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Nonmarine Mollusks from Archaeological Sites on Mo‘orea, Society Islands, French Polynesia, with Descriptions of Four New Species of Recently Extinct Land Snails (Gastropoda: Pulmonata: Endodontidae)¹

Carl C. Christensen,^{2,5} Jennifer G. Kahn,³ and Patrick V. Kirch⁴

Abstract: Nonmarine mollusks recovered during archaeological excavations on the island of Mo‘orea, Society Islands, French Polynesia, were analyzed as part of a multidisciplinary study of anthropogenic environmental change. Records of now-extinct taxa in dated archaeological contexts were combined with historic collection data from the 1830s to the present to determine the chronology of extinction of the 10 species of land snails of the family Endodontidae that formerly inhabited the island. One species known only from a stratum antedating human settlement on the island and three known only archaeologically but from imprecisely dated strata were certainly extinct by the late nineteenth century but may have disappeared earlier. One species collected in 1838 was extinct by the late nineteenth century, and all of the described endodontid species present in the mid- to late nineteenth century are undoubtedly now extinct because none was collected by the 1934 Mangarevan Expedition or by subsequent collectors. Only a single unidentified living endodontid has been observed on Mo‘orea since the nineteenth century. Additional extinctions or extirpations have occurred among the Helicarionidae, terrestrial Assimineidae, and probably also in the Helicinidae. Four new species of Endodontidae are described: *Libera kondoi*, *Minidonta opunohua*, *Nesodiscus nummus*, and *N. cookei*. *Libera jacquinoti*, described in 1850 from poorly localized material and until now not collected subsequently, is shown to have inhabited Mo‘orea.

RECENT ARCHAEOLOGICAL and paleoenvironmental studies have shown that human activities in the Society Islands (Central East Polynesia) and elsewhere in East Polynesia have had substantial effects on island environ-

ments and native biota both during the prehistoric period following initial human settlement of these islands ca. AD 900–1000 and following the advent of European influence and commerce in the mid- to late eighteenth century AD (Anderson 2002, Kennet et al. 2006, Prebble and Wilmshurst 2008, Kirch et al. 2010, McWethy et al. 2010, Newell 2010, Conte and Molle 2014, Kahn et al. 2015). The investigation reported here of land snails obtained during archaeological excavations on the island of Mo‘orea, in the Society Islands of French Polynesia, was undertaken as part of a multidisciplinary study of anthropogenic environmental change.

The terrestrial mollusks of the Society Islands, including Mo‘orea, came to the attention of the scientific community early in the nineteenth century and by 1900 were relatively well studied. During the first half of the century, the island’s land snails were collected by members of two major exploring expeditions, that of the French vessels *Astrolabe* and

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Zelee (1837–1840) and the United States Exploring Expedition (1838–1842). In the second half of the nineteenth century the primary source of information on the island's land snails was through the work of the naturalist Andrew Garrett, who visited the Society Islands at various times from 1857 onward and resided on Huahine from 1870 until his death in 1887 (Thomas 1979). Garrett was a careful collector and published a comprehensive review of the Islands' terrestrial mollusks (Garrett 1884); his work continues to be held in high regard (Solem 1976, Thomas 1979). Although some taxa restricted to high elevations escaped his notice (Solem 1976, 1983, Gargominy 2008), we believe any taxa inhabiting low-elevation sites, such as those under study here, can safely be regarded as having gone extinct by the 1880s if they were not encountered by Garrett. This includes *Orobophana* cf. *maugeriae*, *Libera jacquinoti*, and the four endodontid species here described as new. Henry Crampton intensively studied the island's Partulidae, and members of Bishop Museum's 1934 Mangarevan Expedition made extensive collections on the island (Cooke 1935). More recently, the island's highly endangered Partulidae have been studied (e.g., Murray and Clark 1980, Johnson et al. 1993), and within the last 10 yr the living nonmarine mollusk fauna of the island has been extensively sampled in the course of the Moorea Biocode Project (Moorea Biocode 2016). This is the first study of land snails from paleontological or archaeological sites on Mo'orea and thus provides the first available information about species that had gone extinct before the activities of nineteenth-century naturalists. No comprehensive review of the island's nonmarine mollusks has appeared since Garrett's time, but major monographs on several important families have appeared based on collections up to and including those of the Mangarevan Expedition: Baker (1940) on the Helicarionidae, Cooke and Kondo (1961) on the Achatinellidae, and Solem (1976, 1983) on the Endodontidae and Charopidae. Several other families, especially the Helicinidae, Assimineidae, and Succineidae, remain poorly known and are in need of further study.

MATERIALS AND METHODS

Coastal Transects, Coring, and Test Excavations

As part of a larger project investigating coastal habitations and geomorphology on the island of Mo'orea, several coastal localities and alluvial bottomland contexts were investigated (Kahn et al. 2015). These include five coastal localities (sites ScMo-341, -342, -343, and -349, where we completed transect coring and test excavations, and Lake Temae, where we retrieved a deep pollen core) (Figure 1A, B). These locales represent three contrastive depositional environments. Sites -341, -342, and -343 are low-lying coastal plains situated along the northern shore on the headlands between 'Opunohu Bay and Paopao (Cook's) Bay. They are situated across from barrier reefs and major passes where there was likely to be substantial input of calcareous sediments of marine origin. Site -349 is located along the eastern shore on the headlands of Vaiare Bay. It is also situated across from a barrier reef and a major pass but along a part of the island that receives less rainfall. The Lake Temae pollen core sample was retrieved from the northeastern point of the island. This brackish lake is now separated from the sea by a beach ridge of calcareous sediments. The lake is at the base of Temae Valley. The main sedimentary input was from inland terrigenous sources following deforestation and clearance of the adjacent hillslopes.

Abbreviations used in site descriptions are as follows: AH, augur hole; b.d., below datum; cmbs, centimeters below surface; L, Layer; obj., object; spm., specimen; spms., specimens; and TP, test pit.

Excavation and Sampling Methods

Transects were laid out at sites from the base of the colluvial slopes to the lagoon shore. Coring with a bucket auger proceeded at 10 to 20 m intervals along each transect. Sediments were screened through 3.175 mm (1/8 inch) and 1.588 mm (1/16 inch) mesh; all artifacts and faunal materials were quantified on standardized forms. Based on the augering data, we developed predictions of areas with the densest subsurface cultural deposits,

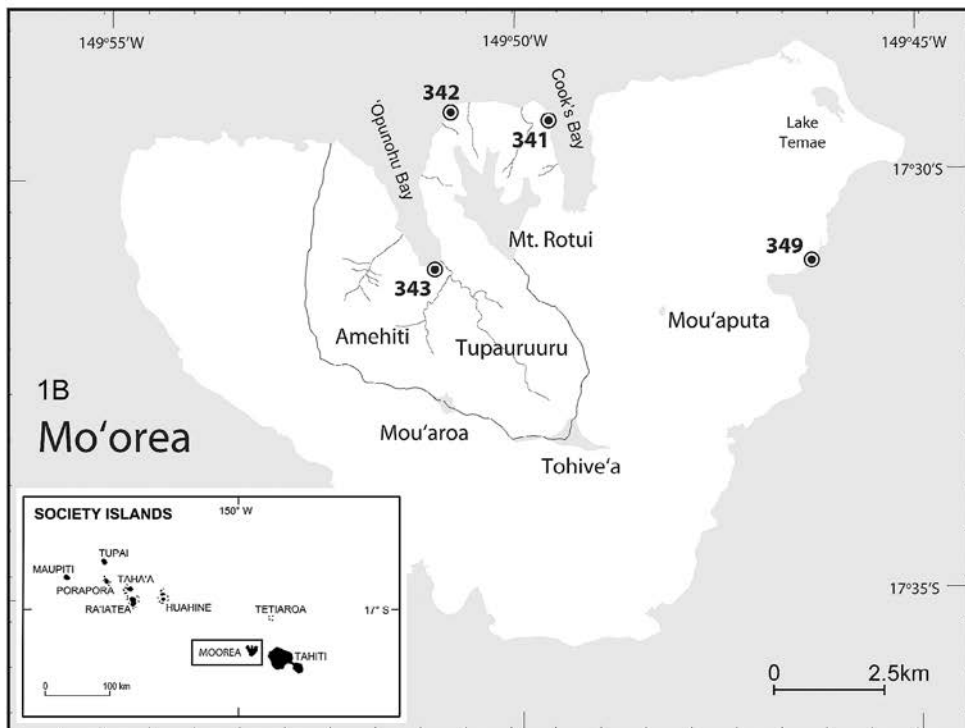
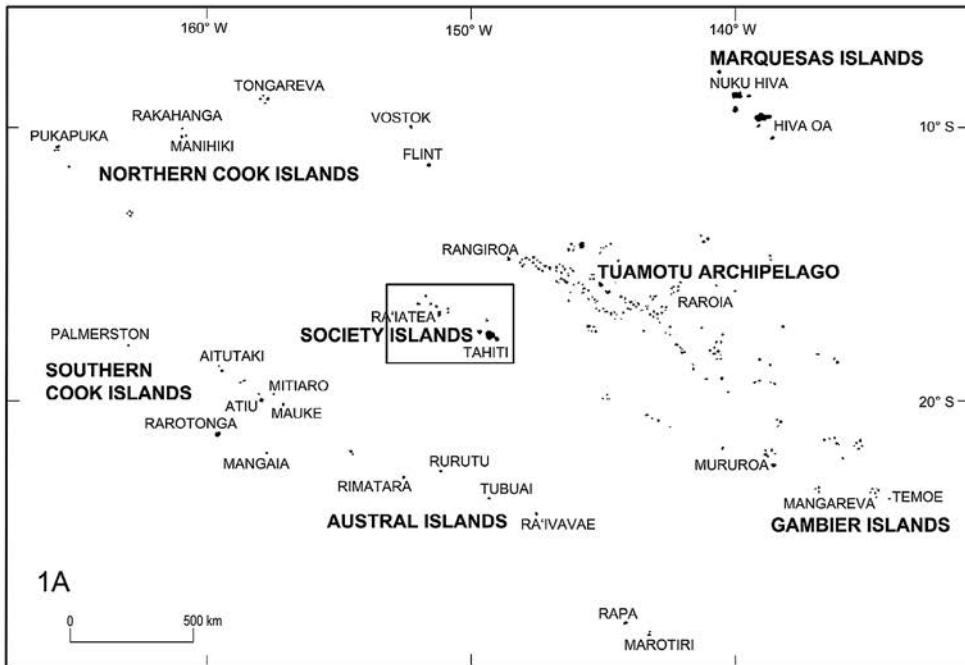


FIGURE 1. (A) Map of the South Pacific Ocean showing location of the Society Islands; (B) Map showing location of the island of Mo'orea (inset) and location of the sites excavated.

which were then opened up for detailed investigation by excavation of 1 m by 1 m test pits or by larger block excavations and trenches via backhoe excavation. These test pits and backhoe trenches allowed us to view broader stratigraphic profiles and to conduct additional pollen and sediment sampling. From these, bulk sediment samples were retained for extraction of land snails. The bulk samples were floated and then wet screened and picked through to retrieve land snail samples for analysis. Snails were recovered from sediment samples by wet screening or flotation in the field, followed by hand picking in the laboratory with the aid of a stereomicroscope. Comparisons were made with material in the malacological collections of the Bernice P. Bishop Museum, Honolulu. Specimens are deposited in the collections of the Bishop Museum (BPBM) and the Muséum National d'Histoire Naturelle, Paris (MNHN). BPBM catalog numbers are cited in the species descriptions.

Stratigraphic Descriptions and Radiocarbon Dating

Radiocarbon dates and stratigraphic descriptions from all sites (except -349) have been published in full elsewhere (Kahn et al. 2015). Age ranges for newly dated deposits at ScMo-341 and summaries of the deposits at all sites containing land snails and short stratigraphic descriptions to place the land snail-bearing deposits in context are presented in the Appendix.

