

**The spread of the introduced freshwater apple snail *Pomacea canaliculata* (Lamarck) (Gastropoda: Ampullariidae) on O'ahu, Hawai'i<sup>1</sup>**

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*Pomacea canaliculata*, a native of South America, was first reported in the Hawaiian Islands on Maui in 1989. By the end of July 1992, the snail had been found at an additional two locations on Maui, two on Kaua'i, five on O'ahu, and two on the island of Hawai'i (Cowie, 1995). In 1995 it was reported from Lāna'i (Cowie, 1996).

Most of the documented impacts of the spread of *P. canaliculata* in the Hawaiian Islands are agricultural (Cowie, 1995, 1997). Initially, it was introduced to taro fields deliberately, in order to provide a secondary source of food and income for the taro-growers. However, the animal is now widely regarded as a pest of taro. Damage level is likely related to snail density, and in taro fields in Hawai'i, densities have exceeded 130 per m<sup>2</sup> (Cowie, in press). Though no figures are available for taro losses, in south-east Asia a density of 1 snail per m<sup>2</sup> can reduce rice yields by 20 % and yields decrease more than 90 % when 8 snails per m<sup>2</sup> are present (Naylor, 1996).

Little is known of the snail's impact on native freshwater snails or freshwater communities. *Pomacea canaliculata* feeds relatively indiscriminately on macrophytes (Neck, 1986; Schnorbach, 1995; Cowie, in press). The animal's voracious appetite, combined with its high fecundity, suggests that it has the potential to significantly alter community dynamics where it establishes (Cowie, in press). In Asia, it has been implicated in the decline of native freshwater snails (Halwart, 1994). Hawai'i's lowland aquatic habitats are already imperiled by urbanization, channelization, and the introductions of other invasive species, both plants and animals; its indigenous snail and other invertebrate species may not be able to withstand further assault.

**Ampullariidae**

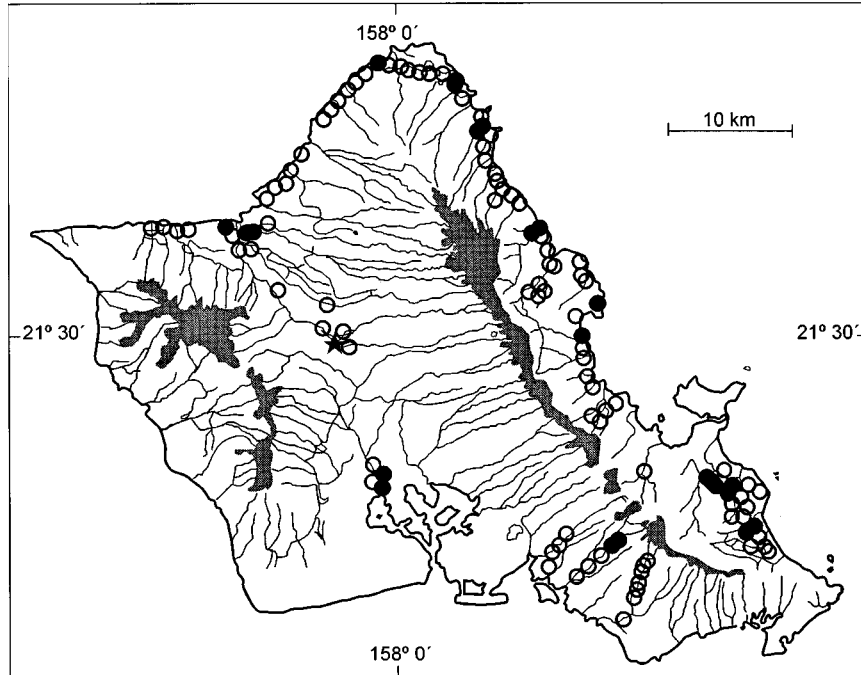
*Pomacea canaliculata* (Lamarck, 1804)

**Range extension**

Here we report on material collected on O'ahu since 1992. Earlier material was reported by Cowie (1995). Two collections were made in 1993 and 1995 (see Material examined), but the majority of these new collections were made by us in 1998. Our focus was on natural, not agricultural (taro), ecosystems, although some collections were made from taro fields.

