montane wet forests on the island of Hawai‘i. The species was known from two sites northeast of Kīlauea volcano in the ‘Ōla‘a Forest Reserve (FR) and Upper Waiākea FR (both owned and managed by the state of Hawai‘i). The species uses the fan leaf palm, *Pritchardia beccariana* (loulu, Kīlauea pritchardia), as a breeding host.

New Status Information:

- Historically, *Drosophila mulli* is known from only two general locations on Kīlauea volcano in montane wet forest (Kaneshiro 2005 in litt., entire; Science Panel 2005, p. 21; Foote 2005 in litt., entire; Magnacca 2006 in litt., entire; Magnacca 2014, entire). *Drosophila mulli* was first collected in 1985 in the ‘Ōla‘a Forest (part of Hawai‘i Volcanoes National Park [Hawai‘i Volcanoes NP]) at an elevation of approximately 3,200 feet (ft) (985 meters [m]) near Volcano Dump Trail in an area dominated by *Metrosideros polymorpha* (‘ōhi‘a). There were no documented collections or observations of this species in 32 surveys conducted in the ‘Ōla‘a Forest prior to 1985. However, it is unknown if loulu was searched during these early surveys because this is the first species of picture-wing fly known to associate with an endemic palm (Perreira and Kaneshiro 1990, pp 79–81; Kaneshiro 2005 in litt., entire). *Drosophila mulli* was not observed in the ‘Ōla‘a Forest again until 1996 when one adult was observed in the same area as the original discovery near the Volcano Dump Trail. This individual was associated with the underside of loulu leaves (Kaneshiro 2005 in litt., entire). In 1997, three *D. mulli* adults associated with loulu were documented in the ‘Ola‘a FR. The last observation of *D. mulli* at the Volcano Dump Trail site was in 2001, when six adults were observed associated with loulu (Kaneshiro 2005 in litt., entire; Foote 2006 in litt., entire).

- In 1999, *Drosophila mulli* was discovered close to the Stainback Highway near the 4,000 ft (1,219 m) elevation in the Upper Waiākea FR (Montgomery 2005 in litt., entire; Kaneshiro 2005 in litt., entire). The five adults observed were associated with a population of loulu. This area is approximately 9.3 miles (mi) (15 kilometers [km]) from the occupied area in the ‘Ola‘a FR (Montgomery 2005 in litt., entire; Science Panel 2005, p. 21). Thorough surveys of loulu at the Waiākea Prison site near the3,600 ft (1,097 m) elevation revealed a wide diversity of insects, but *D. mulli* was not observed (Montgomery 2005 in litt., entire).

- In 2014, Magnacca documented *Drosophila mulli* pupae hanging from the underside of a loulu leaf (Magnacca 2014, entire) in the Upper Waiākea FR. This is the first evidence that *D. mulli* used loulu as a breeding substrate, although the exact larval substrate is unknown. The pupae were suspended from the leaf by an exceptionally strong line attached to the top of the pupa; the line also wrapped around the pupal case (Magnacca 2014, entire). Based on the observation of the pupa position, Magnacca (2014, entire) suggested larvae may use the decaying

leaf when it first dies and rots, but before it falls to the ground, at which time the leaf is likely too decayed and dry for the picture-wing fly to use. Magnacca further surmised that the larvae occupying the decaying leaf use the lowest living leaf to pupate; no pupae were observed on upper leaves (Magnacca 2014, entire).

- The last recorded observation at in the ʻŌlaʻa FR occurred in 2001 (Kaneshiro 2005 in litt., entire; Foote 2006 in litt., entire). This site was surveyed at least 62 times between 1965 and 2001, with fewer than 10 individuals observed on 4 different dates. The species was also observed in 1999 and 2000 in the Upper Waiākea FR near the 4,000 ft (1,219 m) elevation (Science Panel 2005, p 21; Montgomery 2005, in litt, entire). The species' unique association with a fan palm species may have contributed to its late discovery (1985) relative to other *Drosophila* species. Subsequent surveys of loulu in the montane wet forests of the ʻŌlaʻa FR and neighboring Upper Waiākea FR where loulu is found, have not yielded additional individuals or populations of the species (Science Panel 2005, p. 21; Montgomery 2005 in litt., entire). Surveys for the species in areas where it has been documented have frequently failed to detect the species; the height of its host plants likely contributes to the difficulty of observing *D. mulli* even if it is present. In addition, the species is not known to come to bait (Magnacca 2019 in litt., entire).

- The current population size and distribution of *D. mulli* throughout its historically known range (ʻŌlaʻa FR and neighboring Upper Waiākea FR) are unknown.

- The species' primary threats include: habitat and host plant degradation and destruction, nonnative ungulates and plants, predation and parasitization by nonnative species, drought, fire, inadequate regulatory mechanisms to address nonnative species, natural disasters, limited numbers of individuals and populations, climate change, and the interaction of these threats. Most threats to the picture-wing fly and its host plant are not being managed. Although this does not preclude the species' existence at unsurveyed populations of loulu in montane wet forests, *D. mulli* and its host remain at risk throughout their range from unmanaged threats.