RESULTS

Thirty-six species of nonmarine mollusks were recovered during this study, represented by 220 lots and 3,351 individual specimens. Strict quantitative analysis is not possible because collecting methods were not consistent throughout the study (both flotation and wet screening were used), but the three most abundant species were *Assimineia parvula* Mousson, 1865 (20 lots; 1,358 specimens), the aquatic *Tarebia granifera* (Lamarck, 1822) (1 lot, 825 specimens), and a prehistorically

introduced commensal species, *Allopeas gracile* (Hutton, 1834) (21 lots, 556 specimens). A detailed analysis of the taxa represented, the stratigraphic distribution of extinct species and those aliens introduced during the pre-contact and modern eras, and descriptions of four new species of Endodontidae are presented here.

SYSTEMATIC REVIEW

Family NERITIDAE

Clithon sp.

MATERIAL: Vaipahu, ScMo-343: L II, TP1-B2, obj. 9 (2 spms.); L II, TP1-B3, obj. 8 (3 spms.); L II, TP2-A4, obj. 6 (2 spms.); L IIIa, TP2-B1, obj. 6 (3 spms.); L IIIa, TP2-B2, obj. 7 (2 spms.).

REMARKS: The freshwater Neritidae of French Polynesia have been reviewed by Starmühlner (1976), Haynes (1988, 2001, 2005), and Pointier and Marquet (1990). The specimens collected during this study are weathered or eroded and cannot be identified with certainty but most closely resemble *Clithon oualaniensis* as discussed in Starmühlner (1976) and the species identified as "*Clithon* (*Clithon*) sp. (?cf. *chlorostomus*, Broderip, 1832)" and as "*Clithon chlorostoma* (Broderip, 1832)" by Starmühlner (1976) and Haynes (2001), respectively.

Family HELICINIDAE

The taxonomy of Pacific island Helicinidae is confused at the generic level and chaotic at the specific level; the latest monographs (Wagner 1905, 1907–1911) are long out of date. Richling (2009, 2011) and Richling and Bouchet (2013) recently assigned to *Sturanya* New Caledonian, Hawaiian, and Mangarevan species formerly assigned to the genera *Orobophana* and *Pleuropoma*; Richling and Bouchet (2013) erected a new genus, *Nesiocima*, for certain other helicinids occurring on islands from the Cook, Society, and Austral Islands eastward to the Gambier Islands, Pitcairn, and Henderson. The smaller helicinid found on Mo'orea during the current study is here

assigned to *Sturanya*, although with some doubt because the anatomical features said to distinguish *Sturanya* from *Nesiocina* are unavailable for study in this subfossil material. We follow Wagner (1907–1911) in placing Garrett's *Helicina maugeriae* in the genus *Orobophana*, recognizing that further anatomical study, not possible with the material available here, may result in a reassignment. Garrett (1884) reported the following taxa (all assigned by him to the genus *Helicina*) to occur on Mo'orea: *minuta* Sowerby, 1842; *flavescens* Pease, 1865; *rustica* Pfeiffer, 1851; *inconspicua* Pfeiffer, 1848; and *faba* "Pease" Garrett, 1884; seven additional species, including *maugeriae* Gray, 1825, were listed as occurring elsewhere in the Society Islands.

Orobophana sp. cf. *maugeriae* (Gray, 1825)

MATERIAL: Pihaena, ScMo-342: L VI, TP2-B4, obj. 3 (1 spm.).

REMARKS: A single broken specimen was obtained of a large-shelled helicimid with a strongly angulate periphery that resembles *O. maugeriae*, a species not previously reported to occur on Mo'orea and known only from Ra'iātea and Taha'a (Garrett 1884). The level at which this specimen was found dates to the late pre-Polynesian period (2,400–4,600 yr before present).

Sturanya sp.

MATERIAL: Vaipahu, ScMo-343: L II, TP1-B1, obj. 7 (4 spms.); L II, TP1-B3, obj. 8 (2 spms.); L II, TP2-A4, obj. 7 (3 spms.); L IIIa, TP2-B1, obj. 6 (2 spms.); L IIIa, TP2-B1, obj. 7 (10 spms.); L IIIa, TP2-B2, obj. 8 (1 spm.).

REMARKS: The material studied here includes a number of specimens of a small unidentified helicimid with a rounded periphery. The confused taxonomy of the group precludes more precise identification, but this is probably one of the species recorded by Garrett (1884) as inhabiting the island. This species was present on the island in 1934 (e.g., ВРВМ 150954), but no more recent records of helicimids are listed in the database of the Moorea Biocode Project (Moorea Biocode 2016).

Family HYDROCENIDAE

Georissa striata (Pease, 1871)

MATERIAL: Vaipahu, ScMo-343: TP2-A4, obj. 7 (1 spm.).

REMARKS: Garrett (1884) stated that this was the most abundant of the three species of *Chondrella* (= *Georissa*) he found to occur in the Society Islands. This species is widely distributed in the southern Cook Islands, the Society Islands, Austral Islands, Makatea in the Tuamotu Islands, and the Marquesas Islands (Brook 2010 and references cited therein; Gargominy and Fontaine 2015); archaeologically, it has been reported from Rarotonga and Mitiaro in the Cook Islands (Brook 2010, Brook et al. 2010). It survives on Mo'orea (Moorea Biocode 2016).

Family ASSIMINEIDAE

Assimineea parvula Mousson, 1865

MATERIAL: Pihaena, ScMo-342: L VIII, TP 2-B3, obj. 6. 384–401 cm b.d. (1 spm.). Vaipahu, ScMo-343: L II, TP1-B1, obj. 6 (42 spms.); L II, TP1-B1, obj. 7 (82 spms.); L II, TP1-B2, obj. 3 (222 spms.); L II, TP1-B2, obj. 9 (203 spms.); L II, TP1-B3, obj. 7 (4 spms.); L II, TP1-B3, obj. 8 (262 spms.); L II, TP1-B3, obj. 10 (78 spms.); L II, TP2-A4, obj. 6 (36 spms.); L II, TP2-A4, obj. 7 (20 spms.); L IIIa, TP2-B1, obj. 6 (212 spms.); L IIIa, TP2-B1, obj. 7 (124 spms.); L IIIa, TP2-B2, obj. 7 (34 spms.); L IIIa, TP2-B2, obj. 8 (4 spms.). Teavaro, ScMo-349: AH4, obj. 1, 60–90 cm b.s. (6 spms.); AH4, obj. 1, 60–110 cm b.s. (1 spm.); AH4, obj. 1, 120–150 cm b.s. (2 spms.); AH5, obj. 1, 90–120 cm b.s. (13 spms.); AH5, obj. 1, 120–150 cm b.s. (3 spms.); AH8, obj. 1, 0–30 cm b.s. (9 spms.).

REMARKS: This species, including *A. nitida* (Pease, 1865), a synonym according to Cowie (1997b), is widely distributed in Oceania from the Philippines and Micronesia eastward to Hawai'i and French Polynesia (Abbott 1958); it is extant on Mo'orea (Moorea Biocode 2016). In Hawai'i it is said to be a semiaquatic strandline species that lives under rubble at and near the shoreline (Kay 1978), but Brook (2010:179) reported that on Rarotonga, Cook

Islands, *A. parvula* was “fully terrestrial and widely distributed across the island.” As Brook remarked, it appears that additional research will be necessary to determine whether “*A. parvula*” as currently understood includes more than a single species, a concern also expressed by Abbott (1958). Accordingly it would be premature to draw ecological inferences from the occurrence of this species in the material studied here.

Omphalotropis sp.

MATERIAL: Vaipahu, ScMo-343: L I, TP1-A1, obj. 2 (2 spms.); L I, TP1-A2, obj. 2 (1 spm.); L I, TP1-A3, obj. 1 (1 spm.); L II, TP1-B1, obj. 6 (2 spms.); L II, TP1-B1, obj. 7 (9 spms.); L II, TP1-B2, obj. 3 (2 spms.); L II, TP1-B2, obj. 9 (1 spm.); L II, TP1-B3, obj. 8 (2 spms.); L II, TP1-B3, obj. 10 (1 spm.); L II, TP2-A4, obj. 6 (2 spms.); L II, TP2-A4, obj. 7 (5 spms.); L IIIa, TP2-B1, obj. 7 (20 spms.); L IIIa, TP2-B2, obj. 6 (12 spms.); L IIIa, TP2-B2, obj. 7 (1 spm.); L IIIa, TP2-B2, obj. 8 (1 spm.).

REMARKS: Four species of *Omphalotropis* have been reported from Mo‘orea: *O. huabeiensis* (Pfeiffer, 1854), *O. oblonga* (Pfeiffer, 1854), *O. scitula* (Gould, 1847), and *O. terebra-lis* (Gould, 1847); an additional two species occur elsewhere in the Society Islands (Garrett 1884). Little has been published on Society Island Omphalotropidinae since Garrett’s work, and species-level identifications will remain uncertain until the group is revised. A number of specimens of an unidentified species of *Omphalotropis* were recovered during the excavations reported here at levels dating to the period AD 1521 to the present. No *Omphalotropis* were collected in 1934 by Bishop Museum’s Mangarevan Expedition, nor are any current records listed in the database of the Moorea Biocode (2016).

Family TRUNCATELLIDAE

Tabaitia pallida (Pease, 1867)

MATERIAL: Vaipahu, ScMo-343: L II, TP1-B1, obj. 7 (3 spms.); L II, TP1-B2, obj. 3 (1 spm.); L II, TP1-B2, obj. 9 (1 spm.); L II, TP1-B3, obj. 8 (1 spm.); L II, TP2-A4, obj. 6 (1 spm.); L IIIa, TP2-B1, obj. 7 (1 spm.).

REMARKS: Garrett (1884) reported the occurrence of two species of *Tabaitia* in the Society Islands, *T. porrecta* (Gould, 1846), and *T. pallida* (Pease, 1867); only the latter has been reported from Mo‘orea. A few specimens are represented in the material studied here.

Family THIARIDAE

Melanoides tuberculata (Müller, 1774)

MATERIAL: Vaipahu, ScMo-343: AH9, obj. 2, 0–30 cm b.s. (1 spm.); L I, TP2-A1, obj. 2 (2 spms.); L IIIa, TP2-B1, obj. 6 (1 spm.).

REMARKS: *Melanoides tuberculata* is a globally invasive fresh- and brackish-water snail that is now widely distributed in Oceania (Starmühlner 1976, 1993, Pointier and Marquet 1990, Cowie 1997a, Haynes 2001); it currently inhabits Mo‘orea (Moorea Biocode 2016). It has a fossil record in Africa and Indonesia extending back to the Miocene and Pliocene, respectively (Oostingh 1935, van Benthem Jutting 1937, Ladd 1972 and works cited therein; van Damme 1984, van Damme and Pickford 2003, Joordens et al. 2009). Szabó (2009) reported *M. tuberculata* to be present in pre-contact (pre-European contact) sites in Fiji. Bandel and Kowalke (1997), Athens and Ward (2006), and Athens et al. (2007) have suggested that it may be a pre-contact Polynesian introduction, and Kirch et al. (2017) have demonstrated its pre-contact presence on Mangaia in the Cook Islands. Work in progress confirms a pre-contact presence on Ra‘iātea in the Society Islands (C.C.C. and J.G.K., in prep.) and in the Hawaiian Islands (C.C.C. and J. S. Athens, in prep.). The species’ presence in L IIIa of the ScMo-343 site (AD 1521–modern, most likely AD 1521–AD 1767) is suggestive of a pre-contact presence on Mo‘orea but is not conclusive because of dating uncertainties.

Tarebia granifera (Lamarck, 1822)

MATERIAL: Lake Temae: Core 1, L I, 749–753 cm b.s. (825 spms.).

REMARKS: Like *Melanoides tuberculata*, *Tarebia granifera* (also known as *Thiara*

granifera) is a globally invasive aquatic snail that now inhabits numerous Pacific islands (Starmühlner 1976, Pointier and Marquet 1990, Cowie 1997a, Haynes 2001), including Mo'orea (Moorea Biocode 2016). *Thiara granifera* is native to island Southeast Asia, based on its fossil occurrence in Indonesia (Oostingh 1935, van Benthem Jutting 1937). Like *M. tuberculata* it was a pre-contact resident of the Hawaiian Islands (C.C.C. and J. S. Athens, in prep.). The specimens recovered in this study are modern (200 yr or less before present), so provide little information on the date of the species' arrival on Mo'orea.