Snails were found at 28 sites (eggs but no snails at an additional site) in 19 bodies of water (see Material examined) out of a total of 139 sites surveyed in 98 bodies of water (Fig. 1). The appendix lists sites at which *P. canaliculata* was not found. The sites covered most of the localities on O'ahu that we considered possibly suitable for *P. canaliculata*, i.e., slow-flowing low-elevation streams, usually with muddy bottoms (not channelized), ponds, drainage ditches. Some sites at which no *P. canaliculata* were found may, in fact, have been unsuitable (e.g., streams that were too fast-flowing, intermittent streams, slightly brackish water), but we list them because we cannot make that judgement. Of the five locations on O'ahu reported by Cowie (1995), we revisited two (Waialua, Waipahu); snails were present at both. We did not revisit the 1990–92 Kualoa locality but *P. canaliculata* is known to be still present there (R. Helling, pers. comm.). We did not revisit the

1. Contribution No. 1999-020 to the Hawaii Biological Survey.



**Fig. 1.** Map of O'ahu showing water courses. Closed circles are locations at which *Pomacea canaliculata* was found. Open circles are locations that were searched but at which *P. canaliculata* was not found. In some cases circles are coincident because of the scale of the map. The star is the single site at which only eggs (no snails) were found. Shaded areas represent relief above 610 m elevation.

1991 Kahalu'u location, as this was in taro fields, although we investigated nearby areas and found no *P. canaliculata*. Neither did we revisit the precise location of the 1991 Hau'ula site, although we looked at several other sites in the vicinity but found no *P. canaliculata*. Eggs were collected from emergent vegetation in Wahiawā Reservoir (Lake Wilson), but despite extensive searching, no snails have been found there. No snails (or eggs) have been seen in any of the streams, other than those reported here, feeding into Pearl Harbor or Honolulu Harbor, despite extensive biological survey work (R. Englund, pers. comm.). Field notes and maps relating to our 1998 survey are archived at Bishop Museum.

These new records indicate that the distribution of *P. canaliculata* has increased greatly. Moreover, the snail is now found much more widely in areas not associated with agriculture (taro farming), including: Kahawai Stream, Maunawili Stream, Kawainui Marsh, Waikāne Stream, an unnamed stream in Lā'ie connecting 'Ihi'ihi Stream and Kahawainui Stream, Wahiawā Reservoir (eggs only recorded), Kapakahi Stream, and Nu'uuanu Freshwater Fish Refuge. Relative to the distribution of apparently suitable freshwater systems, there does not appear to be a geographic pattern in the snail's known distribution on the island. Field observations suggest that *P. canaliculata* can survive, or even

thrive, in polluted and littered freshwater habitats; frequently we observed snails and eggs on emergent refuse.

The spread of *P. canaliculata* is probably due to a suite of causes: deliberate moving of snails for culture either in artificial aquaculture facilities (from which they escape) or in taro fields; accidental transport of eggs and/or young snails on taro for transplanting; release of snails used in domestic aquaria; natural spread via streams and other interconnected bodies of water; spread resulting from abnormal hurricane or flood events; and possible accidental transport of young snails attached to birds. We do not believe the snail has reached its full potential distribution on O'ahu. Many freshwater habitats appear suitable in terms of flow, vegetation, and available oviposition sites, but are not yet colonized.

