Myriad Mirids: The spectacular radiation of *Pseudoloxops* (Hemiptera: Miridae) plant bugs in French Polynesia (and the kids that love them!)

by

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Abstract

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Studies of natural history and biodiversity may not top most funding agencies' priority lists, but they should. It is an exciting time for the field of biology—we are sequencing whole genomes, devising sophisticated models to cope with accelerating climate change, and even tinkering with the possibility of bringing extinct species back to life. But in the meantime, we continue to ignore the documentation and discovery of the vast majority of extant life on our planet. Millions of species, each with their own unique evolutionary history and trajectory, remain unknown, waiting to tell us their story and teach us their strategies for success. Here, my collaborators and I demonstrate the importance of documenting the diversity contained within a single lineage of insects, from examining the best methods for accurately determining numbers of species to showing the downstream benefits of incorporating that knowledge into local education for the benefit of all.

In the first chapter, we revise the taxonomy of a lineage of plant bugs (Hemiptera: Miridae) that has radiated in the islands of French Polynesia. Six species of endemic *Pseudoloxops* plant bugs were previously known from two islands in French Polynesia, indicating a small radiation. We collected ecological, morphological, molecular, and geographical data for hundreds of fresh and historical *Pseudoloxops* specimens, expanding the genus' range to nine islands in two archipelagoes (the Austral and Society Islands). We combined all of the above data sources in an iterative integrative taxonomy framework to test the six existing species hypotheses and to search for new diversity. We confirmed 3 of the 6 original species designations and synonymized the remaining 3 species, and delimited and described an additional 23 species, for a total of 26. Our analysis demonstrates the value of an integrative approach, as we discovered cryptic species and color polymorphism that may have been missed or misinterpreted using a species concept that relied on a single line of evidence. We also found evidence for population-level diversification and discuss the potential for future research on the role of color in this radiation.

In the second chapter, we explore the relative importance of ecology and geographic isolation in this lineage to provide a first approximation of whether the radiation was adaptive or non-adaptive. We collected *Pseudoloxops* from a wide range of plants, with 27 species in 25 different plant families and 13 orders. We then inferred a combined Bayesian molecular phylogeny from three genes, including 25 of the 26 known *Pseudoloxops* species, to examine the roles of plant affiliation and geography (island distribution) in speciation. We reconstructed the ancestral states

using parsimony for these two characters, and found 12 speciation events that were well-supported in the phylogeny. Both plant-switching and island-hopping were correlated with speciation. For the 7 speciation events for which we could unequivocally determine plant affiliation before and after speciation, 4 were associated with a plant shift. For the 8 speciation events where island distribution could be reconstructed, two involved shifts to a new island. There were 5 cases for which we could determine both character states before and after speciation. In three of them, speciation occurred within the same locality with a switch in plant taxonomic order, suggesting that the lineage has great dietary versatility. However, much more research into feeding needs to be conducted, as anecdotal evidence from *Pseudoloxops* outside of French Polynesia suggests they may be facultative predators. In the other two speciation events, there was neither a geographic shift nor a change in plant affiliation, suggesting some other mechanism for speciation. Based on our results, both plant-switching and geography have played a role in the diversification of this radiation. Finally, plant switching from flowering plants (angiosperms) to ferns was observed in two different parts of the radiation. This finding was surprising for two reasons—first, plant bugs are rarely associated with ferns, likely because of their highly toxic secondary compounds, and second because the expectation on islands is that organisms colonize ferns first and then switch on to other plants, since ferns are often among the first plants to arrive on newly formed oceanic islands. While a better-resolved phylogeny is needed to reconstruct the timing of speciation events, the character polarity in our phylogeny indicates that angiosperm use is basal to fern use.

In the third chapter, we address the larger societal impact of taxonomic and biodiversity research by examining the effect of a natural history-driven curriculum on elementary schoolchildren's scientific knowledge. While studies have demonstrated the potential for natural history education to improve children's attitudes towards and knowledge of science and nature, few studies have been done in areas where indigenous culture heavily influences children's worldview. The lead author taught a nine-month natural history/biodiversity class focused on insects and plants to fifth-graders at the Pao Pao elementary school on the French Polynesian island of Moorea and tested their scientific knowledge before and after receiving the program. We compared their results to a control that did not receive the program, and while both cohorts improved, the experimental group's improvement was significantly greater (mean of 82.2% vs. 30.5%). We performed a delayed post-test evaluation three years after the conclusion of the program with a subset of the experimental cohort to test their retention and interest in science. A one-way ANOVA revealed significant differences between their pre-, post-, and delayed post-test scores, with the post- and follow-up scores significantly higher than the pre-scores. While the raw delayed post-test scores were lower than the post-scores, suggesting some regression, this finding was not statistically significant. The follow-up students also reported a strong interest in science, with 66.7% answering the question "Do you like science?" with "yes" and 20% with "sort of." They also indicated a strong affinity for insects and plants, with 50% of them volunteering insects as their favorite subject in science and 26.7% volunteering plants. Finally, the qualitative coding of the experimental group's test and survey responses revealed both the influence of indigenous culture on their scientific understanding and the appeal of taxonomy and field trips to children. When prompted for an example of a native plant, 24% of the experimental group named a plant introduced by the Polynesians, suggesting the misconception that plants with a prevalent role in indigenous culture have always been there. In the follow-up survey, 36.7% mentioned the field trips among their memories of the course, and 20% gave full scientific names

for species they recalled from the class. The latter contrasts with the commonly held belief that taxonomy is too arcane to connect with the general public.

Overall, our research demonstrates the scientific and societal benefits of thorough natural history and biodiversity studies. The use of integrative methods allowed for the discovery of a staggering number of plant bug species in a very small area of land, and the documentation of ecological attributes allowed us to show how this radiation of bugs has been both adaptive and non-adaptive. The integration of this biodiversity information and a focus on traditionally "uncharismatic" groups of organisms (insects and plants) in local education provided substantial gains in schoolchildren's scientific knowledge, and perhaps more importantly, helped to popularize science and nature. Our hope is that this work inspires future graduate students to pursue research on the unknown and the undiscovered, and to link their findings directly to local communities.

Dedication

I dedicate this dissertation to my parents, Jim and Nikki, for saying yes when their quirky son with the high-pitched voice asked them if they would go with him on an adventure. That adventure started with the unloved islands of Narragansett Bay, described by one author as "squat, low, and brambly," and continued to the majestic peaks of Tahiti, documented in these pages. Their unconditional love early in life gave me the greatest gift of all—the confidence to follow my dreams, no matter how quixotic.

Quotes

“The field of island biogeography is fraught with overgeneralization. The multitudinous groups of plants and animals that live on oceanic islands are highly variable in evolutionary history, taxonomic diversity, dispersal, colonization, population size, habitat preference, reproduction, nourishment, and any other attribute. Therefore, I see little reason why the biology of disparate insular organisms should be governed by any particular set of rules.”

-David Steadman

“Insect ecologists, terrestrial biologists, and entomologists, including graduate students, eventually may turn more and more to mirids as research organisms for illustrating key biological principles and testing hypotheses. Discovery of this intriguing family by more investigators, both applied, and basic, might someday give rise to a “mystique” currently associated only with some of the more popular insect groups.”

-Alfred G. Wheeler Jr.

“Never tell me the odds.”

-Han Solo

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Holy smokes, am I really getting to finally write this part? It takes a village to write a dissertation, and there are so many people who helped me on this journey. First, to the academy—not that Academy, silly, this isn't the Oscars—but to the professors and academics who helped me realize this project despite some pretty long odds. First, to my advisor, Rosie Gillespie, who took a chance on me despite my pre-doctoral sabbatical from science, unorthodox approach to research, and multiple interests throughout grad school. Rosie challenged me and pushed me in all the right ways, allowing me to develop a sense of the bigger picture of my work and the intellectual framework of my project. I will always be grateful for her support, both in the resources she provided and in her encouragement of me to pursue my passions. And on top of that, she is a wonderful person, always kind and compassionate. I'd also like to thank George Roderick for his support of my ideas, crazy as they are at times, and his willingness to always share a laugh and a supportive smile. I thank Dan Polhemus for generously hosting me at his home in Hawaii, his company in the field in the Austral Islands, and for the many energetic conversations about Pacific Island plant bugs. His knowledge of Pacific Island natural history is staggering, and I always walk away from our conversations with my head spinning. I'd like to thank Michael Ranney for joining my committee late in the game and for helping me to develop the education portion of my dissertation despite being a neophyte to the field. While my education study may not have been conceptualized or executed in the ideal way, Michael and his Reasoning group helped me make it work, and always did it with his mix of quick wit and intellectual rigor.