New Threats:

- The western yellowjacket (*Vespula pensylvanica*) is an aggressive, generalist predator that threatens *Drosophila mulli* (Gambino et al. 1987, p. 170; Kaneshiro and Kaneshiro 1995, pp. 40-45). The nonnative yellowjacket was first reported in the Hawaiian Islands in 1919 and on the island of Hawai'i in the ʻŌlaʻa Tract of Hawaiʻi Volcanoes National Park in 1981 (Carson 1982, p. 40; Gambino and Loope 1992,p. 2). This species is now particularly abundant between 1,969 and 5,000 ft (600 and 1,524 m) elevation throughout the State (Gambino et al. 1990, pp. 1088-1095; Foote and Carson 1995, p. 371). It is widespread in montane wet forest on the island of Hawaiʻi from which *D. mulli* are known. In temperate climates, the western yellowjacket has an annual life cycle; in the Hawaiian Islands, colonies often persist through a second year. This facilitates large

populations and thus a greater impact on prey populations (Gambino et al. 1987, pp. 169-170). The wasps have been observed carrying and feeding on adult Hawaiian *Drosophila* (Kaneshiro and Kaneshiro 1995, pp. 40-45). Native picture-wing flies may be particularly vulnerable to predation by wasps due to their conspicuous lekking behavior (male territorial defensive displays with other males) and courtship displays that can last for several minutes (Kaneshiro 2006 pp. 4-5; Kaneshiro 2006 in litt., entire). Western yellowjackets may also feed on picture-wing fly larvae in their host substrate (Carson 1986, pp. 3-9). The concurrent arrival of the western yellowjacket and the decline of picture-wing fly observations in some areas suggest that the wasp may have played a significant role in the decline of some picture-wing fly populations (Carson 1986, pp. 3-9; Foote and Carson 1995, p. 371; Kaneshiro and Kaneshiro 1995, pp. 40-45; Science Panel 2005, pp. 1-23).

- Picture-wing flies evolved in the absence of predation and competition from ants, which can be particularly destructive predators because of their high densities, recruitment behavior, aggressiveness, and broad diet (Reimer 1993, pp. 13-17). Ants can prey directly on picture-wing fly eggs and larvae, or exclude flies, through interference or competition, from breeding resources or shelter sites (Krushelnycky et al. 2005, p. 6). The threat of ant predation on *Drosophila mulli* is amplified by the fact that most ant species have winged reproductive adults (Borror et al. 1989, p. 738), are easily transported by humans, and can quickly establish colonies in new locations (Staples and Cowie 2001, p. 55). These attributes allow some ant species to extirpate isolated populations of native arthropods (Nafus 1993, pp. 19, 22-23).

- All ant species occurring in Hawai‘i are nonnative (Perkins 1913, p. xxxix) and at least four particularly aggressive species threaten *Drosophila mulli.* Big-headed ants (*Pheidole megacephala*), long-legged or yellow crazy ants (*Anoplolepis gracilipes*), Papuan thief ants (*Solenopsis papuana*), and Argentine ants (*Linepithema humile*), are aggressive, generalist predators that have severely impacted native insect fauna (Krushelnycky and Gillespie 2010, entire; Reimer 1993, pp. 13-17). As a group, ants occupy most of Hawai‘i’s habitat types, from coastal to subalpine ecosystems. Many species are still invading mid-elevation montane mesic forests. Ants are more likely to occur in high densities in mesic habitats than the montane wet habitats occupied by *D. mulli* (Reimer 1993, pp. 13–17); however, a few species have been able to colonize undisturbed montane wet habitats (Reimer 1993, pp. 13-17).

- The big-headed ant is considered one of the most invasive and widely distributed ant in the world (Holway et al. 2002, pp. 181–233; Krushelnycky et al. 2005, p. 5). In Hawai‘i, big-headed ants are the most common ant and are found from dry coastal to lowland mesic habitat, although they have been found in some dry and mesic habitats up to 4,000 ft (1,219 m) elevation (Reimer 1993, p. 14). Although *Drosophila mulli* is known from montane wet habitats, populations that occur near the edge or in the transtion zone from mesic to montane wet could be at risk.

With few exceptions, native arthropods have been eliminated in habitats where big-headed ants are present (Perkins 1913, p. xxxix; Gagne 1979, pp. 80-81; Gillespie and Reimer 1993, p. 22). Consequently, big-headed ants represent a potential threat to the picture-wing fly (Reimer 1993, pp. 14, 17; Holway et al. 2002, pp. 181–233; Krushelnycky et al. 2005, p. 5).