Family ELLOBIIDAE

Laemodonta monilifera (H. Adams & A. Adams, 1854)

MATERIAL: Vaipahu, ScMo-343: L II, TP1-B1, obj. 6 (1 spm.); L II, TP1-B3, obj. 8 (2 spms.); L II, TP2-A4, obj. 6 (1 spm.); L IIIa, TP2-B1, obj. 6 (4 spms.); L IIIa, TP2-B2, obj. 7 (1 spm.).

REMARKS: Garrett (1884) reported *Plecotrema mordax* Dohrn, 1859, from Tahiti; he had no specimens from Mo'orea. *Plecotrema mordax* is a synonym of *P. monilifera* H. Adams & A. Adams, 1854, a species occurring throughout the Indo-Pacific region from the Red Sea and East Africa eastward to Rapa and Mangareva in French Polynesia (Hubendick 1956). The species, now assigned to the genus *Laemodonta* Philippi, 1846, is a strandline dweller and occurs "[o]n rocks in a tidal flat area, just above the normal high tide mark." (Raven and Vermeulen 2007:53).

Melampus sp.

MATERIAL: Vaipahu, ScMo-343: L IIIa, TP2-B2, obj. 7 (1 spm.).

REMARKS: Garrett (1884) reported four species of *Melampus* from Mo'orea: *M. luteus* (Quoy & Gaimard, 1832), *M. caffer* (Küster, 1843), *M. fasciatus* (Deshayes, 1830), and *M. philippii* (Küster, 1845) (a synonym of *M. castaneus* Mühlfeldt, 1816, according to Rehder 1980); all now occur on the island, as does *M. bidentatus* Say, 1822 (Moorea Biocode 2016). The single specimen recovered during the excavations reported here is too worn

to permit identification beyond the generic level.

Family ACHATINELLIDAE

Elasmias sp.

MATERIAL: Vaipahu, ScMo-343: L II, TP2-A4, obj. 7 (1 spm.).

REMARKS: Two species of *Elasmias*, *E. apertum* (Pease, 1864) and *E. peaseanum*, inhabit Mo'orea (Garrett 1884, Moorea Biocode 2016). The single specimen obtained during this study cannot be assigned to either species with certainty. Cooke and Kondo (1961) suggested that at least one member of this genus, *E. apertum*, owes its wide distribution (from the Kermadec Islands and Rotuma eastward to Mangareva, Tubuai, and Makatea) to pre-historic translocation by the Polynesians, but Brook (2010) suggested that modern commerce has played a role as well. Because of its uncertain date (post AD 1521) the single specimen obtained yields no information on this question.

Lamellidea micropleura Cooke & Kondo, 1961

MATERIAL: Vaipahu, ScMo-343: L II, TP1-B1, obj. 6 (1 spm.).

REMARKS: This species occurs on Mo'orea (Cooke and Kondo 1961, Moorea Biocode 2016) and has also been reported from Pitcairn and Henderson Islands (Preece 1995) and from Mitiaro and other locations in the southern Cook Islands (Brook et al. 2010). It is presumably native to Mo'orea and the other islands that it inhabits.

Lamellidea oblonga (Pease, 1865)

MATERIAL: Vaipahu, ScMo-343: L II, TP1-B1, obj. 6 (4 spms.); L II, TP2-A4, obj. 7 (2 spms.); L IIIa, TP2-B1, obj. 6 (1 spm.); L IIIa, TP2-B2, obj. 8 (2 spms.).

REMARKS: *Lamellidea oblonga* occurs throughout a triangular region anchored in the southwest by Fiji and the Ellice Islands, in the north by the Hawaiian Islands, and in the southeast by the Pitcairn Islands, including Mo'orea (Cooke and Kondo 1961, Moorea Biocode 2016). "There is little doubt that the wide distribution of this species is due, mainly to the frequent voyages of the Polyne-

sians, who transported food plants on their travels, especially between islands only a few hundred miles apart.” Cooke and Kondo (1961:201). Subsequent archaeological studies reviewed in Christensen and Weisler (2013) have confirmed its pre-contact presence in the Cook Islands (Allen 1992, 1997, 1998; Allen and Christensen 1992, Walter 1998, Brook 2010, Brook et al. 2010), Huahine and Tahiti in the Society Islands (Sinoto 1983, Orliac 1997), the Gambier Islands (Howard and Kirch 2004, Conte and Kirch 2008), the Marquesas Islands (Kirch 1973; Rollett 1992, 1998), Henderson Island (Preece 1998), and the Hawaiian Islands (Dixon et al. 1997, Burney 2002). *Lamellidea oblonga* was *not* present in the Hawaiian Islands before initial human settlement (Cooke and Kondo 1961), so it is not indigenous but is a pre-contact introduction (Christensen and Weisler 2013). It must be native to some island or islands within its current range in southern Polynesia, but its point of origin within that area is as yet unknown. This is a lowland species often associated with economic plants and places of human habitation; it may be abundant under dead leaves from just inland of the shore to elevations of 100 m or so and rarely if ever is found in undisturbed native forest (Cooke and Kondo 1961). All dated specimens obtained here from Mo’orea are from post-AD 1521 levels.

Lamellidea pusilla (Gould, 1847)

MATERIAL: Vaipahu, ScMo-343; L II, TP1-B2, obj. 9 (3 spms.); L II, TP1-B3, obj. 8 (3 spms.); L II, TP2-A4, obj. 6 (4 spms.); L II, TP2-A4, obj. 7 (1 spm.); L IIIa, TP2-B1, obj. 6 (1 spm.); L IIIa, TP2-B1, obj. 7 (1 spm.); L IIIa, TP2-B1, obj. 6 (3 spms.); L IIIa, TP2-B2, obj. 7 (2 spms.).

REMARKS: *Lamellidea pusilla* is widely distributed in Oceania, occurring from the Marshall and Solomon Islands eastward to the Tuamotu and Gambier Islands (Cooke and Kondo 1961, Kondo 1975); the western limits remain undefined because of the uncertain status of related and possibly conspecific taxa occurring in Indonesia, the Bismarck Archipelago, and the Mariana Islands (Kondo 1975, Christensen and Weisler 2013). It is extant on

Mo’orea (Moorea Biocode 2016). It is believed to owe much of its wide distribution to inadvertent transport during the prehistoric period (Cooke and Kondo 1961, Christensen and Kirch 1981, Christensen and Weisler 2013), and it is frequently encountered in pre-contact archaeological sites within this region (Christensen and Weisler 2013 and citations therein). As with *L. oblonga*, all dated specimens recovered here date from the period AD 1521 to the present.

Lamellidea spp.

MATERIAL: Vaipahu, ScMo-343: L II, TP1-B1, obj. 6 (6 spms.); L II, TP1-B1, obj. 7 (3 spms.); L II, TP1-B3, obj. 10 (2 spms.); L II, TP2-A4, obj. 6 (9 spms.); L II, TP2-A4, obj. 7 (1 spm.); L IIIa, TP2-B1, obj. 6 (9 spms.); L IIIa, TP2-B1, obj. 7 (3 spms.); L IIIa, TP2-B2, obj. 7 (1 spm.); L IIIa, TP2-B2, obj. 8 (1 spm.).

REMARKS: Immature, broken, or otherwise nondiagnostic specimens of *Lamellidea* are listed as *Lamellidea* spp.

Tornatellides oblongus oblongus (Anton, 1839)

MATERIAL: Vaipahu, ScMo-343: L II, TP2-A4, obj. 6 (1 frag.); L II, TP2-A4, obj. 7 (1 frag.).

REMARKS: *Tornatellides oblongus oblongus* was sparsely represented in this material; two basal fragments were the only specimens obtained. *Tornatellides o. oblongus* occurs in the Cook, Society, Austral, Marquesas, and Gambier Islands and on Pitcairn Island, with an endemic subspecies, *T. o. parvulus* Cooke & Kondo, 1961, on Henderson Island (Cooke and Kondo 1961, Preece 1995); it was collected on Mo’orea in 1934 (e.g., BPBM 150286) but has not been encountered in recent surveys (Moorea Biocode 2016). “From the similarity of shells from different islands and from different island groups, some of which are separated by as much as 800 miles, it seems that the distribution from its original home has been comparatively recent, probably since the advent of the Polynesians. It was undoubtedly a lowland species disseminated accidentally with food plants” and “is especially abundant on dead coconut, breadfruit, and banana leaves in plantations; on dead leaves in

rather open spaces or in dense thickets of *Hibiscus tiliaceus* and *Pandanus odoratissimus*; and under native trees and plants." Cooke and Kondo (1961:251). *Tornatellides o. oblongus* has been reported from pre-contact archaeological sites in the Cook (Allen 1992, Allen and Christensen 1992, Walter 1998), Society (Sinoto 1983), and Marquesas Islands (Rolett 1998), but no pre-Polynesian records are available to identify the islands to which the species is indigenous. Preece (1998) reported that *T. o. parvulus* was present in pre-Polynesian levels of sites on Henderson Island, indicating that that subspecies occurs there as a native, not as a result of prehistoric or modern human commerce. All specimens recovered during the study reported here dated from the period AD 1521 to the present.

Family VERTIGINIDAE

Gastrocopta pediculus (Shuttleworth, 1852)

MATERIAL: Vaipahu, ScMo-343: L II, TP1-B1, obj. 6 (5 spms.); L II, TP1-B1, obj. 7 (12 spms.); L II, TP1-B2, obj. 3 (21 spms.); L II, TP1-B2, obj. 9 (4 spms.); L II, TP1-B3, obj. 8 (19 spms.); L II, TP1-B3, obj. 10 (8 spms.); L II, TP2-A4, obj. 6 (16 spms.); L II, TP2-A4, obj. 7 (8 spms.); L IIIa, TP2-B1, obj. 6 (31 spms.); L IIIa, TP2-B1, obj. 7 (22 spms.); L IIIa, TP2-B2, obj. 7 (4 spms.); L IIIa, TP2-B2, obj. 8 (1 spm.).

REMARKS: *Gastrocopta pediculus* occurs from the Philippines, Indonesia, and Australia eastward through Melanesia, Micronesia, and Polynesia (Pilsbry 1916–1918; Solem 1959, 1989) [but see Pokryszko (1996), arguing that the taxon described as *Vertigo pediculus samoensis* Mousson, 1865, is a species distinct from *G. pediculus*, a conclusion not adopted here]. It was present on Mo'orea in 1934 (e.g., BPBM 150352) but has not been recorded in recent surveys (Moorea Biocode 2016). Pilsbry (1916–1918) suggested that the broad distribution of *G. pediculus* was due to the commerce of the Pacific islanders, and the species is second only to *Allopeas gracile* in the frequency with which it has been found in archaeological sites in the Pacific islands; its presence has been reported from such sites

in the eastern Solomon Islands, Marshall Islands, Fiji, Samoa, Tonga, Society Islands, Cook Islands, Marquesas Islands, and Henderson Island (Christensen and Weisler 2013 and references therein). Specimens obtained in the study reported here date from the period AD 1521 to present but cannot conclusively be shown to be of pre-contact age.

Gastrocopta servilis (Gould, 1843)

MATERIAL: Vaipahu, ScMo-343: L II, TP1-B1, obj. 7 (1 spm.); L II, TP1-B3, obj. 8 (3 spms.).

REMARKS: This species, native to the New World tropics, is a modern introduction to the Pacific. It was first reported from New Guinea in 1883 (Solem 1989, Brooke 2010) and from Hawai'i in 1892 [Ancey (1892), as *Pupa lyonsiana*]; it is now widely distributed in tropical Oceania (Cowie 1997a, 2001a; Brook 2010, and references cited therein). *Gastrocopta servilis* was unknown to Garrett (1884) but had become established on Mo'orea by 1934 (e.g., BPBM 150353). The few specimens of *G. servilis* recovered in the study reported here are undated but are clearly of modern origin; the species undoubtedly currently inhabits Mo'orea, although it is not listed in a recent survey of the island's fauna (Moorea Biocode 2016).