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CHAPTER 1

An integrative taxonomic approach to species delimitation in the *Pseudoloxops* (Hemiptera: Miridae) plant bug radiation of French Polynesia

Introduction

Alpha taxonomy, the delimitation of groups of organisms into species, provides the foundation for ecological and biodiversity research. The science of species delimitation has advanced significantly in recent years, thanks to technological breakthroughs and an emerging consensus that species be treated as testable hypotheses (Haszprunar, 2011) and circumscribed based on multiple lines of evidence (Fitzhugh, 2005; Samadi & Barberousse, 2009; Padial *et al.*, 2010). This burgeoning field, known as integrative taxonomy, allows for the simultaneous analysis of different data types (molecular, morphological, ecological, behavioral, or chemical) to identify species boundaries and diagnostic characteristics, with the ultimate decisions based on the weight of the evidence provided (Dayrat, 2005; Will *et al.*, 2005; Yeates *et al*., 2010). The use of multiple lines of evidence has enabled the discovery of biodiversity that might otherwise have gone unnoticed, such as cryptic species (Barata *et al*., 2012; Florio *et al.*, 2012). Such investigations can also lead to the discovery of natural history data and patterns (*e.g*., host use, bioacoustics) that can provide a basis for further investigations of diversification or population-level processes (Mallett, 2008; Glaw *et al*., 2010). This integrative approach has improved the repeatability and rigor of taxonomic studies and has counteracted the unfortunate stigma of taxonomy as a purely descriptive enterprise (Wheeler, 2004; Sluys, 2013).

A key principle underlying the integrative taxonomy framework is the recognition that species are lineages, or segments of lineages, and that speciation is in most cases a gradual process (polyploid speciation being an exception) in which one ancestral lineage splits into two (de Queiroz, 1998). Depending on the time along the speciation continuum and the data being examined, the descendant species may or may not show evidence of having completed the split. For example, in a study of endemic *Dysdera* woodlouse hunter spiders from the Canary Islands, Macias-Hernandez *et al.* (2010) described three new species that had significantly diverged ecologically and morphologically, but did not form monophyletic groups in phylogenies of both mitochondrial and nuclear DNA, likely due to incomplete lineage sorting. Examples of conflict between different types of data in a variety of other taxa abound in the literature, from moths (Roe & Sperling, 2007) to geckos (Barata *et al*., 2012) to plants (Lega *et al*., 2012). In many of these empirical examples, the ontology of the species concept is separated from the epistemology of species delimitation (*i.e*., how species boundaries are operationally determined), as suggested by de Queiroz (2007) in his introduction of the unified species concept. The ontology of this species concept is that a species is a "separately evolving metapopulation lineage" (de Queiroz, 2007), while the epistemology is that any line of evidence supporting the existence of a species is sufficient to consider that entity a species, with the understanding that the greater the amount of corroborating evidence, the greater the confidence in the taxonomic decision. Although criticized by some for being too ambiguous or vague (Hausdorf, 2011), the concept is useful for its separation of species ontology and species delimitation and for its recognition that, in practice, there is no uniform criterion for distinguishing species that works across all taxa. The term species itself, much like community and population, is a construct used to group biodiversity at some hierarchical level, but whose utility both within science and for the greater public outweighs any of its semantic shortcomings. However what we end up calling a species has great implications for conservation, as basic diversity measures such as species richness and species composition are often consulted when crafting public policy (Agapow *et al.*, 2004).

In their review of integrative taxonomy, Schlick-Steiner *et al.* (2010) suggest two approaches: the discovery approach, in which organisms are examined without any *a priori* species hypotheses, and the hypothesis-driven approach, in which existing species hypotheses are tested. Much of the recent literature consists of the latter, in which investigators have used an integrative framework to tackle troublesome species complexes (Mousseau & Sikes, 2011; Reeves & Richards, 2011; Gebiola *et al*., 2012). But few studies have taken the discovery approach, perhaps because of the focus on testing the utility of various data types rather than an attempt to fill the taxonomic gap (but see Puillandre *et al*., 2012). Given the taxonomic impediment that exists, particularly for insects and other invertebrates (Wilson, 1987; Cardoso *et al.* 2011), integrative taxonomy could provide a framework for more accurately identifying and diagnosing this diversity than would be done using more traditional means. With only about 14% of the world's estimated 8.75 million species still undescribed (Mora *et al*., 2011) and a dearth of funding and infrastructural support to describe them (Pearson *et al*., 2011), the urgency to document the planet's biodiversity is great, especially in areas threatened by habitat loss and human-mediated extinction, such as the 34 "biodiversity hotspots" (Conservation International, 2013a). Of these, Polynesia/Micronesia has received scant attention, particularly for its terrestrial invertebrate fauna, which is highly endemic and poorly known. Data are so limited that Conservation International's diversity overview of the hotspot does not even list invertebrates as a taxonomic group (Conservation International, 2013b).

Within the Polynesia/Micronesia hotspot, the volcanic archipelagoes of French Polynesia are particularly under-studied (Meyer *et al*., 2005; Gillespie *et al*., 2008). The islands, a territory of France (officially an "overseas collectivity;" Central Intelligence Agency, 2013), are comprised of 118 islands in 5 archipelagoes (the Austral, Gambier, Marquesas, Society, and Tuamotu Islands; see Figures 1-2) formed by underwater volcanic eruptions and so-called "hot spots" in the Earth's crust along the Pacific plate (Clouard & Bonneville, 2001). These islands are oceanic, *i.e.*, have never been connected to the mainland, and thus all of their biota has been derived from overseas dispersal. They range in age from less than 264,000 years old (Mehetia; Demougeot, 2007) to 47.4 million years (Mataiva; Schlanger et *al*., 1984). While the overall biota is generally depauperate when compared to similar mainland environments of similar size, due to the islands' extreme isolation there is considerable invertebrate diversity as a result of *in situ* diversification (Gillespie *et al*. 2008). A trickle of studies in recent years has begun to uncover this diversity. A leading example is the carabid beetle genus *Mecyclothorax*, with 81 described species on the islands of Tahiti and Moorea alone (Liebherr 2012a, 2012b). Other recent studies have documented considerable French Polynesian diversity in a range of taxa, such as cixiid planthoppers (13 species; Hoch, 2006), *Nabis* damsel bugs (8 species; Polhemus, 2010), *Inseliellum* black flies (41 species; Joy & Conn, 2001; Craig, 2003) and *Rhyncogonus* weevils (66 species; Claridge, 2006). With evidence of another 13 radiations in the true bugs (Hemiptera: Heteroptera) alone (Nishida, 2008), French Polynesia is clearly an excellent laboratory for studies of species delimitation aimed at uncovering new diversity.

In this study, we focus on species delimitation in a group of plant bugs (Miridae: Orthotylinae: Orthotylini), in the genus *Pseudoloxops* Kirkaldy 1905. Plant bugs are the most diverse family of "true bugs" (Hemiptera: Heteroptera), with 11,020 described species (Cassis & Schuh, 2012) and thousands more awaiting discovery and documentation (Gerry Cassis, personal communication). Their diversity is likely related to their trophic range (a wide range of herbivores and predators)

and their ability to specialize on host plants, particularly angiosperms (Wheeler, 2001). Plant bugs comprise a significant part of the true bug fauna in French Polynesia, with 19 genera present and at least 4 having radiated within the archipelagoes (*Campylomma*, *Engytatus*, *Pseudoloxops*, and a new genus in the subfamily Mirinae; personal observation). Of these, the genus *Pseudoloxops* has radiated the most extensively, with six described species and preliminary evidence for several more. *Pseudoloxops* is distributed across several zoogeographic regions (Afrotropical, Oriental, Palearctic, Sino-Japanese, Saharo-Arabian, and Oceania), with French Polynesia representing the eastern limit of its range in the Pacific (Holt *et al.*, 2013; Plant Bug Planetary Biodiversity Inventory, 2013). The overall monophyly of the genus is in question due to extreme variability in the male genitalia, the lack of a complete phylogenetic revision, and the discovery of many new species (Tomohide Yasunaga & Gerry Cassis, personal communication). The higher-level systematics are also tenuous, as many genera in the tribe Orthotylini are not well-defined. Although the lack of a phylogenetic framework for the genus across its range makes it impossible to know whether *Pseudoloxops* is monophyletic in French Polynesia, this should not affect our taxonomic analysis, as we are primarily interested in the least-inclusive, well-supported monophyletic clades of individuals to help infer species boundaries.

There are currently 40 described species of *Pseudoloxops*, although recent collections have indicated dozens of undescribed species. The only prior work on French Polynesian *Pseudoloxops* was a single taxonomic study conducted by Knight (1937), who described six species endemic to the islands of Tahiti and Moorea in the Society Islands. He considered color and the structure of the male genitalia to be diagnostic at the species level (with little variation evident in other character systems), despite having only 16 specimens total and two species for which only a single specimen was available (in one case, a female). Preliminary field collecting and searches of historical collections indicated that considerably more endemic diversity exists in French Polynesia both within and beyond the islands of Tahiti and Moorea. The primary goal of this study is to integrate morphological, molecular, geographic, and ecological data to discover, document, and delimit that diversity.

Our goals in this study are to answer the following questions:
1. How many species of *Pseudoloxops* are present in French Polynesia, and what is their distribution?
2. Are Knight's (1937) six species confirmed by our integrative analysis, and if not, how should they be redescribed and assimilated with the rest of the empirical data?
3. How can each *Pseudoloxops* species be delimited and identified?