- The yellow crazy ant was first documented in Hawai‘i in 1952, and now occurs on the islands of Kaua‘i, O‘ahu, Maui, and Hawai‘i, (Reimer et al. 1990, p. 42; AntWeb. Version 8.33, 2020). In general, the species inhabits low- to mid-elevations (less than 2,625 ft (800 m), but ants have been collected as high as 3,938 ft (1,200 m) at Haleakalā National Park (Medeiros et al. 1986, entire; Reimer et al. 1990, p. 42). Although surveys have not been conducted to ascertain this ant species' presence in areas last known to be occupied by *Drosophila mulli*, yellow crazy ants occur in lowland wet forests (Reimer 1993, p. 15). Due to the ant's aggressive nature and ability to spread and colonize new locations, yellow crazy ants can form high densities or supercolonies (many ant colonies united over a large area) in a relatively short period of time with serious consequences for native arthropods (Gillespie and Reimer 1993, p. 21; Lester and Tavite 2004, p. 399–400). Due to the ant's aggressive nature and ability to spread and colonize new locations, yellow crazy ants are a potential threat to the picture-wing fly.

- The Papuan thief ant is the only abundant, aggressive ant that has invaded intact mesic to wet forest, as well as coastal and lowland dry habitats. This species occurs on the main islands of Hawai‘i and is still expanding its range (Reimer 1993, p. 14). Because of the ant's widespread occurrence that overlaps with the habitat of *Drosophila mulli*, this species is a threat to the picture-wing fly throughout its range (Krushelnycky et al. 2017, entire).

- Argentine ants were first noted on O‘ahu in 1940 and are now established on all of the main islands of Hawai‘i (Reimer et al. 1990, p. 42). Argentine ants do not disperse by flight; instead, colonies are dispersed by humans via soil and construction material. The Argentine ant is found from coastal to subalpine habitats on Maui, and on the slopes of Mauna Loa in the mesic habitats on the island of Hawai‘i (Krushelnycky and Gillespie 2010, pp. 643-655). Argentine ants have been documented to reduce or eliminate populations of native arthropods in Haleakalā National Park on Maui (Cole et al. 1992, pp. 1313–1322). These ants severely impact larval stages of many flies; they are significant predators on nonnative fruit flies and are associated with the decline of an endemic phorid fly (*Megaselia* sp.) (Krushelnycky and Gillespie (2010, pp. 643–655). Although there is no documentation of predation by Argentine ants on picture-wing flies, these ants are a threat to native arthropods located at high elevations (e.g., above 6,800 ft [2,070 m]; Cole et al. 1992, pp. 1313–1322; Science Panel 2005, pp. 1–23).

- The Hawaiian Islands support several species of nonnative beetles (family Scolytidae, genus *Coccotrypes*), a few of which bore into and feed on the nuts produced by certain native and nonnative palms, including those in the genus

Pritchardia (Science Panel 2005, pp. 1–23; Magnacca 2005, pers. comm.). These beetles prefer trees with large seeds, like those of loulu. Loulu drop their fruit before reaching maturity due to the boring action of the *Coccotrypes* spp. beetles, thereby reducing natural regeneration (Magnacca 2005 in litt., entire; Science Panel 2005, pp. 1–23). Although loulu are long-lived (up to 100 years), over time these beetles may severely impact the health and growth of loulu, and may lead to secondary infections or infestations.

- In 2014, an ichneumonid wasp*, Gelis tellenae*, emerged from what was believed to be a healthy, intact *Drosophila mulli* pupa (Magnacca 2014, entire) in the Upper Waiākea FR. The extent of the parasitization of *D. mulli* at this location or at the ʻŌlaʻa FR is unknown. Prior to this observation, this wasp was not a known threat to *D. mulli*. Several other species of nonnative, small parasitic wasps (Family Braconidae), including *Diachasmimorpha tryoni, Diachasmimorpha longicaudata*, *Opius vandenboschi*, and *Biosteres arisanus*, were purposefully introduced into the State to control nonnative pest tephritid fruit flies (Funasaki et al. 1988, pp. 105-160). These parasitic wasps attack other fly species, including native flies in the family Tephritidae. While these wasps have not been recorded parasitizing Hawaiian picture-wing flies and, in fact, may not successfully develop in Drosophilidae, females will indiscriminately sting any fly larvae in their attempts to oviposit, resulting in mortality of the larvae (USFWS 2013, p. 64676). Because of this behavior, nonnative parasitoid wasps represent a threat to *D. mulli*.
- Most of the montane wet habitats of *Drosophila mulli* have experienced prolonged periods of abnormally dry to extreme drought conditions for the past 20 to 30 years (NIDIS 2020). This has resulted in overall habitat degradation and can alter decay processes of picture-wing fly host plants. Drought also alters the entire plant community on which the fly depends. ʻŌhiʻa is the main canopy tree in the montane wet habitats of *D. mulli* and has been adversely affected by the prolonged dry period, resulting in a more open canopy and modification of the understory microclimate.