*Material examined.* Unless otherwise stated, all material was collected together by Lori Lach and Robert H. Cowie. All catalog numbers are Bishop Museum (BPBM) Malacology Collection numbers. **O'AHU:** Kualoa Ranch, taro field, D. Carvalho, 7 January 1993 (251211); Waikāne Stream, at Kamehameha Highway bridge, R. Englund & R. Filbert, 28 December 1995 (253569); Kapakahi Stream, downstream of Farrington Highway, 19 May 1998, D.J. Preston, R. Englund, H. James (254031), 11 June 1998 (254054); Kawainui Marsh, off of Kapa'a Quarry Road (five locations from c. 200 m south of the refuse transfer station to just beyond the sharp bend in the road to the north of the model airplane field), 20 May 1998 (254048; dead shell only), 15 June 1998 (254060), 13 August 1998, R.H. Cowie (254049, 254050), 24 August 1998, R.H. Cowie (254051); Maunawili Stream, under bridge on road to country club, 21 May 1998 (254052); Kawai Nui Marsh, stream below Hanale Place, 5 June 1998 (254053); Waipahu Plantation Village, taro fields, 11 June 1998 (254055); Nu'uuanu Freshwater Fish Refuge, at weir under Nu'uuanu Pali Drive bridge, 11 June 1998 (254056); Nu'uuanu Freshwater Fish Refuge (upper lake), 11 June 1998 (254057); Waialua, ditches either side of Pu'uiki Street, 13 June 1998 (254058); Hale'iwa, roadside ditch at 66-240 Waialua Beach Road, 13 June 1998 (254059); Waikāne Stream, c. 100 m upstream from Kamehameha Highway bridge, 17 June 1998 (254061); Waimānalo, Kahawai Stream, at Mahailua Street bridge, 23 June 1998 (254062); Waimānalo, Kahawai Stream, under Kalaniana'ole Highway bridge, 23 June 1998 (254063); Waikāne Stream, c. 300 m downstream from Kamehameha Highway Bridge, 22 June 1998, Alakai Kim-Davis (254064); Punalu'u, ditch alongside Punalu'u Valley Road, 2 July 1998 (254065); ditch beside taro field alongside Punalu'u Valley Road (254066); Kahuku, ditch alongside unpaved road leading to Campbell National Wildlife Refuge, 2 July 1998 (254067); Lā'ie, in stream connecting 'Ihi'ihi Stream and Kahawainui Stream, alongside Po'oha'ili Street, 2 July 1998 (254068); Lā'ie, Hawai'i Reserves, Inc., ditch around taro fields, 2 July 1998 (254069); Kahuku, in stream at western edge of Campbell National Wildlife Refuge, 21 July 1998 (254070); Kawela Stream, where it goes under Kamehameha Highway, just west of Hanopu Street, 21 July 1998 (254071); Hale'iwa, taro field on south side of Waialua Beach Road, just east of Hale'iwa Road, 21 July 1998 (254072); Hale'iwa, ditch on north side of Waialua Beach Road, just east of Hale'iwa Road, 21 July 1998 (254073); Wahiawā, Wahiawā Reservoir (Lake Wilson), near bank opposite Schofield Barracks main entrance, 9 September 1998, A. Brasher, eggs only (254551).

#### Acknowledgments

We thank Anne Brasher for discussion and for assistance with field work, and the various people who provided material in addition to our own survey material. The 1998 field work was supported in part by a grant to LL from the Edna Bailey Sussman Fund.

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#### Appendix. Sites where neither *P. canaliculata* nor its eggs were observed