Our methods to address these questions fall under the umbrella of integrative taxonomy and follow de Queiroz's (2007) aforementioned unified species concept. While most alpha taxonomy in entomology still follows some variation of the morphological species concept based on fixed diagnosable morphological differences between species (although few such studies explicitly state their species concept), we prefer an integrative approach that could potentially recognize cryptic diversity (*i.e.*, species that can be delineated using non-morphological data, such as DNA) and that uses all available data. As part of this approach, we also use individual specimens as the terminal entities in our phylogenetic analyses, rather than trying to group individuals into populations or species *a priori*. This method, while common in molecular phylogeographic

studies “below the species level,” is much less common in morphological phylogenetics, due to the dominance of the “fixed differences” criterion under the morphological species concept. Implicit in this criterion is that the species rank represents a clean, finite line at which gene flow ends and reticulation begins (*i.e.*, the transition between species and populations). Yet an abundance of recent studies incorporating molecular data have shown that speciation is a gradual process, and that in many lineages, determining where that species/population boundary occurs is not simple, due to such complicating factors as hybridization and incomplete lineage sorting (Maddison & Knowles, 2006; Reeves & Richards, 2007). Following Vrana and Wheeler (1992), we do not consider it possible to know *a priori* the way in which characters cluster individuals together into monophyletic groups or the level at which interspecific pattern dissolves into reticulation, and thus we use individual specimens as the terminals in our phylogenetic analyses. In order to guarantee that we are making reasonable comparisons among different data types in our integrative taxonomy analysis, we also sampled different data types from the same individuals, a practice that is often overlooked or simply neglected at the risk of leading to incorrect inferences about species boundaries (Yeates *et al.*, 2011).

The gradual nature of speciation and the subsequent potential for conflict between different data sources precludes us from relying on a single delimitation criterion (hence our justification for using the unified species concept). For example, if we only used a phylogenetic species concept and relied on the delimitation of monophyletic clades of individuals as our sole criterion, we may overlook the existence of species due to incomplete lineage sorting, horizontal gene transfer, or low support values (Funk & Omland, 2003); alternatively, we may “oversplit” species where phylogenetic signal exists below the species level. Underestimating diversity would be particularly unfortunate given the projections of the rate at which we are losing species to extinction (Malcolm *et al.*, 2006). We therefore proceed iteratively in our analysis, beginning with a single data set to infer initial species hypotheses and then testing them against the remaining data sources.

Materials and Methods

Specimen Collection

Museum Work and Databases

The vast majority of historical *Pseudoloxops* specimens from French Polynesia are housed in the Bernice P. Bishop Museum in Hawaii. The first major entomological survey for which specimens were properly stored was the Pacific Entomological Survey, which occurred from 1927-1932 (Bernice P. Bishop Museum, 2013). The specimens from this survey and the Mangarevan Expedition of 1934 provided the bulk of the historical material for this study. Several trips to the museum were made to examine the collection and the holotypes of French Polynesian *Pseudoloxops*. A review of the collection revealed that *Pseudoloxops* is only known from two of the five French Polynesian archipelagoes—the Austral and Society Islands. Given the age and rarity of these specimens, destructive sampling was not permitted. In addition, several congeneric sequences used as outgroups in phylogeny reconstruction were downloaded from GenBank.

Field Work

Field searches for *Pseudoloxops* were conducted on 8 of the 14 Society Islands (Huahine, Maupiti, Mehetia, Moorea, Raiatea, Tahaa, Tahiti, and Tetiaroa) and 4 of the 7 Austral Islands (Raivavae, Rimatara, Rurutu and Tubuai) in 2007-09, and 2011. Of the islands not surveyed, most are atolls, flat coral-based islands with little floral diversity and no historical collections of *Pseudoloxops.* Bora Bora is the only island of considerable size and elevation that was not sampled, due to lack of time and funding. Field time on each island varied considerably depending on cost and access; for example, Moorea and Tahiti were sampled much more extensively because of the University of California at Berkeley's research station (the Richard B. Gump South Pacific Research Station) on Moorea, where the lead author was based, and Tahiti's proximity to Moorea. On each island, every effort was made to sample in the greatest diversity of habitats and elevations as possible. The leaves, branches, and in particular, flowers (often the preferred habitat of plant bugs; Wheeler, 2001) were beaten with a plastic PVC pipe into an insect collecting net, and trapped specimens were aspirated into collecting vials and killed the same day in a freezer. In a few instances, specimens were collected at blacklights during the night. The dead specimens were then transferred to 1.5 mL vials and stored in 95% ethanol in a -80°C freezer for future DNA extraction. Each specimen was given its own vial, as plant bugs' legs easily fall off in ethanol, complicating both morphological and molecular work. Each plant on which *Pseudoloxops* was found ("plant affiliation") was considered a collecting locality and assigned a unique locality code. At each locality, the latitude, longitude, and elevation were recorded using a Garmin eTrex H GPS device. Samples from plants were taken for later identification by local botanists.

Morphological Data

Differences in morphology can provide evidence for the boundaries between species, reflecting reproductive incompatibility or the transformation of homologous characters as lineages diverge. Given the ease of access, morphology has long been a staple of taxonomic work, with almost all species descriptions including some morphological criteria for species identification (Hillis, 1987; Wiens & Servedio, 2000). However, morphology can also be misleading for species delimitation, particularly when the gap between interspecific and intraspecific variation is difficult to identify (Tixier, 2012). Furthermore, phenotypic plasticity can lead to erroneous conclusions, as morphological traits that are environmentally determined are confused for heritable traits that diagnose species. Here, we measured several aspects of morphological variation for all available specimens, as both continuous and discrete characters, to look for evidence of boundaries between species.

Continuous Body Measurements

Each specimen was examined with a Leica MZ APO dissecting microscope and photographed with a Leica DFC425 camera (mounted on the scope) in four different orientations (dorsal, ventral, lateral, and dorsal focused on the head) for voucher photographs and to take measurements. The following 13 trait measurements were taken using Leica software (Figure 3): body length (2 dorsal-view photos were taken in order to get the most accurate measurement; for the first photo, the specimen was oriented to make the pronotum and hemelytra as flat as possible, and the distance from the medial point of the posterior margin of the pronotum to the posterior margin of the hemelytra was recorded as BL1; for the second photo, the specimen was tilted to make the pronotum and head as flat as possible, and the distance from the tip of the clypeus to the posterior margin of the pronotum was recorded as BL2; the two lengths were then

summed for total body length, BL); body width (BW, distance across body at its widest point, dorsal view); labium length (LL; length of the stylets, ventral view); pronotal length (PL; distance from medial point of collar to the posterior margin of the pronotum, dorsal view); pronotal width (PW; distance across pronotum at its widest point, dorsal view); length of each antennal segment (AI-AIV; left antenna was measured unless broken, in which case the right antenna was used); head length (HL; distance from tip of the clypeus to the posterior margin of the head, dorsal view); head width (HW; distance across head, including eyes, at the widest point, dorsal view); vertex width (VW; shortest distance between eyes, dorsal view); and cuneus length (CL; distance from costal fracture to the posterior end of cuneus).

Discrete Character Data Collection

After each specimen was photographed and measured, it was examined under a Leica MZ APO microscope to create and score a morphological matrix for phylogenetic analysis (see Table 1). Although a phylogenetic analysis of *Pseudoloxops* has never been published, we examined the literature in other plant bug groups to assist in our search for morphological characters that appeared more variable between clades than within clades, thus providing good potential evidence of homology. Twenty-one unordered multi-state morphological characters (see Table 2) were scored to capture the variation in color and the structure of the male genitalia, considered the two most diagnostic character systems for *Pseudoloxops* (Linnavuori, 1994).

Male Genitalia

In order to more objectively distinguish interspecific differences in the male genitalia, geometric morphometric tools were used, in which shape is quantified using the establishment of landmarks, Procrustes superimposition and the calculation of relative warp scores. This method, while infrequently applied to insect genitalia, has been effective when implemented. In one study of several Lepidopteran species complexes, geometric morphometrics was found to more accurately discriminate between the genitalia of closely related species than visual examination by experts, the more common method of species delimitation (Mutanen & Pretorius, 2007). Given these results, we analyzed the shape of the male genitalia using a geometric morphometric approach.

For each male specimen with an intact genital capsule (N=75), the genitalia was dissected and mounted as follows: The genital capsule was removed from the rest of the abdomen using fine-tip forceps. The capsule was then soaked in a spot plate in 10% potassium hydroxide solution for 3 minutes to clear tissue. The capsule was rinsed in 95% ethanol, and placed in glycerine in another spot plate. The capsule was dismantled using forceps to separate and isolate the left paramere, right paramere, and aedeagus. Each of these structures was mounted on a slide in a few drops of glycerine, with a coverslip slightly elevated using four tiny clay balls in the corners, to allow for manipulation of the structure while viewing under the microscope. The left and right parameres were examined and photographed using a Leica MZ APO microscope at 80x magnification; the aedeagus was photographed at 63x magnification.

Only the left paramere was analyzed using geometric morphometrics, as it was too difficult to get the right paramere and aedeagus in a consistent two-dimensional plane, and the phallotheca was torn in several specimens during dissection. Differences in shape in the left paramere within the French Polynesian radiation are subtle, making it difficult to qualitatively distinguish

between species. For each left paramere photograph, 4 landmarks were digitized in the program tpsDig 1.4 (Figure 4; Rohlf, 2004). Thirty semi-landmarks were then digitized between each of the landmarks using tpsDig 2.16 (Figure 5; Rohlf, 2010a), which were then transformed into sliding semi-landmarks by removing the control lines in tpsUtil (Rohlf, 2012) and creating a "sliders" file. In order to remove non-shape variation between samples (*i.e.* differences in size, orientation, and position), we superimposed semi-landmark coordinates in the program tpsRelw 1.49 (Rohlf, 2010b) and then transformed those coordinates ("Procrustes superimposition") into principal components (or relative warp scores) in ordination space.