- The plant disease Rapid ʻŌhiʻa Death (ROD) is an ongoing threat to ʻōhiʻa. This lethal disease is caused by two fungal pathogens, *Ceratocystis lukuohia* and *C. huliohia* (Barnes et al., 2018, entire). *Ceratocystis huliohia* is less aggressive and has been found on Kauaʻi, Oʻahu, Maui, and the island of Hawaiʻi; the single infected tree on Maui was removed (Friday et al., 2021, entire). *Ceratocystis lukuohia* is highly aggressive and has been identified on the island of Hawaiʻi and Kauaʻi (Friday et al. 2021, entire; Heller et al. 2019, entire). On the island of Hawaiʻi, thousands of ʻōhiʻa have died and ROD is present throughout the range and current habitat of *D. mulli* (Friday et al. 2020, entire). Like drought, the loss of canopy trees to ROD allows more sunlight to reach the forest floor, increasing temperature and lowering humidity, which adversely affects the picture-wing fly species and its habitat.

- Monitoring data collected in Hawai‘i Volcanoes National Park (NP) during a drought period between 1981 and 1982 suggested that the number of individuals of 14 other picture-wing fly species decreased 1 year after the drought (Carson 1986, pp. 4, 7). Severe droughts not only have the potential to kill individuals or extirpate *Drosophila* populations, but frequently lead to an increase in the number and intensity of wildfires. This results in a reduction of native habitat, an increase in nonnative plant and animal species, and a reduction in availability of picture-wing fly host plants (Giambelluca et al. 1991, p. v; D’Antonio and Vitousek 1992, pp. 77–79; Smith and Tunison 1992, pp. 403–405).

- *Drosophila mulli* is known from montane wet habitat, which typically does not have a high fire risk. However, fire does present a moderate risk to *D. mulli* because the areas where the species has most recently been documented are near areas where volcanic activity and drought increase the risk of fire (Giambelluca et al 1991, entire; Science Panel 2005, entire). Human alteration of landscapes and the introduction of nonnative plants, especially grasses in the mesic forests, has led to greater frequency, intensity, and duration of fires (Abrahamson 2013, entire). Grass-fueled fire often kills most native trees and shrubs and can penetrate into wet forests (D’Antonio and Vitousek 1992, p. 70, 73–74). Extreme drought conditions are also contributing to the number and intensity of wildfires on the island of Hawai‘i (Abrahamson 2013, entire; USFWS 2013, p. 64663–64664). Dead wood accumulation from dead or dying ‘ōhia trees can result in extremely damaging fires.

- *Drosophila mulli* uses loulu as a breeding host. The montane wet habitat of the picture-wing fly and loulu is highly susceptible to damage from nonnative ungulates, mainly feral pigs (*Sus scrofa*), and to a lesser extent, mouflon sheep (*Ovis gmelini musimon*), and goats (*Capra hircus*) (Foote and Carson 1995, pp. 369–371; Science Panel 2005, p. 21–23; Magnacca 2006 in litt., entire). These ungulates root and damage loulu, may browse and trample young plants, consume nuts, and alter the microclimate of the picture-wing flies’ habitat by opening the understory (Magnacca et al. 2008, p. 32). Pig consumption of loulu nuts results in a lack of regeneration. As a result, loulu numbers have decreased throughout their range in areas that are not fenced and ungulate-free.

- Regulatory mechanisms are inadequate to address the ungulate threat (USFWS 2006, p. 26842–26844). The State of Hawai‘i provides non-native game mammal (e.g., feral pigs and goats, axis deer [*Axis axis*], and mouflon sheep) hunting opportunities on State-designated public hunting areas on the island of Hawai‘i (HDLNR 2015, pp. 19–21 and 66–77). The State’s management objectives for game animals range from maximizing public hunting opportunities to support sustained yield in some areas to eradicating game animals by State staff, or their designees, in other areas (HDLNR 2015, entire).

- Natural area reserves on the island of Hawai‘i remain open as hunting units. In addition, portions of the ‘Ōla‘a Forest in Hawai‘i Volcanoes NP are not fenced, and thus face the same threats as do adjacent State FR lands.

- Changes in environmental conditions that may result from climate change include increasing temperatures, decreasing precipitation, and increasing storm intensities, all of which will likely affect the habitats of *Drosophila mulli* (Clark et al. 2020, entire). These stressors may change the habitats on the island of Hawai‘i and exacerbate other threats making habitats unsuitable for *D. mulli*, its host plants, or both. Climate change vulnerability is defined as the relative inability of a species to respond with the necessary behavioral adaptiability or genetic elasticity to persist under changing environmental conditions cause by climate change (e.g. changes in rainfall and temperatures). An assessment of *Pritchardia beccariana* concluded that this *D. mulli* larval host species is vulnerable to climate change, with a vulnerability score of 0.24, with 0 being not vulnerable to 1 being extremely vulnerable (Fortini et al. 2013, p. 69). Additionally, changes in temperature and humidity may alter the decay cycle of the loulu substrates the picture-wing flies require to breed.