Nesopupa sp. cf. *tantilla* (Gould, 1847)

MATERIAL: Vaipahu, ScMo-343: L II, TP1-B1, obj. 6 (3 spms.); L II, TP1-B1, obj. 7 (2 spms.); LII, TP1-B2, obj. 3 (1 spm.); L IIIa, TP2-B1, obj. 6 (3 spms.); L IIIa, TP2-B1, obj. 7 (1 spm.).

REMARKS: Garrett (1884) reported the occurrence of *Nesopupa tantilla* (Gould, 1847) on several of the Society Islands, though not on Mo'orea; he considered *Vertigo armata* Pease, 1871, to be a synonym. Pilsbry and Cooke (1918–1920) regarded *armata* as distinct and added *N. pleurophora* (Shuttleworth, 1852) to the Society Islands list, though again without any specific reference to Mo'orea. Species conspecific with these taxa or closely related to them occur also in Fiji, Niue, and Tonga and in the Cook, Tuamotu, and Marquesas Islands (Garrett 1884, Pilsbry and Cooke 1918–1920, Preece 1995, Brook 2010, Brook

et al. 2010). The material examined here spans much of the range of variation said by Pilsbry and Cooke to characterize the three taxa they recognized as occurring in the Society Islands, but in the absence of a comprehensive review of their status no attempt is made to allocate the specimens examined to particular members of the group, if indeed they are distinct. Specimens recovered here are of late prehistoric to modern age. One or more species of *Nesopupa* now inhabit the island (Moorea Biocode 2016).

Family VALLONIIDAE

Pupisoma (Ptychopatula) orcula (Benson, 1850)

MATERIAL: Vaipahu, ScMo-343: L II, TP1-B3, obj. 8 (1 spm.); L IIIa, TP2-B1, obj. 7 (1 spm.).

REMARKS: Only two specimens were obtained. The identification of one (TP2-B1) is somewhat tentative because the shell is badly broken and incomplete, but the other (TP1-B3) is intact and clearly identifiable as this species. *Pupisoma orcula* is widely distributed in the Old World tropics (Pilsbry 1922–1926) and was translocated into the Pacific islands prehistorically, where it has been recorded archaeologically in the Cook Islands (Brook 2010), Henderson Island (Preece 1998), and probably also in the Hawaiian Islands (Christensen 1984, Brook 2010, Christensen and Weisler 2013). *Pupisoma orcula* currently inhabits Mo'orea (Moorea Biocode 2016). The specimens recovered here cannot be dated with certainty; although L IIIa of ScMo-343 is dated as AD 1521–modern, and most likely dates to between AD 1521–AD 1767, the presence there of *Subulina octona*, a modern introduction, suggests the possibility of soil disturbance.

Family HELICARIONIDAE

Hiona sp. cf. *verticillata* (Pease, 1864)

MATERIAL: Vaipahu, ScMo-343: L II, TP1-B2, obj. 3 (1 spm.).

REMARKS: A single specimen was found of a species of *Hiona* that most closely resembles *Hiona verticillata* (Pease, 1864), a species apparently endemic to Mo'orea, although early

authors reported it to occur also on Tahiti and in the Marquesas (Baker 1940). Two additional species of *Hiona*, *H. scalpta* (Garrett, 1884) and *H. angustivoluta* (Garrett, 1884), have also been reported from Mo'orea (Baker 1940), but no specimens identifiable as either species were represented in the material studied here. L II of ScMo-343 dates to the period AD 1521 to the present. *Hiona verticillata* was not collected by the 1934 Mangarevan Expedition or by later surveys (Moorea Biocode 2016).

Hiona sp.

MATERIAL: Vaipahu, ScMo-343: L II, TP1-B1, obj. 7 (1 spm.); L II, TP1-B2, obj. 9 (1 spm.); L II, TP1-B3, obj. 8 (1 spm.); L II, TP1-B3, obj. 19 (1 spm.); L II, TP2-A4, obj. 7 (1 spm.); L IIIa, TP2-B1, obj. 6 (4 spms.); L IIIa, TP2-B1, obj. 7 (4 spms.); L IIIa, TP2-B2, obj. 7 (1 spm.); L IIIa, TP2-B2, obj. 1 (1 spm.).

REMARKS: A number of immature specimens were obtained of a second species of *Hiona* with a strongly angulate periphery; these cannot be assigned with certainty to any of the members of this genus known to occur on Mo'orea. All date to the period AD 1521 to the present.

Family ENDODONTIDAE

Libera jacquinoti (Pfeiffer, 1850)

MATERIAL: Pihaena, ScMo-342: L VIII, TP2-B3, obj. 5 (1 spm.); L VIII, TP2-B3, obj. 6 (2 spms.). Vaipahu, ScMo-343: L II, TP1-B1, obj. 1 (1 spm.); L II, TP1-B1, obj. 1, ca. 70 cm b.s. (1 spm.); L II, TP1-B1, obj. 7 (2 spms.); L II, TP1-B2, obj. 3 (8 spms.); L II, TP1-B2, obj. 9 (2 spms.); L II, TP1-B3, obj. 10 (3 spms.); L III, TP1-C1, obj. 1 (1 spm.); L I, TP2-A1, obj. 2 (2 spms.); L I, TP2-A2, obj. 1 (1 spm.); L IIIa, TP2-B1, obj. 7 (8 spms.); L IIIa, TP2-B2, obj. 7 (1 spm.); TP2-B2, obj. 8 (3 spms.); surface near AH8 (1 spm.).

REMARKS: The descriptions of *Helix cavernula* Hombron & Jacquinot, 1852, and presumably also of its senior synonym *H. jacquinoti*, were based on material obtained during the voyage of the French exploration vessels *Astrolabe* and *Zelée*, which visited the

Society Islands in 1838 (Rosenman 1992). Pfeiffer (1850:128) reported his new species to occur "in insula Tahiti, et in insulis Marquesas," but Solem (1976:418) noted the unreliability of early locality records from that region and concluded that the range of the species was "[u]nknown, but probably Tahiti or Moorea, Society Islands." *Libera jacquinoti* was not observed by Garrett (1884:111), who expressed the opinion that "it probably inhabits the Austral Islands." The material reported here is the first new collection of this species in more than 150 yr and conclusively establishes *L. jacquinoti* as a former Mo'orea endemic, now undoubtedly extinct.

The rediscovery of *L. jacquinoti* is analogous to the rediscovery by Orliac (1997) of *L. spuria* (Ancey, 1889) and *L. incognata* Solem, 1976, in an archaeological site on Tahiti; both species were unknown to Garrett and were described from poorly localized material collected in the early to mid-1800s (Solem 1976). Three of the five species of *Libera* whose island of origin could not be verified by Solem have now been rediscovered in the course of recent archaeological investigations; the origins of *L. streptaxon* (Reeve, 1852) and *L. heynemanni* (Pfeiffer, 1862) remain unknown.

Libera dubiosa Ancey, 1889

MATERIAL: Pihaena, ScMo-342: L V, TP2-B4, obj. 3 (1 spm.). Vaipahu, ScMo-343: L IIIa, TP2-B2, obj. 8 (1 spm.).

REMARKS: The collection date of Ancey's specimens of *Libera dubiosa* is unknown, although Solem (1976) has suggested that they were probably obtained during the exploratory expeditions of the early nineteenth century. The species was unknown to Garrett (1884), and fresh or live-collected specimens have not been obtained subsequently.

Libera kondoi Christensen, Khan & Kirch, n. sp.

Figure 2(A-C)

MATERIAL: Holotype (BPBM 276694): Society Islands, Mo'orea, Vaipahu, ScMo-343: TP2-C2, obj. 2.

Paratypes: Mo'orea, Pihaena, ScMo-342: E2, obj. 6, N102 E102 (BPBM 276654, 1 spm.); TP2-B3, obj. 5 (BPBM 276646, 1 spm.); TP2-

B3, obj. 6 (BPBM 276657, 2 spms.); TP2-B4, obj. 3 (BPBM 276648, 2 spms.). ScMo-343: TP1-B3, obj. 10 (BPBM 276711, 2 spms.); TP2-B1, obj. 7 (BPBM 276958, 1 spm.); TP2-B2, obj. 8 (BPBM 276702, 2 spms.).

Additional referred material: Pihaena, ScMo-342: TP2-B3, obj. 5 (BPBM 276644, 1 spm.); TP2-B3, obj. 6, 384-401 cm b.s. (BPBM 276661, 1 spm.; BPBM 276833, 1 spm.); TP2-B4, obj. 6 (276647, 1 spm.). Vaipahu, ScMo-343: TP2-B1, obj. 6 (BPBM 276846, 1 spm.).

DESCRIPTION: Shell extremely large for the family; in *Libera* only *L. jacquinoti* [maximum diameter 9.28 mm according to Solem (1976)] approaches it in size; diameter 6.8-9.7 mm, height 3.3-4.7 mm, height/diameter ratio 0.47-0.57, with from 6-7/8 to 7-7/8 normally coiled whorls. Spire strongly elevated, broadly rounded in outline above periphery, body whorl sometimes deflected slightly below periphery of its predecessor. Umbilicus secondarily narrowed to form a brood chamber, occasionally again decoiling just before the aperture, variable in size relating to the occasional presence of this terminal decoiling, contained 4.41-8.33 times in the diameter. Apical surface of postnuclear whorls usually with numerous very finely spaced low rounded riblets, too numerous and indistinct for accurate quantification, strongly protracted and weakly sinuate, spiral sculpture absent. Sutures very shallow, whorls rounded down to broad and shallow to very shallow suprapерipheral sulcus, periphery strongly protruded and strongly keeled, a shallow subperipheral sulcus immediately below. Riblets on basal surface absent or much reduced except immediately below periphery, when present sometimes evident only as weak closely spaced growth wrinkles. Parietal barriers 2, the upper high and slender, ascending very gradually anteriorly and terminating rather abruptly posteriorly well before the limit of visibility; lower parietal barrier not as high, with or without a low threadlike anterior extension, otherwise originating gradually about 1/8 whorl posterior to origin of upper palatal, terminating posteriorly simultaneously with upper palatal and in a similar manner. Columellar barrier low, recessed.