Molecular Data

DNA Extraction and Amplification

Following the collection of morphological data, molecular data were collected from 181 specimens (specimens for which no molecular data were accessible were either holotypes or failed to yield enough DNA through extraction and amplification). Early attempts to extract sufficient DNA for amplification and sequencing from 2-3 legs of a specimen failed. Therefore, to obtain enough total genomic DNA, each specimen was poked multiple times with a minuten pin and then soaked in the DNAEasy® tissue kit's extraction buffer (with proteinase K) overnight, followed by completion of the manufacturer's DNA extraction protocol for animal tissue. Fragments of the mitochondrial cytochrome oxidase I (CO1; 814 base pairs) and 16S ribosomal sub-unit genes (508-535 base pairs, due to gaps and insertions) were amplified using the polymerase chain reaction (see Table 3 for PCR conditions and protocols); a fragment of the nuclear 28S ribosomal sub-unit gene (633-648 base pairs) was also amplified. DNA was amplified using the following primers: for CO1: CI-J-2195, or MTD10/MTD12 (Simon *et al.*, 1994); for 16S: 16Sa/16Sb (Xiong & Kocher, 1991); and for 28S: 28SD2F/28SD2R (Weirauch & Munro, 2009); see Table 4 for primer sequences. PCR products were cleaned up and Sanger sequenced at UC Berkeley's Barker DNA Sequencing Facility. Sequences were aligned in the program Geneious Pro 5.6.2 using the Geneious Alignment function and its default settings (cost matrix: 65% similarity (5.0/-4.0); gap open penalty 12, gap extension penalty 3), and corrected by eye.

Phylogenetic Analyses

Several phylogenetic analyses were performed to provide baseline species hypothesis for this integrative taxonomy study, with a total of 202 specimens examined.

Outgroups

We gathered as many outgroup samples as possible through collaborators and GenBank. We included as many *Pseudoloxops* samples as possible, along with sequences from other genera in the tribe Orthotylini, in order to test the monophyly of French Polynesian *Pseudoloxops* given the samples available (although without better sampling from other Pacific Island archipelagoes, we cannot rigorously test this hypothesis).

Individual Gene Trees

We used the program PartitionFinder (Lanfear *et al.*, 2012) to determine the most appropriate model of evolution for each of the following ingroup gene alignments: 16S (163 sequences, 516

base pairs); 28S (158 sequences, 640 base pairs); CO1 (148 sequences, 814 base pairs). For each alignment, we selected the model that best fit the data under the Bayesian Information Criterion *(i.e.*, the model with the lowest log-likelihood score; Lemey *et al.*, 2009). To infer phylogenies for each gene, we used Mr. Bayes 3.1.2 (Ronquist & Huelsenbeck, 2003) on the CIPRES Science Gateway (Miller *et al.*, 2010). For each analysis, we performed 2 independent runs of 4 chains each for 20 million generations, sampling trees every 1,000 generations. After running to completion, we verified that the standard deviation of split frequencies fell below 0.01 to ensure convergence of the 2 runs. A 50%-majority rules consensus tree was then constructed, discarding the first 25% of trees as the burn-in. The models of evolution used in each analysis were as follows: 16S: HKY+I; 28S: K80+I; CO1: HKY+I+G.

Combined Gene Trees

We combined our three loci (16S, 28S, and CO1; although 16S and CO1 are not truly independent of each other, as they are both part of the mitochondrial genome) to infer a molecular phylogeny. We concatenated our alignments from all 3 loci into a single alignment in Mesquite 2.75 (Maddison & Maddison, 2011) for a total dataset of 181 sequences and 1,998 base pairs (including outgroups). We used PartitionFinder to find the best model of evolution according to the Bayesian Information Criterion, which was GTR+I+G, and the best partitioning scheme, which was having no partitions. We then loaded the combined alignment into Mr. Bayes 3.1.2 on the CIPRES Science Gateway and performed two independent runs of four chains each under the GTR+I+G model for 20 million generations, sampling every 1,000 generations. After running to completion, we verified that the standard deviation of split frequencies fell below 0.01 to ensure convergence of the 2 runs. A 50%-majority rules consensus tree was then constructed, discarding the first 25% of trees as the burn-in. Since the outgroups for which we had molecular data were from areas geographically distant from French Polynesia, the long branches in the resulting phylogeny likely impacted the support values of the ingroup nodes. We therefore also inferred a Bayesian phylogeny using the above method but only included ingroup sequences (N=164).

Morphological Phylogeny

Phylogenetic reconstruction was performed under maximum parsimony with 21 discrete morphological characters in the program TNT (Goloboff *et al.*, 2008). For the ingroup data set of 176 specimens, we used three “new technology” methods (sectorial search, parsimony ratchet, and tree fusion) that heuristically search tree space for the most parsimonious tree, with 100 random addition sequences and a random seed=1. One hundred most parsimonious trees (all being equally parsimonious) were saved, and a strict consensus tree was constructed. We then ran 100 bootstrap replicates with replacement to test for support in the tree.

Molecular and Morphological Combined Analysis

We combined our molecular and morphological alignments to create a total data set (including outgroups) of 202 terminals and 2,019 characters. Since the program PartitionFinder had returned zero partitions as the best scheme in our previous analysis concatenating genes, we included only two partitions here: 1 for DNA sequence data (characters 1-1,998) and 1 for morphological data (characters 1,999-2,019). We loaded the combined alignment into Mr. Bayes 3.1.2 on the CIPRES Science Gateway and performed two independent runs of four chains each for 30 million generations, sampling every 1,000 generations, with a mcmc temp=0.5. The

GTR+I+G model was used for the molecular partition, and a default Markov model was used for the morphological partition. After running to completion, we checked to see if the standard deviation of split frequencies fell below 0.01 to ensure convergence of the 2 runs.

Iteration 1

In order to operationalize our integrative approach, we followed an iterative procedure of examining different data sets using different delimitation criteria (Yeates *et al.*, 2011). We started with the phylogenetic methods described above, using Bayesian phylogenetic inference on three sets of data: (1) discrete multi-state morphological data; (2) DNA sequence data (combining 3 genes); and (3) combined morphological and DNA data. Since the DNA sequence data alone provided the most well-resolved, well-suppported topology (see Results), we used these data for the first iteration of our integrative taxonomic analysis. Using the molecular phylogeny, we labeled all of the least-inclusive, well-supported (posterior probability ≥ 0.90) clades as putative species. Singletons were considered putative species provided that the node connecting to their sister taxa was well-supported and well-resolved; several individuals that did not meet these criteria were left "unassigned" to species for the time being (individuals for which molecular data were not available were also left "unassigned"). The putative species (species hypotheses) were then iteratively tested using the data and methods described below. Unassigned individuals were also examined using these methods, with all individuals ultimately assigned to a species in the final iteration.

Cluster Analysis of Morphological Data

In the first round of iterative taxonomy, the molecular phylogeny was used to provide a set of initial species hypotheses, called "putative species." These species boundaries were then tested against the multivariate continuous morphological data (body length, body width, etc.), which were organized into clusters for comparison. We excluded the data for the length of antennal segments III and IV because of an excess of missing data; missing data for the remaining variables (due to shriveled specimens that prevented a measurement) were replaced by the mean value for that variable across all specimens, due to the software's inability to handle missing data. Using the program PC-ORD 5.1 (McCune and Mefford, 2011), the data for the remaining 11 continuous morphological traits were used to construct cluster dendrograms depicting the similarity between all individuals, using Ward's method and Euclidean distances. A separate analysis was conducted for males and females due to the potential for sexual dimorphism to distort the data. For each putative species recognized from the molecular phylogeny, we then examined the placement of its constituent individuals in the dendrograms; if they all clustered together *(i.e.*, were all sister to each other), then the putative species was considered "supported" by this line of evidence. The same method was used to create dendrograms from the first 74 principal components (relative warp scores; 74 PCs because there were 75 individuals) resulting from the morphometric analysis of the male genitalia. The putative species were then tested against these dendrograms as another line of evidence.

Genetic Distance

We tested our putative species against the molecular data in another way by examining interspecific genetic distances for CO1. For the 148 individuals with CO1 data, we used the program MEGA 5.1 (Tamura *et al.*, 2011) to calculate the uncorrected p-distance (proportion of

nucleotide sites that are different) between each pair of putative species, using group means where a species was represented by multiple individuals. While no objective interspecific threshold distance exists, 2% distinct has been used in many studies (Cognato, 2006), and in a study of true bugs, a set of closely related plant bug species in the genus *Apolygus* were up to 1.3% different (Jung *et al.*, 2011). We therefore established 1.5% different as our cutoff. We went through the molecular phylogeny node by node to examine the genetic distance between putative species; if the distance was greater than or equal to 1.5%, the putative species was considered supported.