- Species such as *Drosophila mulli* that are restricted to a few known locations are less resilient to threats that might otherwise have a relatively minor impact on widely distributed species. For example, the reduced availability of host plant substrate or an increase in predation or parasitization would likely be inconsequential to a widely distributed species but could result in a significant decrease in survival or reproduction of a species with a limited distribution. The limited distribution of this species magnifies the severity of the effects of other threats.

- Like most native island biota, the Hawaiian picture-wing fly is particularly sensitive to disturbances due to the likely low number of individuals and populations, few known occupied areas, small geographic range, and distance between known populations. As a result, *Drosophila mulli* is vulnerable to extinction due to those threats which are exacerbated by low number of individuals and population numbers. The species was last observed in 2000 and 2001 at both of its original historical locations and was observed at one of these locations in 2014 (Foote 2005 in litt., entire; Service Panel 2005 in litt. entire; Magnacca 2006 in litt., entire; Magnacca 2014, entire). Because this species is only known from two populations that are only separated by 9.3 mi (15 km), a single catastrophic event (e.g., hurricane, drought, volcanic activity) could result in the extirpation of one or both populations and the extinction of the species.

New Management Actions:

- *Drosophila mulli* is not known from Hawai‘i Volcanoes NP, but it may be present because of the Park’s contiguous forests, which supports loulu and provides for similar conditions at the same elevations used by *D. mulli* in the ‘Ōla‘a FR (Magnacca 2006 in litt., entire). Although no fencing or other management

activities have occurred within the area of ʻŌlaʻa FR occupied by *D. mulli*, the species and its associated loulu have likely benefited from fencing and ungulate control conducted in the nearby montane wet ʻōhiʻa forests of Hawaiʻi Volcanoes NP, Puʻu Makaʻala Natural Area Reserve (NAR), and Kūlani (USFWS 2015a, entire; USFWS 2015b, pp. 2–4; Magnacca 2019 in litt., entire). Pig management within and adjacent to *D. mulli* habitat is likely benefitting loulu and possibly undocumented *D. mulli* populations (Foote 2005 in litt., entire).

- Rat control experiments have been conducted at Hawaiʻi Volcanoes NP and regeneration of loulu has been observed. However, researchers are uncertain if loulu regeneration was due to reduced rat predation on loulu nuts or due to pig management (i.e., fencing and control) (Science Panel 2005, pp. 21–22; Magnacca 2006 in litt., entire).

- At the population of *Drosophila mulli* located within the Upper Waiākea FR, some pig fencing has been constructed enclosing habitat that includes loulu (Magnacca 2006 in litt., entire). The pig fencing in both the Park and Upper Waiākea FR will eliminate pig damage to host plants within fenced areas (Science Panel 2005, pp. 21–22; Magnacca 2006 in litt., entire).

Table 1. Known populations of *Drosophila mulli* from listing to this 5-year status review.

Date	Populations	Individuals	Recovery Criteria[1]
2006 listing	≥2 (based on surveys from 1965 to 2001)	unknown	N/A
2006 recovery outline	≥2	unknown	N/A
2008 critical habitat	≥2	unknown	N/A
2012 5-year review	≥2	unknown	N/A
2020 recovery outline	≥2	unknown	N/A
2021 species report	≥2	unknown	N/A
2020 5-year review	≥2	unknown	N/A

[1]N/A=not available at this time; the recovery plan and species-specific recovery criteria are currently under review. The Draft Recovery Plan for 50 Hawaiian Archipelago Species is expected to be completed in 2021.

Table 2. Status of threats to *Drosophila mulli* and ongoing conservation efforts.

Threat	Listing Factor	Current Status	Conservation/Management Efforts
Ungulates	A	Ongoing	Partial—some strategic ungulate fencing and control has occurred in the Hawai‘i Volcanoes NP, Pu‘u Maka‘ala NAR, and Kūlani adjacent to the ‘Ōla‘a FR. As a result, natural recruitment of loulu has occurred; fencing has been constructed in the Upper Waiākea FR that protects some loulu.
Invasive nonnative plants	A	Ongoing	Partial—some control on nonnative plants occurs in Hawai‘i Volcanoes NP and Pu‘u Maka‘ala NAR adjacent to the ‘Ōla‘a and Upper Waiākea FRs.
Fire	A	Ongoing	Partial—general fire management plans are in place for the ‘Ōla‘a and Upper Waiākea FRs, but fuel load is an ongoing threat.
Stochastic events (e.g., drought, hurricane, volcanic activity)	A	Ongoing	None
Altered decay cycle of host plants	A	Ongoing	None
Predation by wasps	C	Ongoing	None
Predation by ants	C	Ongoing	None
Parasitization by wasps	C	Ongoing	None
Inadequate existing regulatory mechanisms	D	Ongoing	Partial—restrictions on transport of invasive species to the islands are insufficient to prevent introduction of invasive species and diseases; habitat and host plant loss due to ungulates has been reduced or eliminated in fenced areas.
Habitat altering plant disease	E	Ongoing	None
Loss of plant hosts	E	Ongoing	Partial—some natural regeneration of loulu as a result of ungulate control, fencing, and rat control is occurring in montane wet habitat of Hawai‘i Volcanoes NP and Upper Waiākea FR that may be suitable for *Drosophila mulli* establishment or reintroduction.