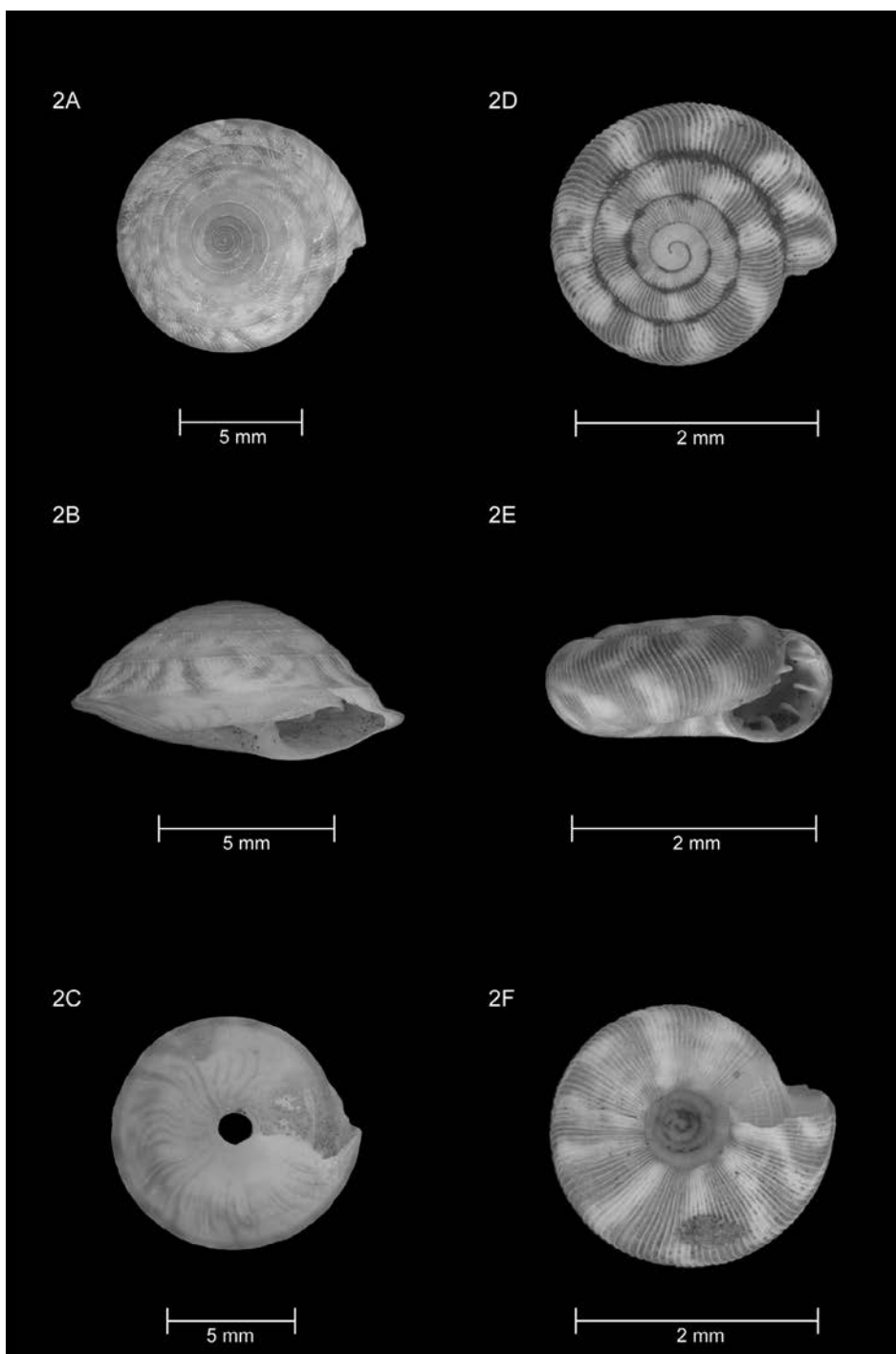


FIGURE 2. *Libera kondoii*, n. sp., holotype, BPBM 276694: (A) apical view; (B) lateral view; (C) basal view. *Minidonta opunuboa*, n. sp., holotype, BPBM 277701: (D) apical view; (E) lateral view; (F) basal view.

Palatal barriers 4, the first subperipheral, evenly spaced, bladellike, the second subperipheral barrier sometimes more strongly developed than others except much reduced in one specimen, all subperipheral palatals ascending gradually and terminating more abruptly; supraperipheral palatal situated midway between periphery and parietal-palatal margin, much lower than subperipherals but extending farther posteriorly, ascending and descending very gradually. Shell with sinuous reddish-brown flammules in specimens retaining color. One specimen (BPBM 276647) is referred to this species with some doubt because it is unique in having radial sculpture that extends onto basal surface of the shell, where it is crossed by fine raised spiral striae. Measurements are based on the holotype (BPBM 276694) and eight adult paratypes (BPBM 276646, 276654, 276657/2, 276702/2, 276711, 276958), although not all measurements could be taken on all specimens because of damage.

REMARKS: *Libera kondoi* is very similar to *L. jacquinoti* (Pfeiffer, 1850) in size, overall shape, and apertural barriers, but is distinguished from it by having consistently much finer and more numerous riblets on the apical surface of the shell and the absence of strong basal sculpture. According to the key published by Solem (1976:390–391), *L. kondoi* most resembles *L. dubiosa* Ancy, 1889, and *L. gregaria* Garrett, 1884, which are also endemic to Mo'orea. The large size, lack of spiral cording, and more strongly protruding periphery of *L. kondoi* distinguish it from *L. dubiosa*; and also from *L. gregaria*, which is further distinguished by having only 2 instead of 3 subperipheral palatal barriers.

Libera kondoi is one of four previously unknown species of Endodontidae recovered from pre-contact levels of archaeological excavations undertaken during the study reported here. The fact that this prominent lowland species was not encountered by the early collectors who discovered *L. jacquinoti*, and was unknown to Garrett (1884), strongly suggests that it had become extinct before Garrett's extensive collecting efforts in the 1860s through 1880s, perhaps before initial European contact in the late eighteenth cen-

ture. *Libera kondoi* is represented at levels from the pre-Polynesian era to the post-AD 1521 period, indicating that it survived into the period of Polynesian occupation but became extinct in late prehistory or soon after initial European contact.

ETYMOLOGY: The species is named in memory of Yoshio Kondo, Malacologist at Bishop Museum for many years, and mentor to C.C.C. and P.V.K.

Minidonta opunohua Christensen, Khan, & Kirch, n. sp.

Figure 2(D–F)

MATERIAL: Holotype (BPBM 277071): Society Islands, Mo'orea, Vaipahu, ScMo-343: TP1-B3, obj. 8.

Paratypes: Same data as holotype (except test pit number), ScMo-343, TP1-B1, obj. 6 (BPBM 274992, 5 spms.); TP1-B1, obj. 7 (BPBM 276724, 2 spms.); TP1-B2, obj. 3 (BPBM 276740, 7 spms.); TP1-B2, obj. 9 (BPBM 275001, 2 spms.); TP1-B3, obj. 8 (BPBM 276635, 9 spms.); TP2-A4, obj. 6 (BPBM 274979, 4 spms.); TP2-A4, obj. 7 (BPBM 276755, 1 spm.); TP2-B1, obj. 6 (BPBM 276847, 8 spms.); TP2-B1, obj. 7 (BPBM 276772, 3 spms.).

DESCRIPTION: Shell minute, 0.9–1.2 mm in height, 2.0–2.6 mm in diameter, with from 4-3/8 to 4-7/8 normally coiled whorls. Apex flat to very slightly elevated, early postnuclear whorls descending gradually, the last slightly more rapidly. Height/diameter ratio 0.41–0.52. Umbilicus deeply cup-shaped, early whorls decoiling regularly, the last more rapidly. Diameter/umbilicus ratio 3.01–3.38. Postnuclear whorls with numerous sharply defined regularly spaced ribs whose interstices are 2 to 3 times their width, body whorl with 88–117 ribs. Microsculpture of several very fine riblets between each pair of ribs. Sutures impressed, periphery not angulate, regularly rounded except slightly compressed at base. Parietal barriers 4, the first 3 blade-like, simple, the first the highest, extending about one-fourth whorl into aperture, the second and third slightly lower, weakly downturned; fourth parietal much lower, less distinct, sometimes barely indicated. Columellar barrier absent. Palatal wall with 5 major simple blade-like barriers, usually with a much

lower minor barrier between first and second palatals, similar minor barriers sometimes also in interstices between remaining major palatals. Color, in those specimens retaining it, of regularly spaced reddish-brown flammulations. Measurements are from the holotype and 10 unbroken adult paratypes (BPBM 274992, 275001, 276635/2, 276724, 276740/2, 276847/3).

REMARKS: The combination of 4 parietal barriers and 5 major palatal barriers distinguishes *M. opunobua* from all members of the genus reviewed by Solem (1976), including all of the previously described taxa known to inhabit the Society Islands. Most species of *Minidonta* subsequently described from Rarotonga, Cook Islands (Brook 2010); Rūrutu, Austral Islands (Sartori et al. 2013); the Gambier Archipelago (Abdou and Bouchet 2000); and Henderson Island (Preece 1998) are similarly distinguishable. Among the exceptions is *M. boucheti* Sartori, Gargominy & Fontaine, 2013, from Rūrutu, which is generally similar to *M. opunobua* but has a more prominent fourth parietal barrier than the latter species, which lacks the fifth and sixth parietals sometimes present in *M. boucheti*. Three Rarotongan species must also be discussed. In *M. matavera* Brook, 2010, *M. pue* Brook, 2010, and *M. rutaki* Brook, 2010, the shell is more elevated than that of *M. opunobua* and the umbilicus narrower; *M. matavera* also possesses a columellar barrier, absent in *M. opunobua*.

Minidonta opunobua is another previously unknown species apparently endemic to Mo'orea and now extinct.

ETYMOLOGY: The species takes its name from 'Opunohu Bay, the type locality.

Nesodiscus nummus Christensen, Kahn & Kirch, n. sp.

Figure 3(A–C)

MATERIAL: Holotype (BPBM 276655): Society Islands, Mo'orea, Pihaena, ScMo-342: E2, obj. 6, N102 E102.

DESCRIPTION: Shell 1.5 mm in height, 6.3 mm in diameter, height/diameter ratio 0.24, with 6-1/8 whorls; diameter at third whorl 1.1 mm, at fourth whorl 1.6 mm, and at fifth whorl 2.4 mm; spire depressed, last whorl not descending at aperture; umbilicus 3.7 mm,

very broadly open, diameter/umbilicus ratio 1.70; on apical surface sculpture of nuclear whorls lost to erosion, surface of post-nuclear whorls with 7–9 low spiral cords crossed by low growth striae, the spiral cords first appearing on third whorl and becoming obsolete on last 1/2 whorl, sutures moderately impressed; basal surface of post-nuclear whorls with sculpture similar to that of apical surface, sutures deeply impressed; margin of aperture rounded at apical suture, flattened above and broadly rounded below angled periphery; plane of aperture inclined at an angle of 30° from shell axis; a single low parietal barrier, receding out of sight within aperture, columellar and palatal barriers absent; color off-white with rather regularly spaced reddish-brown flammulations.

DIAGNOSIS: *Nesodiscus nummus* is distinguished from all previously described members of the genus by its depressed spire, large umbilicus, with a d/u ratio of 1.70 [Solem (1976) gave a range of 1.90–2.15 for species known to him; the umbilicus of *N. cookei* is very slightly smaller than that of *N. nummus*, with a d/u ratio of 1.74], and prominent sculpture of fine spiral cords crossing the growth lines. *Nesodiscus nummus* is most similar to *N. cookei* (description following), from which it differs primarily in sculpture. Spiral striae are the dominant sculptural element in *N. nummus*, whereas these are much reduced in *N. cookei* and are limited to recessed areas at the sutures and in the depths of the supra-peripheral and subperipheral sulci. *Nesodiscus nummus* lacks the sulci so prominent in *N. cookei*.

Solem noted that some species of *Nesodiscus*, especially *N. tanae* (Garrett, 1872), exhibit substantial intraspecific variation in shell form and remarked (1976:349) that “[m]ore than in any other genus of Endodontidae, certain identification [within *Nesodiscus*] requires the availability of series.” The limited number of specimens of *N. nummus* and *N. cookei* available to us (one shell of the former, two of the latter) prevents a proper review of the range of variation within each species. Nevertheless, although the two are obviously more closely related to each other than to any non-Moorean member of the genus, the