Plant Affiliation and Geography

In our first iteration of testing putative species boundaries, we also examined ecology ("plant affiliation") and geographic distribution. Each individual's plant affiliation was recorded as the plant where it was collected (it would be premature to consider the plant a true "host" without nymphs), and a GPS reading recorded its precise location. Assuming high phylogenetic signal, we tested our putative species against the criterion that all individuals within a species would be affiliated with the same species of plant. We then did the same for distribution, assuming that all individuals within a species would be found on the same island (broadly sympatric). Thus plant affiliation and island distribution provided two further independent lines of evidence to test putative species against.

Iteration 2

After testing the initial putative species against all of the above lines of evidence, we eliminated any putative species that were not supported by a single additional line of evidence. One at a time, we then examined each remaining putative species and the data supporting and refuting its recognition as a species, along with the individuals that were not provisionally assigned to a species resulting from the initial molecular phylogeny. Weighing the evidence and considering possible biological explanations for discrepancies between data sources (following Schlick-Steiner, 2010), we then inferred species boundaries and assigned all individuals to a species.

Canonical Variates Analysis

After having inferred species boundaries, we subjected our delineations to a final test by re-examining the left paramere shape data. First, we performed a principal components analysis on the left paramere morphometric data, and then examined the resulting scree plot to see how much of the variance in the data was explained by each subsequent principal component. After determining that the first 30 principal components of the Procrustes-superimposed landmark coordinates explained over 99.99% of the variation, we used the program PAST 2.16 (Hammer *et al.*, 2001) to perform canonical variates analysis (CVA) on those 30 PCs to test for significant differences between groups *(i.e.,* species). CVA is an ordination method that requires groups (in this case, species) to be assigned *a priori*, and that searches for the axes (canonical variates) that best discriminate between groups relative to the variation within them. Since some of the species delineated in this study were known only from females, a subset of the overall diversity was analyzed using this method. The minimal Mahalanobis distance (the "classifier" function in PAST) was then used as a criterion to check these data's ability to accurately assign a given individual to its correct species, which was then cross-checked by jackknifing the data.

Results

Sampling

Pseudoloxops specimens were collected in the field on 9 of the 12 islands surveyed (see Table 5; only Mehetia and Tetiaroa in the Society Is. and Raivavae in the Austral Is. did not yield any specimens). Specimens were found at 114 of 520 collecting localities on 27 different plant species. A total of 183 ingroup specimens were analyzed in the taxonomic study (see Table 6), with an additional 17 specimens or GenBank sequences serving as outgroups for phylogenetic analyses. A further 91 specimens in the Bishop Museum were examined; all species found in the historical material were also found among the field collections.

Phylogenetics

The combined Bayesian gene tree with outgroups is shown in Figure 6. Long branches characterized most of the outgroups, with *Pseudoloxops* overall coming out as paraphyletic, although the outgroup sampling was quite limited. A major but well-supported polytomy defined a clade containing most of the terminals, including all of the ingroup specimens and outgroups from New Caledonia and Australia. *Pseudoloxops* therefore does not appear unequivocally monophyletic in French Polynesia, although without sampling from the archipelagoes intermediate between New Caledonia and French Polynesia (*e.g.*, Samoa, Tonga, Fiji), this question remains unanswered. Given the great geographic distance between the outgroups and French Polynesia and the basal polytomy, we consider our ingroup phylogeny reliable for addressing taxonomic questions. The ingroup molecular combined phylogeny (see Figure 7) was generally well-supported and well-resolved, and served as the basis for the first iteration of grouping specimens into putative species.

The individual ingroup gene trees generally tracked the combined gene tree topology, with the expected differences based on data type. The mitochondrial genes (16S and CO1) were the best resolved (see Figures 8-9), given their faster rate of evolution (with CO1 fastest), while the nuclear gene (28S) contained several large polytomies (see Figure 10). For the 16S alignment, 83/516 (16.1%) of nucleotide sites were variable; for CO1, 240/814 (29.5%) sites were variable; for 28S, 55/640 (8.6%) were variable.

The TNT analysis of the discrete morphological data alone resulted in 100 most parsimonious trees with a score of 195 changes (1,830,400,290 rearrangements tried). We combined the 100 trees into a strict consensus tree, which revealed very little phylogenetic signal (see Figures 11-13). The tree had little resolution, with only 7 nodes distinguishing 176 terminals, and 5 of those nodes comprising a polytomy; support is also generally low. For the trees in which the morphological and molecular data were combined, the Bayesian analysis failed to converge for both the full (including outgroups) and ingroup data sets (in the full analysis, the standard deviation of split frequencies was .075 after 40 million generations; for the ingroup analysis, it was .09 after 30 million generations). Since there was little phylogenetic signal in the morphological data alone and the combined analyses did not converge, we relied on the combined ingroup gene tree to provide initial species hypotheses.

Iterative Taxonomy

Using the ingroup gene tree and the criterion of least-inclusive, well-supported (posterior probability ≥ 0.90) monophyletic clades, we identified 48 putative species to begin the iterative taxonomy process (see Figure 6; nodes identifying species are marked and numbered). These 48 species hypotheses were then subjected to testing using the following additional lines of evidence: morphological phylogeny ("discrete morphology;" see Figures 11-13); dendrogram of females' morphology for continuous traits (see Figure 14); dendrogram of males' morphology for continuous traits (see Figure 15); dendrogram of principal components for left paramere shape (see Figure 16); pairwise genetic distance (see Table 7); plant affiliation (see Table 6); and island distribution (see Table 6). The results of this iterative testing are summarized in Table 8. We discuss the specific results of this process below, beginning at the base of the tree. Species were inferred considering the lines of evidence supporting and against their existence. The nodes defining all putative species are numbered in Figure 7. Genetic distances referred to below are CO1 distances, unless otherwise indicated. Several individuals included in this initial analysis were not yet assigned to a species, as they did not fit into any least-inclusive, well-supported clades. These individuals are assigned to species in the species descriptions that follow.

Putative spp. 1-3 (Figure 17)
Putative sp. 1 is located at the base of the tree as part of a polytomy with several other specimens from Tahiti and Moorea. All 3 of the specimens comprising this species are from the same locality on Moorea, but they do not come out as a distinct cluster according to any of the morphological data. This species is only 0.6% genetically different from putative sp. 2, which contains specimens that are all from the same collecting locality (Pihaena, Moorea) and superficially look very similar. The next nearest putative sister species, sp. 3, closely resembles sp. 1 and 2 (Figures 25, 29) but is found in the Leeward Society Islands, over 100 miles away (Figure 2). While the male genitalia of sp. 3 is very similar to that of sp. 1 and 2, the shape of the left paramere is distinctly different (Figure 23), and this species is also 3% genetically distinct from sp. 2. We therefore consider it a distinct, cryptic species (n. sp. 1), while sp. 1 and 2 are lumped together into a single species, the existing *Pseudoloxops rubrocuneatus* (Knight, 1937).

Putative sp. 4 (Figure 17)
Putative sp. 4 is represented by 2 individuals, both males, from the Austral Islands of Rurutu and Tubuai. While these two individuals do not cluster together in the morphological data, they both were found on the same plant (*Metrosideros colliina*) and are highly distinct genetically from their sister species, putative sp. 3 (5.5% different). We therefore consider this a distinct, new species (n. sp. 2).

Putative sp. 5 (Figure 17)
Eight individuals from the island of Huahine comprise a monophyletic group designated as putative sp. 5. The morphometric analysis of the left paramere clusters this species together, and its status as a species is further supported by geography (all occurring on the same island) and genetic distance (4% different from putative sp. 6). The male genitalia is quite distinct, with the endosomal spicule of the aedeagus very thick. We therefore consider this a distinct, new species (n. sp. 3).

Putative spp. 6-7 (Figure 17)

The individuals comprising putative sp. 6-7 superficially resemble putative sp. 5 (see Figures 35, 38), with pale yellow/green coloration and lacking any red markings. However, the node representing their split into 2 monophyletic groups is highly supported, and their geographic distributions do not overlap. Sp. 7 is represented by a single individual from Maupiti (Z58), while sp. 6 is known only from Raiatea. Although we were unable to sequence sp. 7 at CO1, sp. 7 is only 0.8% different from its closest relative within sp. 6 at the locus 16S. Given the low genetic distance and the lack of any other data distinguishing these species, we lump putative sp. 6 and 7 together into a single new, distinct species (n. sp. 4). The male genitalia of this new species is distinct, with the basal part of the left paramere's sensory lobe highly rounded, the right paramere consisting of a single lobe, and the phallotheca with three lobes (see Figure 39).

Putative spp. 8-11 (Figure 18)
The individuals comprising putative spp. 8-11 all have a simple yellow/green color without any red markings (see Figures 41, 43, 45, 47), and are all found in either Tahiti or Moorea. The branches connecting these monophyletic groups are long, implying that they may be among the oldest species in the radiation. Putative sp. 8 is represented by 2 individuals collected on 2 different plants and found in geographically distant localities on the island of Tahiti. However, they are very close genetically, and as a group, are 4.4% different from their sister species, putative sp. 9. We therefore consider sp. 8 a new, distinct species (n. sp. 5). Putative sp. 9 and 10 form a well-supported monophyletic group from the same collecting locality, but sp. 10 is 2.7% genetically distinct from sp. 9. The individuals comprising sp. 9 also cluster together in the analysis of continuous morphological traits. Since all of the individuals for these 2 species are females, we cannot compare the shape of the male genitalia. Given the genetic and morphological differences detected, we consider sp. 9 and sp. 10 distinct, new species (n. sp. 6 and n. sp. 7, respectively). Finally, putative sp. 11, known only from the island of Moorea, forms a well-supported monophyletic group whose left parameres cluster together in the shape analysis (Figure 23). Furthermore, the species is highly genetically distinct, being 6% different from its sister species, putative sp. 10. We therefore consider sp. 11 to be a new, distinct species (n. sp. 8). The morphology of the aedeagus of this new species is also unique, with a thin endosomal spicule that curls past the distal margin of the phallotheca (see Figure 48).