Table 2. continued.

Threat	Listing Factor	Current Status	Conservation/Management Efforts
Rats	E	Ongoing	Partial—rats prey on the nuts, bark, and flowers of loulu and impede natural regeneration; rat control experiments have been conducted at Hawai‘i Volcanoes NP and some loulu natural recruitment has occurred.
Limited numbers	E	Ongoing	None
Distance between populations	E	Ongoing	The distance between the two known populations of *Drosophila mulli* and the sparcity of loulu impedes genetic exchange between picture-wing fly populations.
Climate change	E	Ongoing	None

Summary and Synthesis:
Drosophila mulli (Mull's picture wing fly) in the family Drosophilidae is endemic to montane wet ‘ōhi‘a forests northeast of Kīlauea volcano (Perreira and Kaneshiro 1990 pp. 79–81) The species has been documented at only two locations (Kaneshiro 2005 in litt., entire; Montgomery 2005 in litt., entire; Science Panel pp. 20–21; Magnacca 2006 in litt., entire). Last observed in 2014, one population occurs within the Upper Waiākea FR; the other population, observed in 2000 and 2001, occurs about 9.3 mi (15 km) south within the adjacent ‘Ōla‘a FR habitat (Kaneshiro in litt., 2005; Science Panel 2005, p. 21; Foote 2005 in litt., entire; Magnacca 2006 in litt., entire; Magnacca 2014, entire). The number of *D. mulli* individuals in each population is unknown. Discovered in 1985, this picture-wing fly uses the fan palm, *Pritchardia beccariana* (loulu) as a breeding host (Perreira and Kaneshiro 1990 pp. 79–81). Adult flies are typically seen on the underside of the fronds and are believed to be generalist microbivores (i.e., microbe eating). In general, picture-wing flies use decaying bark, stems, leaves, or fermenting bark or sap fluxes as a larval substrate (Montgomery 1975, entire). The specific loulu substrate chosen by the *D. mulli* female for oviposition (i.e., laying of eggs) and subsequent larval development is unknown (Perreira and Kaneshiro 1990, pp. 79–81; Mull 1994 pers. comm., entire; Montgomery 2005 in litt., entire; Science Panel 2005, p. 21; Magnacca 2006 in litt., entire). Magnacca (2014 in litt., entire) suggests larvae may use the decaying leaf when the leaf first dies and rots, but before the leaf falls to the ground, at which time the leaf is likely too decayed and dry for the picture-wing fly. In 2014, the first pupae of *D. mulli* were observed suspended from the leaf underside of a loulu, confirming the use of loulu as a breeding host (Magnacca 2014, entire). Pupae have not been observed on the upper surfaces of loulu leaves. One of the pupa observed during the 2014 surveys in the Upper Waiākea FR appeared healthy and intact, but had been parasitized by an ichneumonid wasp. The parasitic wasp that emerged from the pupal case was identified as *Gelis tellenae*, a previously unknown threat to this species (Magnacca 2014, entire). It is not known how widespread the parasitization of *D. mulli* pupae is nor its effect on the species.

Although adult *Drosophila mulli* are generalist microbivores, the species depends on the availability of suitable decaying substrate of the loulu for oviposition and larval development (Perreira and Kaneshiro 1990, pp. 80–81; Mull 1994 pers. comm., entire; Montgomery 2005 in litt., entire; Science Panel 2005, p. 21; Magnacca 2006 in litt., entire). The loss or degradation of host plant resources or of habitat providing the humidity needed by the picture-wing fly and for the decay cycle of the loulu substrate threaten the existence of *D. mulli*. The limited number of *D. mulli* populations make it vulnerable to catastrophic events such as fire, hurricanes, and volcanic activity as well as predation by wasps and ants and parasitization by nonnative wasps. The lengthy and conspicuous lekking and courtship behaviors of the species and its relatively large size increase the species' vulnerability to predation by western yellowjacket. These wasps are also believed to feed on picture-wing fly larvae. Other nonnative wasps, such *Gelis tellanae* or Braconid wasps, may indiscriminately sting the pupa or larva of *D. mulli* resulting in mortality. The species is also vulnerable to predation by ants. The plant hosts of *D. mulli* are particularly vulnerable to ungulate damage from browsing and trampling and pigs and rats feed on nuts, impeding natural seeding and regeneration. Scolytid beetles attack the loulu and cause premature nut drop. Loulu populations are relatively rare and isolated from one another, which impedes genetic exchange between the limited number of populations of *D. mulli* that may utilize different loulu populations. It is suspected that many picture-wing fly species travel some distance to reach host plants (around 328 ft [100 m] has been estimated), especially within contiguous forest (Science Panel 2005, p. 5). However, species feeding on isolated host plants probably do not frequently move between plant populations (Science Panel 2005, p. 5).