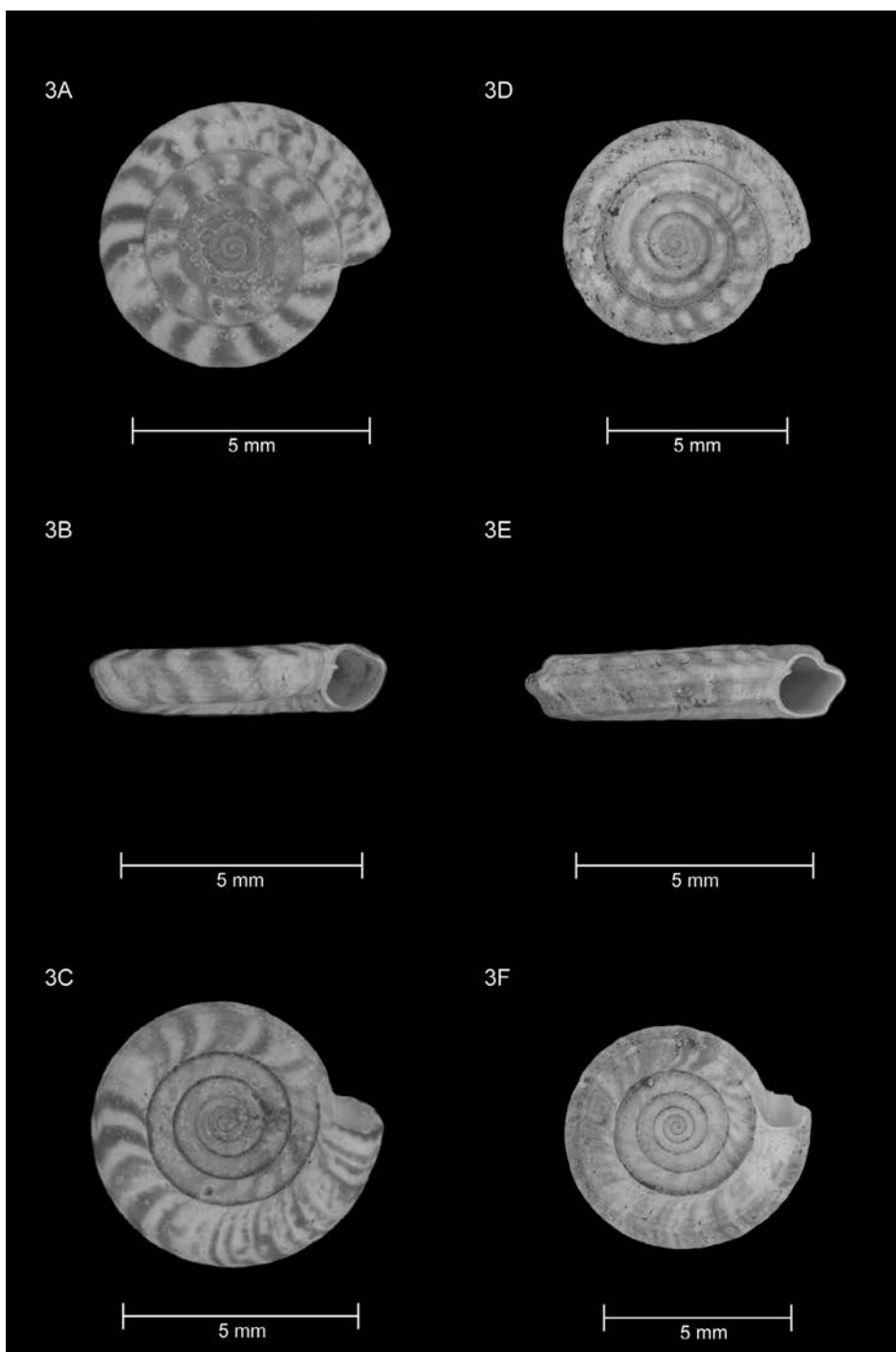


FIGURE 3. *Nesodiscus nummus*, n. sp., holotype, BPBM 276655: (A) apical view; (B) lateral view; (C) basal view. *Nesodiscus cookei*, n. sp., holotype, BPBM 276658: (D) apical view; (E) lateral view; (F) basal view.

differences in shell sculpture and form between *N. nummus* and *N. cookei* fully justify their treatment here as two distinct species.

REMARKS: *Nesodiscus* is endemic to the Society Islands, where seven species were reported by Solem (1976) to occur in the islands of Borabora, Maupiti, Huahine, Ra'iātea, and Taha'a; none has previously been reported from Mo'orea. The unique specimen of *N. nummus* was obtained from an undated stratigraphic level.

ETYMOLOGY: The name is from the Latin *nummus*, a small coin, and refers to the appearance of the shell; it is treated as a noun in apposition.

Nesodiscus cookei Christensen, Kahn & Kirch, n. sp.

Figure 3(D–F)

MATERIAL: Holotype (BPBM 276658): Society Islands, Mo'orea, Pihaena, ScMo-342: TP2-B3, obj. 6.

Paratypes: TP2-B3, obj. 6, 384–401 cm b.d. (BPBM 276660, 1 spm.); TP2-B4, obj. 3 (BPBM 276650, 1 spm.).

DESCRIPTION: Shell 6.8 mm in diameter, 1.6 mm in height, height/diameter ratio 0.24, with 6-1/4 whorls; diameter at third whorl 1.1 mm, at fourth whorl 1.6 mm, and at fifth whorl 2.6 mm; spine depressed, last whorl not descending at aperture; umbilicus 3.9 mm, very broadly open, diameter/umbilicus ratio 1.74; apical sculpture of nuclear whorls lost to erosion, post-nuclear whorls with a deep supraproperipheral sulcus and rough growth striae, recess of sulcus marked with 2 to 3 weak spiral cords, sutures deeply impressed; basal surface nuclear whorls without visible sculpture, post-nuclear whorls with a weak subperipheral sulcus and several weak spiral cords in recess of sulcus and adjacent to suture; suture of last whorl deeply impressed, of preceding whorls less so; margin of aperture rounded at apical suture, strongly angulate at periphery, weakly angulate below subperipheral sulcus; plane of aperture inclined at an angle of 40° from shell axis; a single moderately strong parietal barrier receding out of sight within aperture, a single low but long subperipheral palatal barrier deeply recessed within aperture, columellar barriers absent; color leached

in all specimens seen but showing remnants of reddish-brown flammulations.

DIAGNOSIS: Discussed under *N. nummus*.

REMARKS: *Nesodiscus cookei*, a species endemic to Mo'orea, was found only in levels dating to the period before initial human settlement of the island.

ETYMOLOGY: The species is named for Charles Montague Cooke, Jr., founder of the Bishop Museum's vast Pacific malacology collections and leader of the Museum's 1934 Mangarevan Expedition.

Family CHAROPIDAE

Sinployea modicella (Férussac in Deshayes, 1840)

MATERIAL: Vaipahu, ScMo-343: L II, TP1-B1, obj. 7 (1 spm.); L II, TP1-B3, obj. 8 (2 spms.); L II, TP2-A4, obj. 6 (2 spms.); L IIIa, TP2-B1, obj. 6 (8 spms.); L IIIa, TP2-B1, obj. 7 (6 spms.).

REMARKS: *Sinployea modicella* is endemic to Mo'orea (Solem 1983); it was collected on the island in 1934 (Solem 1983) and is still extant at high elevation (J. D. Slapcinsky, pers. comm., 20 June 2016).

Sinployea sp.

MATERIAL: Vaipahu, ScMo-343: L IIIa, TP2-B1, obj. 7 (1 spm.).

REMARKS: A single badly worn specimen was found of a species of *Sinployea* that is much more widely umbilicate than is *S. modicella*. It has some resemblance to *Discocharopa aperta* (Möllendorff, 1888) but is larger than that species [shell diameter 2.2 mm versus <2.0 mm in *D. aperta* (fide Solem 1983)]. The single specimen dates from the period AD 1521 to the present.

Family SUBULINIDAE

Allopeas gracile (Hutton, 1834)

MATERIAL: Pihaena, ScMo-341: L I, TP1-A2 (4 spms.); L I, TP2-A4, obj. 7 (1 spm.); L I, TP3-A1, obj. 4 (3 spms.). Vaipahu, ScMo-343: L I, TP1-A1, obj. 1 (2 spms.); L I, TP1-A3, obj. 1 (1 spm.); L II, TP1-B1, obj. 6 (14 spms.); L II, TP1-B1, obj. 7 (44 spms.); L II, TP1-B2, obj. 3 (42 spms.); L II, TP1-B2, obj.

9 (15 spms.); L II, TP1-B3, obj. 7 (1 spm.); L II, TP1-B3, obj. 8 (37 spms.); L II, TP1-B3, obj. 10 (15 spms.); L II, TP2-A4, obj. 6 (51 spms.); L II, TP2-A4, obj. 7 (47 spms.); L IIIa, TP2-B1, obj. 7 (91 spms.); L IIIa, TP2-B1, obj. 6 (86 spms.); L IIIa, TP2-B1, obj. 7 (91 spms.); L IIIa, TP2-B2, obj. 7 (16 spms.); L IIIa, TP2-B2, obj. 8 (8 spms.). Teavaro, ScMo-349: AH5, obj. 1, 90–120 cm b.s. (1 spm.); L III, TP1-B1, obj. 3 (1 spm.).

REMARKS: *Allopeas gracile* (= *Lamellaxis gracile* and *Opeas oparanum*) is a circumtropical species widely distributed by human commerce (Pilsbry 1906–1907; Cowie 1997a, 2001a). It was the only subulinid reported from the Society Islands by Garrett (1884), who referred to it as *Stenogyra tuckeri* (Pfeiffer, 1846). It is the anthropophilic land snail most often recovered from pre-contact archaeological sites in Oceania; records include the eastern Solomon Islands, New Caledonia, the Marshall Islands, Fiji, the Cook Islands, Samoa, Tonga, and the Society, Gambier, Marquesas, and Hawaiian Islands (Christensen and Weisler 2013, 2017, and references cited therein). On Mo'orea it was well represented at sites dating from the late prehistoric period or later, but its presence (with *Lissachatina fulica*, a modern introduction) in the pre-Polynesian L III of ScMo-349 suggests contamination or soil disturbance.

Leptinaria unilamellata (d'Orbigny, 1837)

MATERIAL: Pihaena, ScMo-341: L I, TP1-A2 (2 spms.); L I, TP2-A3, obj. 4 (2 spms.); L I, TP3-A2, obj. 6 (1 spm.). Vaipahu, ScMo-343: L II, TP1-B1, obj. 7 (4 spms.).

REMARKS: This species occurs in the West Indies, Central America, Venezuela, Peru, Bolivia, and Brazil (Pilsbry 1906–1907, Dutra 1988, Robinson et al. 2009). *Leptinaria unilamellata* was first reported from French Polynesia (without further details) by Soubeyran (2008) and more recently has been found to inhabit Mo'orea (Moorea Biocode 2016) and Rūrutu and Raivavae in the Austral Islands (Gargominy and Fontaine 2015).

Opeas hannense (Rang, 1831)

MATERIAL: Pihaena, ScMo-342: AH3, obj. 13, 330–360 cm b.s. (1 spm.); ScMo-343:

L II, TP1-B2, obj. 3 (3 spms.); L II, TP1-B3, obj. 8 (4 spms.); L II, TP1-B3, obj. 10 (3 spms.); L II, TP2-A4, obj. 6 (1 spm.); L II, TP2-A4, obj. 7 (4 spms.); L IIIa, TP2-B1, obj. 6 (4 spms.); L IIIa, TP2-B1, obj. 7 (3 spms.).

REMARKS: This species, formerly known as *Opeas pumilum* (Pfeiffer, 1840), has been carried throughout the tropics by modern commerce and is widely distributed in the islands of the Pacific (Pilsbry 1906–1907; Cowie 1997a, 2001a; Brook 2010). It was not recorded by Garrett (1884) but had become established on Mangareva in the Gambier Islands by the mid- to late nineteenth century and on Mo'orea by 1925 (Brook 2010). It is still extant on Mo'orea (Moorea Biocode 2016). Fresh shells have been found in archaeological excavations on Rarotonga, Cook Islands, at depths of up to 0.25 m, suggesting that the species is partly subterranean in habitat (Brook 2010), and thus that its presence in deeper stratigraphic levels has little stratigraphic significance.

Paropeas achatinaceum (Pfeiffer, 1846)

MATERIAL: Pihaena, ScMo-341: L I, TP1-A1, obj. 7, 0–10 cm b.s. (4 spms.); L III, TP1-B3, obj. 2 (1 spm.); L I, TP2-A1, obj. 4 (4 spms.). Pihaena, ScMo-342: L I, TP1-A1, obj. 3, 0–10 cm b.s. (25 spms.); L I, TP1-A2, obj. 6, 10–20 cm b.s. (1 spm.); L I, TP1-A3, obj. 6, 20–30 cm b.s. (1 spm.); L III, TP1-C7, obj. 3 (1 spm.). Vaipahu, ScMo-343: L I, TP2-A1, obj. 2 (1 spm.).

REMARKS: This is another species that has become widely distributed in the islands of the Pacific as a result of modern commerce (Pilsbry 1906–1907; Cowie 1997a, 2001a). The earliest record from Polynesia is from Hawai'i in 1904; *P. achatinaceum* had become established on Tahiti by 1925 (Brook 2010) and was present on Mo'orea by 1934 (e.g., BPBM 150364) and currently inhabits the island (Moorea Biocode 2016). The presence of this modern immigrant in L III of ScMo-342 suggests contamination.