Putative sp. 12 (Figure 18)
The first association with ferns (all preceding species have been associated with angiosperms) occurs in putative sp. 12, comprised of three individuals from the island of Tahaa. Several lines of evidence support this as a new, distinct species—the females cluster together in the analysis of continuous morphological traits, and the species is 6.8% different from its sister, putative sp. 13. This species also has a conspicuous and unique color pattern, with red markings on the clavus, posterior half of the cuneus, lateral thirds of the pronotum, and roughly circular red vittae on the corium (see Figure 50). We consider this to be a new species, n. sp. 9.

Putative spp. 13-15 (Figure 18)
The individuals comprising putative sp. 13 and 15 look very similar to each other (see Figures 53, 59) and are all from the same area of Tahiti (the trail to Mt. Aorai). However, they come out as two distinct monophyletic groups, and are separated in the phylogeny by putative sp. 14, whose appearance is superficially much different (see Figure 56). While sp. 13 and 15 are associated with ferns, sp. 14 was collected from the angiosperm *Leptecophylla pomarae*. While

the analysis of morphological traits was of little help in distinguishing between these putative species, they are genetically distinct from each other. Putative sp. 13 is 1.6% different at CO1 from sp. 14, and sp. 14 is 1.9% different from sp. 15. Based on the non-monophyly of sp. 13 and 15, the plant association of sp. 14, and the genetic distance among all three, we establish each as a new, distinct species (putative sp. 13 = n. sp. 10; putative sp. 14 = n. sp. 11; putative sp. 15 = n. sp. 12). The male genitalia for putative sp. 13 and 14 are similar (only females were collected for sp. 15), but are distinguished by the small flap in the phallotheca in sp. 13 (see Figure 54a).

Putative spp. 16-20 (Figure 18)
The individuals comprising putative sp. 16-20 share a similar color pattern and are all associated with ferns (see Figure 61). Morphologically, both for the male genitalia and the continuous traits, they are indistinguishable, and the greatest genetic distance between them is only 1.1%. Given the genetic homogeneity and lack of conflicting lines of evidence, we consider sp. 16-20 to be a single, new species (n. sp. 13). All but one individual (Z73) included in this species is found on Tahiti; Z73, collected on Moorea, superficially looks closer to putative sp. 13 or 15, but is nested within the clade defining this new species.

Putative sp. 21 (Figure 18)
The individuals comprising putative sp. 21 were all collected on Raiatea, albeit from different plant species. While they did not cluster together in the morphological analyses, they are highly genetically divergent (7%) from the nearest putative species. Sp. 21 is also defined by the synapomorphy of lacking an endosomal spicule in the aedeagus (see Figure 65a) and a unique color pattern on the clavus, prontum, and pronotum (see Figure 64). We therefore consider this a new, distinct species (n. sp. 14).

Putative sp. 22 (Figure 19)
While superficially resembling putative sp. 11 and having been collected on the same island (Moorea), the single individual representing putative sp. 22 (Z77) is found on a branch of the phylogeny all by itself as part of a well-supported clade comprising putative spp. 25-30. The analysis of left paramere shape places it closest to putative sp. 4 (Figure 16), which is in a very different part of the tree. Sp. 22 is 5.9% genetically distant from its closest relative, sp. 25. Given its position in the phylogeny and its genetic distinctness, we consider this to be a new, singleton species (n. sp. 15).

Putative spp. 23-24 (Figure 19)
These two putative species are sister to each other, but highly genetically divergent (9.1%). Putative sp. 23 is known from a single individual from Rimatara in the Austral Islands (Z16), while a single individual of putative sp. 24 was collected on Huahine in the Society Islands (Z213). They are also quite different ecologically, with sp. 23 collected on the angiosperm *Hibiscus tiliaceus* and sp. 24 collected from the angiosperm *Glochidion temehaniense*. Since these putative species are singletons, the morphological analyses were of little use. However, sp. 24 is morphologically identical to putative sp. 12, and despite being genetically very distinct from it (9.6%), we consider this another example of a cryptic species. In addition, despite the morphological similarity, sp. 24 is associated with an angiosperm, while sp. 12 is associated with a fern. Although sp. 12 and 24 are not monophyletic, they are both nested within nodes that are

poorly supported, and so the phylogeny may not accurately reflect the true relationship between them. We consider sp. 23 (n. sp. 16) and sp. 24 (n. sp. 17) to be new, distinct species.

Putative sp. 25 (Figure 19)
Putative sp. 25 consists of 5 individuals from Tahiti with a distinctive dark green coloration. The individuals do not cluster in any of the morphological analyses, nor are they associated with a single plant species. However, they are 3.5% different from their closest relative, putative sp. 26, and we consider them to comprise a new, distinct species (n. sp. 18).

Putative spp. 26-30 (see Figure 19)
While there is some phylogenetic structure within the well-supported clade that includes putative spp. 26-30, the individuals comprising these putative species all share the same color pattern (see Figure 78) and are all found on Tahiti or Moorea. The genetic distances between them are small, and the apophysis of the right paramere always has two lobes. We lump these putative species together into a single new, distinct species (n. sp. 19).

Putative sp. 31 (Figure 20)
The individuals comprising putative sp. 31 match the description of *Pseudoloxops rubroclavus*. They are associated with ferns on the island of Moorea, and despite not clustering together morphologically, they are 2.2% distinct from their closest relative, putative sp. 32. We consider putative sp. 31 to be the species *P. rubroclavus*, confirming Knight's (1937) description and assessment.

Putative sp. 32 (Figure 20)
The individuals comprising putative sp. 32 closely resemble putative spp. 33-44, but form their own well-supported monophyletic group and are genetically distinct (2.6% different from sp. 33). Despite its similarity ecologically and morphologically to spp. 33-44, we consider sp. 32 to be a new, cryptic species (n. sp. 22).

Putative spp. 33-44 (Figure 20)
Morphologically, the individuals comprising putative species 32-44 represent a large amount of variation (see Figure 89), so much so that Knight (1937) classified them into 3 species and a fourth subspecies (*Pseudoloxops adamsoni*, *P. nigribasicornis*, *P. tahiticus*, and *P. tahiticus rubromarginatus)*. However, all of these individuals are very closely related genetically (the node defining this clade is a big polytomy, and genetic distances are small), all are found on either Tahiti or Moorea, and all are associated with ferns, with no sign of any fern species specificity. In some cases, the clades nested within this clade match Knight's (1937) species designations (putative sp. 38 and 40 for *P. nigribasicornis*), but in others they do not, with *P. tahiticus rubromarginatus* coming out paraphyletic (sometimes nested with *Pseudoloxops adamsoni*, sometimes with *P. tahiticus*). There is evidence of divergence within the male genitalia, as the *P. nigribasicornis* specimens generally have a reduced basal process in the sensory lobe of the left paramere, but all of the specimens in this clade cluster together in the shape analysis (Figure 23). Given the lack of ecological stratification, divergence in genitalia, phylogenetic resolution within this clade, and genetic distance, we consider there to be insufficient evidence to split this clade into multiple species. We therefore retain the name *P. tahiticus* and relegate *P. adamsoni* and *P. nigribasicornis* to the status of synonyms.

Putative spp. 45-48 (Figure 20)
The individuals comprising putative spp. 45-48 have the same superficial appearance (see Figures 81, 83) but do not cluster together in the morphological analysis. Nonetheless, spp. 46-48 are all from the island of island of Moorea and are genetically very close to each other, while sp. 45 is a singleton from Huahine that is 1.8% different from spp. 46-48. We therefore consider sp. 45 to be a new, cryptic species (n. sp. 20) and sp. 46-48 to be a single, new species (n. sp. 21).

Principal Components Analysis
The first two principal components of the Procrustes-superimposed landmark coordinates resulting from the morphometric analysis of the left paramere shape were plotted, with PC 1 explaining 40.71% of the variation and PC2 explaining 30.43% of the variation (Figure 21). A scree plot (Figure 22) showed that the first 30 or so PCs explained over 99.99% of the variation, and so only those 30 PCs were used in the CVA analysis.

Canonical Variates Analysis
After all of the data sources were integrated and species decisions were made as described above, we performed a final check of our species delineation by using canonical variates analysis (CVA), a form of discriminant analysis, on the shape data of the left parameres. Of the 26 species delineated above, only 15 were represented in this analysis due to a lack of samples (and the fact that 6 of the 26 species are known only from females). The existence of all 15 species was deemed highly statistically significant in the CVA analysis (versus the null hypothesis that the specimens were all from a single species), with the Wilks' lambda statistic= 1.093×10^{-10} ($p=1.03 \times 10^{-33}$) and Pillai trace statistic= 9.338 ($p=3.599 \times 10^{-18}$). The CVA scatterplot shows that most species form distinct, non-overlapping clusters (although n. sp. 18 and n. sp. 21 clearly overlap, as do n. sp. 10, n. sp. 13, and *rubroclavus*; see Figure 23). The classifier function accurately assigned all individuals to their proper species 100% of the time, while the results using jackknifing were more mixed (see Tables 9-10).