**O'AHU:** Windward: Waimānalo, unnamed stream at Kalaniana'ole Highway near Kaiona Beach Park; Waimānalo, tributary to Ino'a'ole Stream at Hihimanu Street; Waimānalo, tributary to Ino'a'ole Stream at Ahiki Street, at Makakalo Street, and at Hihimanu Street; Waimānalo, Ino'a'ole Stream off of Kalaniana'ole Highway; Waimānalo, unnamed stream at Waikupanaha Street, at Mokulama Street, and at Hihimanu Street; Waimānalo, Kahawai Stream at Waikupanaha Street, at Kaka'ina Street, and at Mekia Street; Waimānalo, Waimānalo Stream at Kalaniana'ole Highway, at Kumuhau Street, and at Kaka'ina Street; Enchanted Lake, Ka'elepulu tributary between Kanapu'u Drive and Kalaniana'ole Highway, at Keolu Drive, and as it enters Enchanted Lake at Kiuke'e Place; Enchanted Lake, stream at 'Akumu Street, at Kāhili Street, at Alahaki Street, and at Keolu Drive; Lanikai, unnamed stream at 'A'alapapa Drive; Kailua, east side of Kawainui Marsh, alongside levee from Oneawa Channel to Kailua Road; Kailua, stream under Kailua Town Bridge, Kailua Road; Kailua, Ulupō Heiau off Kailua Road; Maunawili, Kahana Iki Stream under Kalaniana'ole Highway, and at Auloa Road; Maunawili, unnamed tributary to Maunawili Stream at Auloa Road between Maunawili Road and Luna'ai Street; Maunawili, unnamed tributary to Maunawili Stream off Maunawili Road before Aloha 'Oe Drive, and at Aloha 'Oe Drive between Kika Street and Mei Place, and at Aloha 'Oe Drive between Kukana Place and Maleko Street, and its tributary at Aloha 'Oe Drive between Hepaki Place and Lopaka Place; Maunawili, unnamed tributary to Maunawili Stream before Aloha 'Oe Drive at Maunawili Road; Maunawili, unnamed tributary to Maunawili Stream at Kelewina Street, and at Maunawili Road between Aloha 'Oe Drive and Kelewina Street; Maunawili, unnamed tributary to Maunawili Stream between Maunawili Road and Kelewina Place; Maunawili, Maunawili Stream upstream of Kelewina Street, after trailhead, at electric gate; Kāne'ohe, Ho'omaluhia Botanical Garden Reservoir; Kahalu'u, unnamed stream at Kahekili Highway and Aha'olelo Road; Kahalu'u, tributary to Waihe'e Stream at Ahilama Road and Māpele Roads; Kahalu'u, taro fields at Ahilama Road; Kahalu'u, tributary of Waihe'e Stream at Māpele Road and Māpele Place; Kahalu'u, Waihe'e Stream at Ahilama Road; Kahalu'u, unnamed stream at 47-653 Kamehameha Highway; Kahalu'u, Ka'alea Stream at Country Market; Waikāne, stream just south of Waikāne Stream off of Kamehameha Highway; Kualoa, stream at 49-176 Kamehameha Highway; Ka'a'awa, Ka'a'awa Stream at Kamehameha Highway; Ka'a'awa, unnamed stream between Ka'a'awa Place and Pōhuehue Road; Ka'a'awa, Makaua Stream at Kamehameha Hwy; Kahana, taro field at Kahana Bay across Kamehameha Highway from lagoon; Kahana, tributary to Kahana Stream near Kahana Valley

State Park; Kahana, Kahana Stream back of Kahana Beach Park; Punalu'u, unnamed stream near southern end of Punalu'u Beach Park; Punalu'u, Punalu'u Stream at Kamehameha Highway; Punalu'u, unnamed stream off of Punalu'u Valley Road; Punalu'u, Ponds at Punalu'u; between Punalu'u and Hau'ula, unnamed stream at Puhuli Street; Hau'ula, Kaluanui Stream from parking lot to Sacred Falls; Hau'ula, unnamed stream at Pokiwai Place; Hau'ula, Mākao Stream at Hāla'i Street and Hau'ula Homestead Road; Hau'ula, unnamed stream at Kamehameha Highway between Kukuna Road and fire station; Hau'ula, Mahe'iwi Stream at Kamehameha Highway and at Hau'ula Homestead Road; Hau'ula, ditch along Kamehameha Highway between Pipilani Place and Hau'ula Homestead Road; Hau'ula, Kaipapa'u Stream near Pipilani Place; Hau'ula, Kokololio Stream at Kamehameha Highway; Lā'ie, Koloa Stream at Kamehameha Highway; Lā'ie, unnamed stream at Kamehameha Highway just south of Pakelo Place; Lā'ie, Lā'ieloa Stream at Kamehameha Highway; Lā'ie, Kahawainui Stream at Kamehameha Highway.