Subulina octona (Bruguière, 1789)

MATERIAL: Pihaena, ScMo-341: L I, TP1-A2 (8 spms.); L I, TP2-A1, obj. 4 (1 spm.); L I, TP2-A3, obj. 4 (2 spms.); L I, TP2-A4, obj.

7 (1 spm.). Vaipahu, ScMo-343: L II, TP1-B1, obj. 6 (2 spms.); L II, TP1-B1, obj. 7 (2 spms.); L II, TP1-B2, obj. 9 (1 spm.); L I, TP2-A1, obj. 2 (1 spm.); L II, TP2-A4, obj. 6 (2 spm.); L II, TP2-A4, obj. 7; L IIIa, TP2-B1, obj. 6 (2 spms.); L IIIa, TP2-B1, obj. 7 (8 spms.).

REMARKS: This is yet another invasive circumtropical species now widely distributed in Oceania (Pilsbry 1906–1907; Cowie 1997*a*, 2001*a*). The view of Solem (1964) that it is of tropical American origin is confirmed by its presence in a pre-Columbian archaeological site in the U.S. Virgin Islands (Quitmyer 2003). It is a modern introduction to the Pacific islands, having reached New Caledonia by 1888, the Hawaiian Islands by 1903, and the Society Islands by 1925 (Brook 2010); it was present on Mo'orea in 1934 (e.g., BPBM 150328) and still inhabits the island (Moorea Biocode 2016). Its presence in ScMo-342: L II indicates either a modern age for this level or contamination.

Subulinidae (Unidentified)

MATERIAL: Vaipahu, ScMo-343: L II, TP1-B2, obj. 3 (1 spm.).

REMARKS: This specimen, too immature for precise identification, undoubtedly belongs to one of the species of Subulinidae reported here.

Family ACHATINIDAE

Lissachatina fulica (Bowdich, 1822)

MATERIAL: Teavaro, ScMo-349: L III, TP1-B1, obj. 3 (1 spm.).

REMARKS: The Giant African Snail, formerly placed in the genus *Achatina*, is a notorious invasive species (Mead 1961, 1979) native to East Africa that first became established on Tahiti in 1967 and soon spread to Mo'orea and other nearby islands (Clarke et al. 1984). It is represented in the material reported here by a single apical fragment found at a supposedly pre-Polynesian level of ScMo-349.

DISCUSSION

It is now clear that both prehistoric and modern human activities have had a devastating

effect on the native land snails inhabiting the high islands of tropical Polynesia (e.g., Christensen and Kirch 1986, Cowie 2001*b*, Bouchet and Abdou 2003, Lydeard et al. 2004, Richling and Bouchet 2013; Regnier, Achaz, et al. 2015; Regnier, Bouchet, et al. 2015; Brodie et al. 2016). This process began with initial human settlement and has only accelerated since the initiation of Western contact in the eighteenth century (Solem 1976, 1990; Cowie 1992; Regnier, Bouchet, et al. 2015). The disappearance of many of the region's native snails has been accompanied by their partial replacement with assemblages of nonnative species, the earliest of them arriving with the prehistoric voyages of the Pacific islanders (Christensen and Kirch 1981, Christensen and Weisler 2013). The rate of introduction increased with the vast expansion of inter-island, interarchipelago, and now intercontinental commerce during the modern era (Cowie 2001*a*, 2001*b*). The study reported here sought to investigate the chronology of this process of land snail extinction and replacement on the island of Mo'orea.

We focus especially on the endemic Endodontidae of Mo'orea, because this group is one of the most species-rich elements of the island's nonmarine molluscan fauna and because prior studies (Garrett 1884, Solem 1976) have provided data on historical collections of these snails essential to a chronological analysis of the extinction process. The land snail family Endodontidae, used here in the restricted sense of Solem (1976), is endemic to the islands of Remote Oceania. Representatives of the family occur from Palau eastward through the Ellice Islands, Lau Archipelago of Fiji, Tonga, Samoa, Cook Islands, Society Islands, Austral Islands, Tuamotu Archipelago, and Gambier Archipelago to Henderson Island and northward to the Hawaiian Islands; fossil taxa extend the range of the family to the Marshall Islands and Midway Island in the northwestern Hawaiian Islands (Solem 1976, 1977). Solem's 1976 monograph was based primarily on live-collected or recently dead specimens obtained from the early nineteenth century to the mid-twentieth century. Since the publication of Solem's work, material from paleontologi-

cal and archaeological excavations has demonstrated that the Polynesian endodontid fauna was much more diverse than previously known. Numerous recently extinct taxa from such sites have been described from the Hawaiian Islands (Christensen 1982), Cook Islands (Brook 2010), Austral Islands (Zimmermann et al. 2009, Sartori et al. 2013), Gambier Islands (Abdou and Bouchet 2000), Makatea in the Tuamotu Archipelago (Sartori et al. 2014), and Henderson Island (Preece 1998). The study reported here adds four previously unknown endodontid species to the Moorean fauna and demonstrates that one additional species, described early in the nineteenth century from poorly localized material, was in fact endemic to Mo'orea.

Solem (1976) and Bouchet and Abdou (2003) have shown how the review of historical records and museum collections can document the chronology of the extinction of insular land snail faunas, the former in the context of the Endodontidae of the Society Islands. The study reported here extends that methodology by incorporating records of now-extinct native taxa and prehistorically introduced alien taxa from dated pre-contact archaeological contexts to provide a more comprehensive understanding of this process of faunal extinction and replacement.

Extinction of Mo'orea's Native Nonmarine Mollusks

Solem (1976) identified six endodontid species endemic to Mo'orea and discussed the chronology of their disappearance. The study reported here adds one species known only from the period before initial Polynesian settlement, two species known only from pre-historic or early historic era archaeological contexts, one species from undated archaeological material, and one species described early in the nineteenth century from unlocalized material but now shown to have inhabited Mo'orea. Two of the four previously unknown endodontid species recovered from archaeological contexts (*Libera kondoi* and *Minidonta opunobua*) must have become extinct during the pre-contact period or early in the historic period; they were certainly extinct

by the time of Garrett's activities in the late nineteenth century. The precise timing of the extinction of the two new species of *Nesodiscus* is unclear because one is known only from pre-Polynesian material and the other only from an undated specimen; neither was encountered by nineteenth-century collectors, and they were undoubtedly extinct by Garrett's time. The helicinid here identified as *Orobophana* sp. aff. *maugeriae* appears to have had a similar history, because it was not known to inhabit Mo'orea before the study reported here. *Libera jacquinoti*, described in the early to mid-nineteenth century but not collected subsequently until now, must have become extinct after 1838 but before Garrett's time. Solem (1976) concluded that collections of *Libera dubiosa* also date from the early nineteenth century, and thus the time frame of that species' extinction was probably similar to that of *L. jacquinoti*, because both had disappeared by Garrett's time. Four species collected by Garrett but not seen subsequently, *Mautodontha* (*Garrettoconcha*) *punctiperforata*, *M. (G.) perforata*, *Libera gregaria*, and *L. recedens*, are undoubtedly now extinct and had probably disappeared by the time of the 1934 Mangarevan Expedition, which failed to find them. None of these is listed as extant in the database of the Moorea Biocode Project (Moorea Biocode 2016), although a single unidentified species of endodontid was found at high elevation in 2010 (J. D. Slapcinsky, pers. comm., 20 June 2016). By contrast, the island's diverse fauna of Partulidae apparently suffered relatively little from prehistoric and early modern human activities, because those snails were still abundant in the early twentieth century (Crampton 1932). The partulids persisted in good numbers (Murray and Clarke 1980, Murray et al. 1982, Johnson et al. 1986) until the misguided introduction in 1977 of the carnivorous snail *Euglandina rosea* (Férussac, 1821), in an unsuccessful biological control program targeting the Giant African Snail, *Lissachatina fulica*. The introduction of *Euglandina* resulted in the rapid extermination of most of the island's partulids (Tillier and Clark 1983, Clarke et al. 1984, Murray et al. 1988, Cowie 1992), although a few scattered populations apparently persist

(Lee et al. 2009). Species of *Omphalotropis* and *Hiona* known formerly to have inhabited the island also appear to have become extinct since the late nineteenth century.

It appears that the extinction of Mo'orea's endemic land snails has been a continuing process since the initial human settlement of the island (or perhaps earlier, given the uncertain timing of the disappearance of the two *Nesodiscus* species), although difficulties in resolving the pre-contact/post-contact interface make it impossible to ascribe any extinction events to the earlier period conclusively. The timing of that process has varied among the different taxonomic elements of the fauna. With regard to Polynesian endodontids, Solem attributed their extinction to habitat disturbance and predation by nonnative ants, noting (1976:100) that with only two exceptions "no endodontids have been taken from disturbed primary forest or secondary vegetation zones." He attributed the relatively low diversity of native endodontids in Samoa to the presence there of endemic ants. More recently (Athens 2009, Drake and Hunt 2009), biologists have become aware of the major role of the prehistorically introduced Pacific Rat, *Rattus exulans*, as an agent of ecological change on oceanic islands. The native land mollusks of Mo'orea, especially the ground-dwelling endodontids, undoubtedly suffered from the influence of rats both through direct predation (not detectable in the fossil record of the small to minute species represented here because their shells would be entirely destroyed when eaten by rats) and as a result of rat-induced changes in the lowland vegetation. As in Hawai'i (Hadfield and Sauffler 2009), predation on arboreal snails by climbing rats has also been a factor (Cowie 1992), but Moorean partulids nevertheless continued to thrive until the recent introduction of *Euglandina*, a highly efficient alien predator against which they had no defense.

It has been shown elsewhere in Polynesia that endemic land snails may survive at the higher elevations of tropical Polynesian islands (Solem 1972, Gargominy 2008), including as yet undescribed species of Endodontidae (Brook 2012). This may well be true of Mo'orea as well, because the Moorea Biocide

Project (2016) recorded the existence of a possible new species of charopid on the island's peaks, where an unidentified endodontid also occurs (J. D. Slapcinsky, pers. comm., 20 June 2016). In any event, it is clear that the native land snail faunas that once inhabited the coastal lowlands of Mo'orea have been devastated by ecological changes that are the direct and indirect result of human activities.

Comparison with Tahiti

Archaeological studies and museum collections from Tahiti present a similar picture of continuing extinctions among the native Endodontidae, although again there the native partulids persisted in good numbers until the introduction of *Euglandina*. Among the endodontids, Solem (1976) identified three species of *Mautodontha* and six of *Libera* inhabiting Tahiti, suggesting that four or five additional species described in the nineteenth century from poorly localized material might also have come from Tahiti. Garrett encountered four species, *Mautodontha parvidens* (Pease, 1861), *Libera bursatella* (Gould, 1846), *L. garrettiiana* Solem, 1976, and *L. retunsa* (Pease, 1864), but of these only *L. bursatella* has been collected subsequently. Specimens of subspecies *L. b. orofenensis* Solem, 1976, were collected at high altitude by Mangarevan Expedition personnel, and a single specimen of the nominate subspecies was collected in 1946 by a collector for Field Museum. Four of the species recognized by Solem, *Mautodontha zimmermani* Solem, 1976; *M. aoraiensis* Solem, 1976; *L. micrasoma* Solem, 1976; and *L. cookeana* Solem, 1976, were high-elevation species collected by members of the 1934 Mangarevan Expedition. As on Mo'orea, recent archaeological investigations supplement existing museum collections by providing evidence of species that had disappeared before the earliest biological collections on the island. Orliac (1997) excavated sites in Tahiti's Papeno'o Valley where he obtained specimens of a number of native land snails from pre-contact contexts. As with *Libera jacquimoti* and the study reported here, Orliac confirmed that two species previously known only from unlocalized material collected in the first

half of the nineteenth century, *Libera spuria* (Ancey, 1889) and *L. incognata* Solem, 1976, were in fact native to Tahiti; he also recorded four previously unknown and undescribed taxa that he identified as *Mautodontha* aff. *parvidens* (Pease, 1861), *Nesodiscus* aff. *cretaceus* (Garrett, 1884), *Libera* aff. *dubiosa* (Ancey, 1889), and *L. aff. incognata* Solem, 1976. To summarize, Tahiti is now known to have been inhabited by four species of endodontids that became extinct during the prehistoric or early post-contact period, two species that survived until the nineteenth century but that had evidently gone extinct by the late 1800s, and five species that survived until the period 1934–1946, although only at high elevations.