Summary
A total of 26 *Pseudoloxops* species from French Polynesia were found, with 3 of Knight's original 6 species confirmed and the remaining 23 species being new to science. The final diversity is summarized in Tables 11-13, and the species assignments for all ingroup specimens are given in Table 14. Figure 24 provides a phylogeny showing the relationships between all 26 species. Species descriptions follow below.

Species Descriptions

Below we describe 23 new species of *Pseudoloxops* and redescribe 3 of Knight's (1937) original 6 species. They are described in an order that follows the species phylogeny (Figure 24), starting from the base of the tree (*P. rubrocuneatus*). For each species, all specimens examined are listed along with their 8-digit database code for the American Museum of Natural History's Plant Bug Planetary Biodiversity Inventory (AMNH_PBI XXXXXXXX) and the institution where they are deposited (UCB=UC Berkeley's Essig Museum of Entomology; BPBM=Bernice P. Bishop Museum). Paratype collecting events (labels) are separated by //. All continuous morphological

measurements are given in millimeters, with the range for a trait followed by the mean ± standard deviation. Missing data are given as N/A; where there was a single specimen examined, a single number is provided. Distribution maps were created in ArcMap 10.1 using the program's basemap imagery.

***Pseudoloxops* Kirkaldy 1905**
Type species: *Capsus coccineus* Meyer-Dür, 1843, monotypic (nom. n. for *Loxops* Fieber, 1858, preocc. by *Loxops* Cabanis, 1847, Aves); Schuh 1995.

Synonyms:
Aretas Distant, 1909
Loxops Fieber, 1858
Zonodorellus Poppius, 1915

Generic description as in Linnavuori (1994) with the exception of color. Several species with bright red coloring and markings, but such coloration is not diagnostic for the genus, as some species have simple yellow or green color throughout. Body elongate-ovoid, with frons anteriorly projected and head flat in dorsal view. With the addition of this study, 60 species are now described in the genus, although dozens more (at minimum) await description (Gerry Cassis, personal communication).

Distribution: Afrotropical, Oriental, Palearctic, Sino-Japanese, Saharo-Arabian, and Oceania zoogeographic regions.

Pseudoloxops rubrocuneatus Knight, 1937 (Figures 25-28)

Material examined: Holotype: ♀, Tahiti, Society Islands. Tuauru River, one mile from sea, alt. 50 ft. A.M. Adamson. Sept. 5, 1928. Paratypes: Moorea Is. Pihaena, 17.4894°S 149.84723°W, 13 m, 09-12-2008, on *Terminalia catappa*, Brad Balukjian, 1 ♂ (AMNH_PBI 00384489) (UCB)// 22-02-2009, at blacklight, Brad Balukjian, 9 ♂ (AMNH_PBI 00384430, AMNH_PBI 00384439, AMNH_PBI 00384447, AMNH_PBI 00384446, AMNH_PBI 00384471, AMNH_PBI 00384473, AMNH_PBI 00384468, AMNH_PBI 00384440), 1 ♀ (AMNH_PBI 00384436) (UCB)//Tahiti Is. Motu Uta, 17.5342°S 149.5774°W, 17 m, 03 04 2009, on *Terminalia catappa*, Brad Balukjian, 1 ♂ (AMNH_PBI 00384431), 1 ♀ (AMNH_PBI 00384478) (UCB)//Tahiti Is.: Fare Hape Village, 17.6424°S 149.4429°W, 321 m, 04-04-2009, on *Hibiscus tiliaceus*, Brad Balukjian, 1 ♀ (AMNH_PBI 00384477) (UCB).

Other material examined: Moorea Is. Baie de Cook, Mar 1955, N. L. H. Krauss, 1 ♂ (AMNH_PBI 00043019) (BPBM)//Tehau Pt., 3 m, 24 Sep 1934, E. C. Zimmerman, 1 ♂ (AMNH_PBI 00042783) (BPBM)//Tahiti Is. Papeete, 0-100 m, 17.533°S 149.566°W, Dec 1977, N. L. H. Krauss, 1 ♀ (AMNH_PBI 00042784) (BPBM)//Point Venus, 19 Jan 1963, C. Yoshimoto and N.L.H. Krauss, 1 ♂ (AMNH_PBI 00042778) (BPBM).

Diagnosis

This species is polymorphic and cryptic (bearing superficial resemblance to *Pseudoloxops* n. sp. 1), but can be identified using canonical variates analysis on the shape of the left paramere (Figure 23).

Description

COLORATION: Two color morphs, one pale green/yellow throughout (Figure 26), the other with pale green/yellow and bright red markings (Figure 25). Head: Vertex pale yellow or with medial longitudinal red line connecting to two diagonal red lines and forming a "Y" or bird's foot pattern, sometimes with medial red dot on posterior margin; frons pale yellow with medial red dot or red Fu Manchu mustache pattern; clypeus pale yellow, sometimes with faint red longitudinal medial stripe or faint red transverse medial stripe; dorsal half of mandibular plate covered by red band, the rest yellow, sometimes completely yellow; dorsal half of maxillary plate covered by red band, the rest yellow. Antennae: AI yellow, sometimes with red dots at distal tip; AII pale yellow, sometimes with red at base and distal tip; AIII yellow, sometimes with red at distal tip; AIV yellow and brown at tip. Pronotum: Highly variable: sometimes completely yellow, sometimes yellow with brown tinging lateral corners at hind margin and faint thin red stripes laterally in posterior half, sometimes mostly red with yellow showing underneath, sometimes yellow with two lateral red stripes originating at posterior margin and extending two-thirds of the way towards anterior margin with medial red vitta posteriorly, sometimes yellow with scattered red specks. Mesoscutum: Yellow and dusky, sometimes with longitudinal medial and posterior red or brown markings, sometimes with medial red vitta and two lateral red vittae. Scutellum: Yellow/green, sometimes with anterior two-thirds red, posterior third yellow. Hemelytra: One color morph completely pale yellow/green except for dark red/brown at apex of cuneus and membrane pale with pale veins; second color morph with clavus mostly pale yellow with red markings anteriorly near junction with pronotum; corium yellow except for red markings in posterior region and margin where it meets the wing membrane, extending into cuneus; apex of cuneus red, anterior two thirds of cuneus pale yellow except for anterior red triangle, continuous with red coloring in corium; membrane veins red; membrane pale. Legs: Pale yellow.

STRUCTURE: Head: Head flat in dorsal view, vertex sometimes medially sulcate, frons projected anteriorly and clypeus not visible, posterior margin of head slightly carinate and rectilinear to convex, collar separating eyes from anterior margin of pronotum. Pronotum: Anterior margin sinuate and sometimes slightly carinate, posterior margin excavated, callar region slightly raised, disc flat. Mesoscutum: Exposed, about half of scutellum length, raised laterally and depressed medially. Scutellum: Flat. Male genitalia: Right paramere with ventral medial process with 4 or 6-8 teeth perpendicular to apophysis with 1-2 or 4 teeth (Figure 27c); spicule of aedeagus reaching near top of phallotheca and of medium width (Figure 27a); phallotheca glove-shaped with two lobes of unequal size (Figure 27a); left paramere with distinct basal process on sensory lobe (Figure 27b).

Measurements

Males (n=9): BL: 3.312-4.059 (3.61±0.25); BW: 1.012-1.396 (1.24±0.12); LL: 1.091-1.304 (1.2±0.08); PL: 0.374-0.474 (0.42±0.03); PW: 0.925-1.077 (0.99±0.06); AI: 0.384-0.517

(0.45±0.04); AII: 1.357-1.679 (1.55±0.12); AIII: 0.566-0.797 (0.64±0.07); AIV: 0.247-0.563 (0.47±0.13); HL: 0.311-0.442 (0.37±0.05); HW: 0.741-0.81 (0.76±0.03); VW: 0.297-0.344 (0.33±0.02); CL: 0.381-0.621 (0.48±0.07).

Females (n=4): BL: 3.669-3.966 (3.85±0.14); BW: 1.157-1.488 (1.33±0.14); LL: 1.223-1.398 (1.31±0.09); PL: 0.373-0.443 (0.42±0.03); PW: 0.951-1.106 (1.05±0.07); AI: 0.457-0.549 (0.51±0.04); AII: 1.459-1.706 (1.56±0.11); AIII: 0.687-0.713 (0.7±0.01); AIV: 0.512-0.54 (0.53±0.02); HL: 0.408-0.535 (0.44±0.06); HW: 0.668-0.719 (0.7±0.02); VW: 0.344-0.398 (0.37±0.02); CL: 0.526-0.593 (0.55±0.04).

Distribution

P. rubrocuneatus is known from one location near sea level on Moorea and two locations on Tahiti (Figure 28).

Plant Affiliation

P. rubrocuneatus has been collected on the flowers and young leaves of two plants, *Hibiscus tiliaceus* (Malvaceae) and *Terminalia catappa* (Combretaceae).