The primary threats to the species, its plant host, and its habitat are habitat degradation and destruction by nonnative ungulates, consumption of or damage to loulu nuts by various nonnative species, nonnative plants, rarity and isolation of the the species' plant host, drought, fire, volcanic activity, severe storms and hurricanes, predation and parasitization by nonnative invertebrates, inadequate regulatory mechanisms to address nonnative species, limited numbers of individuals and populations, potential environmental changes, and the interaction of these threats. While some of these threats have been partially managed, many remain unaddressed or cannot be feasibly managed with current techniques. Due to the species extreme rarity in targetted surveys, a multitude of threats, including new ones, such as ROD, that are largely unmanaged, and limited conservation actions, this species meets the definition of endangered, as it is in danger of extinction throughout its range. A draft recovery plan for *D. mulli* is expected to be completed in 2021.

For a species to thrive, it needs to have multiple stable to growing populations occurring throughout its range representing all known ecological and species-specific genetic diversity. Redundancy is the ability of *Drosophila mulli* to withstand catastrophic events and is measured by the number of populations (redundancy/duplication), distribution of the populations across the landscape, and connectivity among populations. To achieve redundancy, the distribution of .picture-wing fly populations across their geographic range should exceed the area of impact of a catastrophic event that would otherwise overwhelm the resilience of the popluations. Essentially, the more populations of *D. mulli*

and the broader the distribution of those populations, the more redundancy the species will exhibit, thereby increasing its ability to survive a catastrophic event. For *D. mulli*, redundancy requires the presence of multiple, stable to increasing populations distributed across its montane wet forest range between the elevations of 3,200 to 4,000 ft (975 to 1,220 m) where their host plant is abundant.

Representation is the ability of *Drosophila mulli* to adapt to changing environmental conditions over time and can be measured by having one or more populations occupying the species' full range of suitable habitat. Alternatively, representation can be characterized by a species' breadth of genetic diversity, within and among, populations. This allows the species to adapt to changing environmental conditions over time. The mobility of *D. mulli* facilities the species' ability to maintain genetic exchange and representation. However, connectivity is determined by the distance that can reasonably be traveled by individuals, which is estimated at about 328 ft [100 m] (Science Panel 2005, p. 5) and is hampered by fragmentation of suitable habitats with host substrate and limited occurrence of *D. mulli*.

Hawaiian picture-wing flies, including *Drosophila mulli*, evolved in isolated habitats, resulting in tremendous speciation (Foote and Carson 1995, pp 368-369; Kaneshiro 1976, p. 276; Magnacca and Price 2015, entire); as a result, small population size may be less of a threat for this genus than limited habitat or limited range, decreasing availability of suitable oviposition and larval host substrates, and predation (Science Panel 2005, entire; Kaneshiro 2004, entire). Resiliency is the capacity of a population to withstand demographic and environmental stochasticity. The survival rate of *D. mulli*, population demographics, and growth rate needed to sustain a population in the presence of threats are unknown. For picture-wing flies to be abundant, individuals must reproduce. This requires mating and having a stable to positive population growth rate. Thus, we base resiliency of *D. mulli* on host availability, habitat quality and population abundance and growth rate, and to a lesser extent, on population size.

In summary, the two populations of *Drosophila mulli* observed in the last 20 years occupy isolated areas within the ʻŌlaʻa FR and the adjacent Upper Waiākea FR (Kanashiro 2005 in litt., entire; Montgomery 2005 in litt., entire; Magnacca 2014, entire). Despite targeted surveys through 2014 in one of its historically occupied areas, the species has not been observed in theʻŌlaʻa Forest (Science Panel 2005 p. 21; Montgomery 2005 in litt., entire; Magnacca 2019 in litt., entire) since 2001. The species was observed in the Upper Waiākea FR in 2014, when pupae, were observed, although one pupa was parasitized. Limited survey results do not preclude the existence of other undocumented populations. Detection of *D. mulli* is difficult because of the height of its loulu host, which requires the use of binoculars or climbing the tree to observe the species on the undersides of the loulu fronds. In the last decade, surveys for this species have been very limited. Both known populations on Kīlauea are at risk of extirpation, which would lead to extinction of the species, provided there are no unidentified populations. Resiliency of the populations is extremely low because the number of known populations is small, populations of loulu are limited and isolated, there is an apparent lack of growing populations, and the picture-wing fly and its host are affected

by a suite of threats. The species has extremely low redundancy because only two populations have been observed in the last 20 years. Species representation is extremely low given the low number of populations and distance between those two popuation, which likely impedes genetic exchange. Therefore, the current viability of *D. mulli* is extremely low. Based on the species' extremely low redundancy, representation, and resiliency, *Drosophila mulli* meets the criteria of endangered.