North: Kahuku, Māla'ekahana Stream at Kamehameha Highway; Kahuku, unnamed stream at Kamehameha Highway between unnamed road to airstrip and gated road, 0.25 km from each; Kahuku, unnamed stream at Kamehameha Highway between Marconi Road and unnamed road to airstrip; Kuilima, unnamed stream at Kamehameha Highway just north of Marconi Road; Kuilima, unnamed stream at Kamehameha Highway opposite golf links; Kuilima, Ō'io Stream at Kamehameha Highway; Kawela, Kawela Stream at Hanopū Street; Waiale'e, Pahipahi'ālua Stream at Kamehameha Highway; Waiale'e, Waiale'e Stream at Kamehameha Highway; Waiale'e, unnamed stream at Kamehameha Highway near University of Hawaii Waiale'e Livestock Research Farm; Sunset Beach, unnamed stream at Kamehameha Highway between Mamao Place and Wehiwa Place; Sunset Beach, Paumahalu Stream at Kamehameha Highway near Paumalū Place; Sunset Beach, Pākūlena Stream at Ke Wa'ena Road and Kamehameha Highway; between Sunset Beach and Waimea, Kālunawaika'ala Stream at Kamehameha Highway near Kaha'e Road; Kawailoa Beach, unnamed stream at Kamehameha Highway and Punalau Place; Kawailoa Beach, unnamed stream between Pōhakuloa Way and Ashley Road at 68-489 Kamehameha Highway; between Kawailoa Beach and Hale'iwa, unnamed stream between Pāpa'iloa Road and Pōhakuloa Way; Hale'iwa, 'Uko'a Pond along Kawailoa Road, and behind the sugar mill, and at Hale'iwa bypass; Hale'iwa, Lokoea Pond at Kamehameha Highway and at Lokoea Place; Hale'iwa, Anahulu River at Hale'iwa bypass; Hale'iwa, Paukauila Stream at Kamehameha Highway, and at Hale'iwa bypass; Hale'iwa, Ki'iki'i Stream at Waiālua Beach Road; Hale'iwa, Poamoho Stream at Kaukonahua Road; Waiālua, Kaukonahua Stream at Farrington Highway; Mokulē'ia, unnamed stream at Farrington Highway west of Mahina'ai Street; Mokulē'ia, unnamed stream at Farrington Highway just east of polo field; Mokulē'ia, unnamed stream at Farrington Highway between Lā'au Pa'ina Place and Ho'omana Place; Mokulē'ia, unnamed stream at Farrington Highway, across from Dillingham Airfield.

Central: between Wahiawā and Waiālua, Poamoho Agriculture Research Station pond and irrigation ditches along Kaukonahua Road; Wahiawā, Poamoho Stream at Kamehameha Highway near Poamoho Camp; Wahiawā, Wahiawā (Wilson) Reservoir at Kamehameha Highway and Avocado Street, and at the west end of Wahiawā Freshwater Park, and at Wilikina Drive just west of Lakeview Circle, and at Wilikina Drive just east of the main entrance to Schofield Barracks, and at Wilikina Drive opposite Schofield Barracks near Kemo'o Farm; Wahiawā, stream outlet from reservoir at Wilikina Drive.

Leeward: Waipahu, Waikele Stream under Waipahu Street bridge, and between Farrington Highway and Waipahu Plantation Village.

East: Honolulu, Mānoa Stream and tributaries at Date Street and alongside Kaimukī High School playing field, and at Woodlawn Drive at Mānoa Market Place, East Mānoa Road at 'Ono Road, Lowrey Avenue near East Mānoa Road, Mānoa Gardens at Kahaloa Drive, East Mānoa Road below Kaamalio Drive, at footbridge between Pāwaina Street and Paumaka Place, Wa'akaua Road,

and Wa‘aloa Way; Honolulu, Nu‘uanu Stream at the two sites where Nu‘uanu Pali Drive crosses the stream downstream from the Nu‘uanu Freshwater Fish Refuge; Honolulu, Nu‘uanu Stream at Lili‘uokalani Gardens; Honolulu, Kapālama Drainage Channel alongside Kohou Street; Honolulu, Kalihi Stream at Wilson Street and Likelike Highway, at Nalani‘eha Street, and at Numana Road.