Again as on Mo'orea, Tahiti's native Partulidae survived well into the twentieth century but have been virtually extirpated since the introduction of *Euglandina* (Crampton 1916, Coote et al. 1999), though again as on Mo'orea a few populations have thus far survived this new onslaught of predation (Coote 2007).

Introduction of Alien Nonmarine Mollusk Species

The pre-contact voyages of the Pacific islanders resulted in the interisland translocation of at least 10 species of land snails into or within tropical Polynesia; some were introduced into the region from Island Southeast Asia, and others that were originally native to one or more islands within the region became much more generally distributed (Christensen and Weisler 2013). The speed of the process accelerated greatly with the advent of European influence in the region in the sixteenth century and in the Society Islands post-AD 1767 with the ever-increasing frequency of outside contact with once-isolated island communities (Cowie 2001a, 2001b). The study reported here documented the presence on Mo'orea of five species previously shown to have been transported into and/or within Polynesia (*Lamellidea oblonga*, *L. pusilla*, *Gastrocopta pediculus*, *Pupisoma orcula*, and *Allopeas gracile*), although limitations on chronological precision make it impossible to conclusively demonstrate their pre-contact presence on Mo'orea. An additional six species (*Gastro-*

copta servilis, *Opeas bannense*, *Paropeas achatinaceum*, *Subulina octona*, *Leptinaria unilamellata*, and *Lissachatina fulica*) are historic-era introductions, the latest of them, *L. unilamellata*, first being reported from Oceania in 2008. Two aquatic species, *Melanooides tuberculata* and *Tarebia granifera*, will probably prove to have been prehistoric introductions to the Society Islands; the material reported here suggests but does not prove a pre-contact arrival for *M. tuberculata*. Determination of the dates of introduction of certain species is made more difficult by anomalous occurrences at improbably early levels due to sediment disturbance, possibly as a result of crab burrowing (Specht 1985).

CONCLUSION

Mo'orea provides yet another example of the extreme vulnerability of the native land snail faunas of Polynesian islands. As with the land birds of the region (Olson and James 1982; Steadman 1995, 2006; Duncan et al. 2013), the native terrestrial mollusks of the high islands of Polynesia are rapidly disappearing as a result of the direct and indirect effects of human activities, both pre- and post-contact. Although examination of historical museum collections can yield much information about the extent and chronology of modern molluscan extinctions (Solem 1976, Bouchet and Abdou 2003), analysis of materials from paleontological and archaeological investigations will be essential to determine the true extent of the original diversity of the terrestrial mollusk faunas of these islands and the full chronology of the extinction process. Furthermore, the presence of alien land snail species introduced during both the pre- and post-contact eras provides a method of dating similar to the use that has been made of evidence of the presence of the Polynesian rat, *Rattus exulans* (e.g., Wilmshurst and Higham 2004). Unfortunately, relatively few studies of native land snails from dated pre-contact sites in tropical Oceania are yet available (e.g., Christensen and Kirch 1986, Orliac 1997, Preece 1998), and as the study reported here shows, it can be difficult to conclusively distinguish pre-settlement, post-settlement/

pre-contact, and early post-contact extinction events. Nevertheless, nonmarine mollusks are often well represented in sediments from Pacific sites, and their study is an important complement to paleoenvironmental studies in the region.

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Appendix

ScMo-341 (Lat. 17° 29’ 24” S, Long. 149° 49’ 37” W):
The -341 transect ran from near the base of a steep
ridge (rising to an elevation of 140 m) across the gen-
tly sloping coastal plain to the shoreline, a total dis-
tance of 100 m. Three 1 m by 1 m test pits were ex-
cavated along this transect. TP1 was located ca. 50 m
inland of the circle-island road and had the deepest
stratification where seven depositional units were en-
countered (Kahn et al. 2015). The uppermost deposit,
L I (L I, 0–50 cm below surface), was a massive de-
posit of sandy-clay loam, well sorted with occasional
angular to subangular volcanic clasts and occasional
charcoal flecks. This was the only land snail-bearing
deposit found at the site; artifact recovery and geo-
morphology suggest that it represents modern and
historic fill used to level the coastal plain. Below
this, L II (50–65 cmbs) included a deposit of fluvi-
ally transported sand and gravel incorporating larger
subrounded to rounded volcanic clasts; it most likely
represents a flood event from the nearby ephemeral
stream. L III (65–145 cmbs) was a deposit of massive,
structureless, well-sorted, highly compact silty clay
with occasional subangular volcanic clasts and char-
coal flecks. L IV (145–150 cm) was a dark grayish-
brown (10YR4/3-2) lens of silt and sand with rounded
and subrounded volcanic clasts (1–5 cm size range),
representing a single fluvial depositional event. L V
(150–273 cmbs) represented a massive deposit of silty

clay largely devoid of volcanic clasts, and L VI (273–
282 cmbs) was a gleyed, compact, sticky clay, entirely
lacking volcanic clasts with a thin lens of compressed
peat at its upper limit. L VII (282–322 cmbs), the
basal deposit, was a calcareous marine sand contain-
ing shells of marine gastropods that was coarser-
grained and included water-rolled pieces of *Acropora*
branch coral in its lower part.

Land snail-bearing deposits at -341 include those found
in TP1 L I (19–36 cmbs) and TP3 L I (0–17 cmbs)
(Kahn et al. 2015), a dark brown (10YR4/3) deposit
of fluvi-ally transported sand and gravel incorporating
larger subrounded to rounded volcanic clasts. This
most likely represents a flood event from the nearby
intermittent stream. Earlier work at the same site, but
at its southern extent, dated the upper part of the
fluvial deposit (presumably the same as our L II) to
between the late seventeenth–twentieth centuries AD
(Kahn 2012), which provides a terminus post quem
date for L I. Two new dates on short-lived species
from L III provide calibrated age ranges of AD 1410–
1455 (Beta-411454, 510 ± 30 BP) and AD 1710–1950,
respectively (Beta-411453, 80 ± BP) at 2σ. The latter
date has multiple intercepts; given that we did not re-
cover historic artifacts in the deposit, the most likely
age range is AD 1690–1730.

Current data suggest that L I most likely postdates the
eighteenth century. A cultural deposit underlying this
fluvial deposit (and apparently not extending to the
northern portion of the site) was dated AD 1031–1210
(Kahn 2012) and provides a best estimate for the ini-
tial settlement of ScMo-341. This sample dates to the
early Polynesian period (after initial colonization of
the island, as opposed to pre-Polynesian, before set-
tlement of the island).

ScMo-342 (Lat. 17° 29’ 14” S, Long. 149° 49’ 52” W):
This transect is situated 500 m west of -341, near the
western edge of an alluvial fan that emanates from
the mouth of Vaioma Valley. The transect ran 300 m
from the shore across the gently sloping coastal
flat to the ephemeral Vaioma Stream. Two 1 m by
1 m test units were excavated, in addition to a 4 m by
3 m block excavation. The stratigraphy encountered
in TP1 was similar to that found at -341. L I (0–
38 cmbs) had a blocky ped structure, and the upper
15 cm is the A horizon. L II (38–62 cmbs) was a
highly compact sandy-clay loam with rounded to sub-
rounded volcanic clasts and charcoal flecking. Large
basalt cobbles forming a pavement were associated
with dense charcoal concentrations in a hearth, indi-
cating the presence of a former occupation and pos-
sibly a cookhouse. L III (62–184 cmbs) was a massive,
structureless, silty-clay loam with occasional char-
coal flecking, the lowest 15 cm becoming strongly
mottled. L IV (184–200 cmbs) was a gleyed, compact,
structureless, and well-sorted clay, containing some
fibrous plant material. The basal deposit, L V (200–
240 cmbs), included a calcareous marine sand, fine- to
medium-grained, with fragments of marine shell.

Land snail-bearing deposits at -342 include those re-
covered in TP2 and excavation unit N102 E102 in
L V, the very dark gray (5YR3/1) medium- to coarse-

grained calcareous sand with marine shells and abundant anaerobically preserved plant remains. Seed samples dated from these sediments yielded ages of 3030 ± 30 , 3120 ± 30 , and 3740 ± 30 BP, consistent with a pre-Polynesian period dating to between 4600 and 2400 BP (Kahn et al. 2015).

ScMo-343 (Lat. $17^{\circ} 29' 49''$ S, Long. $149^{\circ} 51' 03''$ W): This site is situated near the eastern headland of 'Opunohu Bay (Vaipahu Point) (Figure 1B). Here, the coastal plain is approximately 170 m wide and terminates at a steep ridge. We excavated two 1 m test pits in swampy ground. Four stratigraphic deposits were exposed in TP1 and TP2. L I (0–6 cmbs) was a silty-clay loam with a few scattered subrounded volcanic clasts. L II (6–96 cmbs) was a massive, structureless silty-clay loam with scattered charcoal flecks and a few scattered subrounded volcanic clasts. L IIIa (96–ca. 140 cmbs) included a compact, structureless, gleyed, and well-sorted clay containing some fibrous plant material and with abundant land snails at the base. L IIIb (ca. 140–190 cmbs) was a lens of dark gray, compact, structureless, gleyed, and well-sorted clay, containing some fibrous plant material. L IV (140–200 cmbs), the basal deposit, was a medium- to coarse-grained calcareous sand with marine shells.

At -343, the land snail-bearing deposits include TP2, L II, a dark brown (7.5YR3-4/2), massive, structureless deposit of silty-clay loam with scattered charcoal flecks and a few scattered subrounded volcanic clasts. Land snails were also recovered from TP1 and TP2 L III deposits, a dark gray, gleyed (N4/), very compact, structureless, well-sorted clay, containing some fibrous plant material. L III was not dated, but it is bracketed by dates of 4610 ± 30 BP from L IV (pre-Polynesian) and 250 ± 30 BP from L II (highest probability intercept of cal. AD 1626–1679, Polynesian period).

ScMo-349 ($17^{\circ} 30' 49''$ S, $149^{\circ} 46' 15''$ W): This site is situated on the northeastern side of Mo'orea Island in Teavaro, where there is a wide coastal plain (240 m). Four stratigraphic deposits were located during the site excavations. L I (0–44 cmbs) was a structureless, medium brown deposit of silty clay with scattered subangular volcanic clasts. This deposit had high frequencies of basalt flakes and debitage and moderate amounts of charcoal. L II is a dark orange-brown deposit of fluviially and alluvially transported sand, gravel, and clay incorporating larger subrounded to subangular volcanic clasts. L III represents a compact, structureless, gleyed, and well-sorted clay containing fibrous plant material. The basal deposit, L IV, is a medium- to coarse-grained calcareous sand with marine shells.

Land snail-bearing deposits at -349 include those from L I and those from L II. Although samples from -349 have not yet been dated, excavations and artifact recovery from these deposits are indicative of Polynesian-era deposits.

Lake Temae: This is a brackish-water lake situated in the basin of a former lagoon ($17^{\circ} 29' 05''$ S, $149^{\circ} 46' 08''$ W). Parkes (1997) analyzed sediment cores from Lake Temae and dated changes in charcoal content and pollen spectra thought to represent initial island colonization to AD 690–990. Our project is analyzing and dating newly taken cores from Lake Temae that suggest initial anthropogenic impact on sedimentation rates and vegetation change at or around AD 1000 (J. Stevenson, pers. comm.). Aquatic snails recovered from L I at a depth of 115–166 cm below the lake bottom are in a deposit with a terminus quem of modern to ca. 200 yr BP, signaling that these samples derive from the post-contact or historic period (Stevenson et al., in press).