Recommendations for Future Actions:

- Develop measurable recovery criteria for *Drosophila mulli*.
- Develop an efficient and reliable survey methodology for *Drosophila mulli*.
- Conduct range-wide surveys for *Drosophila mulli* to determine or confirm current distribution and status.
- Determine the demographic structure of each *Drosophila mulli* population.
- Identify genetic diversity of *Drosophila mulli*.
- Monitor and assess the abundance of *Drosophila mulli* individuals and the growth trend of populations.
- Establish a captive rearing program for *Drosophila mulli*.
- Develop microclimate models to determine potential future climate conditions and identify future suitable habitat based on existing and historical distributions of *Drosophila mulli* and loulu.
- Identify threats impacting all sites occupied or selected to be occupied by *Drosophila mulli* populations used to satisfy recovery criteria for the species.
- Prioritize and select sites based on factors including conservation value to the species and likelihood of threat control success.
- Identify and prepare suitable habitats for translocation of *Drosophila mulli*.
- Construct and maintain ungulate-proof fences around all sites occupied by populations of *Drosophila mulli* and loulu.
- Remove ungulates from fenced areas needed for the recovery of the species and keep these sites ungulate-free.
- Control or eradicate habitat-modifying invasive plants at all sites occupied by populations designated for recovery.
- Outplant populations of host plants (loulu) in suitable habitats if necessary for site preparation.
- Develop and implement rat control to protect loulu and *Drosophila mulli* populations.
- Develop and implement fire management plans for all populations of *Drosophila mulli,* loulu, and their habitat.

- Control invasive plant species that compete with loulu in *Drosophila mulli* habitats.
- Identify new and emerging threats, such as *Gelis tellenae,* and determine their range and impact on *Drosophila mulli*.
- Develop and implement effective control methods for nonnative predatory and parasitic wasp species at all *Drosophila mulli* populations.
- Develop and implement effective control methods for ant species at all *Drosophila mulli* populations.
- Develop and implement control of Scolytid beetles in *Drosophila mulli* and loulu habitats.
- Intercept and control new threats to *Drosophila mulli* and loulu before they become widespread.
- Prevent other habitat modifying threats, including incipient invasive species, from arriving and establishing at sites occupied by populations designated for recovery.
- Control other existing threats to sites occupied by populations designated for recovery.
- Identify individuals suitable for translocation and develop and implement translocation plans for each according to IUCN Reintroduction Guidelines (2013).
- Select populations for translocation.
- Consider the feasibility and conservation benefit of translocating species outside of their known historical range as appropriate (e.g., assisted colonization).
- Monitor management and use results to adapt management actions.
- Develop tools to enhance habitat and species survival and reproduction.
- Develop tools to inform actions that will improve species viability *in situ* and *ex situ.*
- Develop tools for monitoring population growth and status.
- Maintain long-term studies on the range, demographics, and dispersal of *Drosophila mulli*.
- Conduct research on threats to species' viability.
- Conduct population viability analyses for *Drosophila mulli*.
- Conduct studies on optimizing conservation translocation survival and success.
- Conduct long-term genetic studies on captive and wild populations of *Drosophila mulli*.
- Monitor the range-wide populations, status, population trends, and distribution at time intervals appropriate for the species.

- Identify, develop, and support alliances and partnerships to plan and implement *Drosophila mulli* habitat restoration and management to benefit and recover the species.
- Ensure long-term protection of *Drosophila mulli* and loulu.
- Provide support to implement the Hawai‘i interagency biosecurity plan to prevent the arrival and spread of new pests and invasive species into the Hawaiian Archipelago and inter-island movement of invasive species already established in the archipelago.

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U.S. FISH AND WILDLIFE SERVICE
SIGNATURE PAGE for 5-YEAR STATUS REVIEW of
***Drosophila mulli* (Mull's picture-wing fly)**

Pre-1996 DPS listing still considered a listable entity? N/A

Recommendation resulting from the 5-year status review:

_____ Delisting
_____ Reclassify from Endangered to Threatened status
__X__ Reclassify from Threatened to Endangered status
_____ No Change in listing status

EARL CAMPBELL Digitally signed by EARL CAMPBELL
Date: 2021.11.02 11:08:25 -10'00'

Project Leader, Pacific Islands Fish and Wildlife Office Date:_____

Digitally signed by KATHERINE NORMAN
Date: 2021.11.05 09:48:44 -07'00'

Assistant Regional Director, Ecological Services,
Interior Regions 9/12 Date_____