Remarks

Formerly known only from Tahiti, we have expanded *P. rubrocuneatus*' range to the neighboring island of Moorea. The species is polymorphic, with the two main color morphs sometimes co-occurring on the same plants. The all-green color morph was initially classified as *Pseudoloxops flavus* by Knight (1937), but our integrative analysis revealed this to simply be a variant of *P. rubrocuneatus*. We therefore synonymize *P. flavus*. For the red and green color morph, there is significant variation in the coloration of the pronotum. *P. rubrocuneatus* does not come out as monophyletic in our combined gene phylogeny (Figure 17), likely due to incomplete lineage sorting. It is sister to P. n. sp. 1, found in the Leeward Society Islands, and can only be distinguished based on molecular characters or a morphometric analysis of the left paramere. It is also 3% divergent from P. n. sp. 1 at CO1. In all phylogenetic analyses, *P. rubrocuneatus* comes out towards the base of the radiation, and is the only species in Tahiti and Moorea found at sea level. Its persistence in the face of human pressure may be due to its ability to use both native (*Hibiscus tiliaceus*) and introduced (*Terminalia catappa*) plants as hosts.

***Pseudoloxops* n. sp. 1** (Figures 29-31)

Material examined: Holotype: ♂, French Polynesia: Huahine Is. Circle-Island Road, 16.7296°S 151.037°W, 7 m, 31-05-2009, on *Hibiscus tiliaceus* det. Ravahere Taputuarai, Brad Balukjian, (AMNH_PBI 00384445) (UCB). Paratypes: Huahine Is. Circle-Island Road, 16.7296°S 151.037°W, 7 m, 31-05-2009, on *Hibiscus tiliaceus*, Brad Balukjian, 2 ♀ (AMNH_PBI 00384457, AMNH_PBI 00384460) (UCB).//Circle-Island Road, 16.7331°S 151.0008°W, 90 m, 30-05-2009, on *Hibiscus tiliaceus* Brad Balukjian, 2 ♀ (AMNH_PBI 00384455, AMNH_PBI 00384451), 1 ♂ (AMNH_PBI 00384452) (UCB).//Maupiti Is. Motu Pitiahe, 16.4811°S 152.2479°W, 17 m, 06-06-2009, on *Hibiscus tiliaceus* Brad Balukjian, 1 ♀ (AMNH_PBI

00384424), 1 ♂ (AMNH_PBI 00384484) (UCB).//Mt Nuupure, 16.447°S 152.2552°W, 362 m, 07-06-2009, on *Hibiscus tiliaceus* Brad Balukjian, 1 ♂ (AMNH_PBI 00384459) (UCB).//Mt Nuupure, 16.446°S 152.2506°W, 134 m, 07-06-2009, on *Triumfetta rhomboidea*, Brad Balukjian, 1 ♂ (AMNH_PBI 00384423) (UCB).//Mt Nuupure, 16.447°S 152.2552°W, 362 m, 07-06-2009, on *Allophylus rhomboidalis*, Brad Balukjian, 1 ♂, (AMNH_PBI 00384459) (UCB).

Diagnosis

This species can be recognized by its yellow-green base coloration and red vittae in the following areas: covering most of the scutellum, anterior portion of the clavus up to hind margin of pronotum, anterior portion of cuneus crossing into posterior region of corium. The shape of the left paramere is distinct (Figures 23, 30b), and the species forms a monophyletic group in our molecular phylogeny that is defined by node 3 (Figure 7).

Description

COLORATION: Head: Generally yellow; vertex pale yellow with red dot medially on posterior margin, sometimes with red medial longitudinal stripe originating at posterior margin and running along half the length of vertex, sometimes parallel to two longitudinal red stripes bordering eyes and connecting to form bird's foot; frons usually pale yellow, sometimes with medial red dot near top of clypeus or with red Fu Manchu mustache pattern; clypeus usually pale yellow, rarely with longitudinal red stripe on upper portion connecting to transverse red band ventrally; mandibular plate with dorsal half of mandibular plate covered by red band, the rest yellowish, rarely completely yellow; dorsal half of maxillary plate covered by red band, the rest yellowish, sometimes mostly brown or yellow. Antennae: AI-III yellow, often with red dots distally; AIV yellow. Pronotum: Variable; sometimes yellow with two longitudinal red stripes in posterior half, sometimes brown with medial yellow longitudinal stripe, sometimes completely yellow, sometimes brown/fuscous and somewhat transparent to reveal underlying medial red vitta and red stripes on lateral thirds. Mesoscutum: Variable, sometimes yellow and dusky with red markings posteriorly and longitudinal medial red stripe, sometimes yellow anteriorly and fuscous posteriorly, sometimes completely yellow, sometimes mostly red. Scutellum: Usually anterior two-thirds red with yellow in posterior third, sometimes yellow except for brown in anterior corners and medially along anterior margin. Hemelytra: clavus mostly pale yellow with red markings anteriorly near junction with pronotum; corium yellow except red in posterior region and margin where it meets the membrane, extending into cuneus; apex of cuneus red or black; membrane veins pale or red, sometimes with red dot in posterior corner of larger membrane cell; membrane pale. Legs: Pale yellow.

STRUCTURE: Head: Head flat in dorsal view with slight medial sulcation in vertex with frons swollen and projected anteriorly and clypeus not visible, collar separating eyes from anterior margin of pronotum. Pronotum: Anterior margin sinuate, posterior margin excavated, callar region slightly raised, disc flat. Mesoscutum: Exposed, slightly rounded into transverse ridge. Scutellum: Flat. Male Genitalia: Right paramere with ventral medial process with 4 or 7-8 teeth perpendicular to apophysis with 0-1 teeth (Figure 30c); spicule of aedeagus reaching near top of phallotheca and of medium width (Figure 30a); phallotheca glove-shaped with two lobes of unequal size (Figure 30a); left paramere with distinct basal process on sensory lobe (Figure 30b).

Measurements

Males (n=6): BL: 3.336-3.97 (3.59± 0.23); BW: 1.169-1.349 (1.24± 0.07); LL: 0.962-1.321 (1.21± 0.13); PL: 0.384-0.427 (0.41± 0.01); PW: 0.991-1.111 (1.04± 0.04); AI: 0.436-0.501 (0.47± 0.02); AII: 1.559-1.682 (1.63± 0.05); AIII: 0.493-0.73 (0.63± 0.08); AIV: 0.427-0.635 (0.52± 0.11); HL: 0.29-0.475 (0.39± 0.08); HW: 0.755-0.798 (0.78± 0.02); VW: 0.328-0.344 (0.34±0.01); CL: 0.431-0.527 (0.47±0.04).

Females (n=5): BL: 3.264-4.09 (3.79±0.35); BW: 1.139-1.491 (1.36±0.14); LL: 1.114-1.404 (1.26±0.12); PL: 0.358-0.432 (0.4±0.03); PW: 0.965-1.079 (1.01±0.04); AI: 0.449-0.529 (0.48±0.03); AII: 1.307-1.618 (1.44±0.13); AIII: 0.482-0.72 (0.63±0.09); AIV: 0.295-0.611 (0.5±0.14); HL: 0.356-0.48 (0.43±0.06); HW: 0.657-0.734 (0.71±0.03); VW: 0.339-0.379 (0.37±0.02); CL: 0.234-0.561 (0.46±0.13).

Distribution

P. n. sp. 1 is known from the islands of Huahine and Maupiti (Figure 31).

Plant Affiliation

P. n. sp. 1 has been collected on *Allophylus rhomboidalis* (Sapindaceae), *Hibiscus tiliaceus* (Malvaceae), and *Triumfetta rhomboidea* (Malvaceae). We collected a series of specimens on *H. tiliaceus* and consider it a likely host.

Remarks

P. n. sp. 1 superficially resembles one of the color morphs of *Pseudoloxops rubrocuneatus*, and we therefore consider it a cryptic species. It is restricted to the Leeward Society Islands, and we consider its disjunct distribution on Huahine and Maupiti (but not the intervening Raiatea) to be likely due to inadequate sampling time on Raiatea.

***Pseudoloxops* n. sp. 2** (Figures 32-34)

Material Examined: Holotype: ♂, French Polynesia: Tubuai Is. Mt Taitaa, 23.37018°S 149.46973°W, 324 m, 12-09-2007, on *Metrodisderon collina* det. Brad Balukjian, Brad Balukjian, (AMNH_PBI 00384425) (UCB). Paratype: Rurutu, Taatioe summit, 22.46302°S 151.139°W, 388 m, 18-11-2003, on *Metrosideros collina* and ferns, Ron Englund, 1 ♂.

Diagnosis

This species can be recognized by its simple yellow-green coloration and red pigment in the vein connecting the two cells of the wing membrane. Its male genitalia are also distinct, particularly the aedeagus and the shape of the left paramere (Figures 23, 33). The species forms a monophyletic group in our moleculaer phylogeny and can be diagnosed by the following synapomorphies at node 4 (Figure 7): Base 307: A→T; Base 339: A→G; Base 776: T→A; Base 1060: T→G.

Description

COLORATION: Head: Entire head pale yellow, except for red dot or red band on upper half of maxillary plate. Antennae: A1 yellow, sometimes with thin faint red longitudinal stripe; AII-III yellow except some black or brown distally; AIV yellow. Pronotum: Yellow. Mesoscutum: Yellow. Scutellum: Sometimes yellow, sometimes red with specks of yellow. Hemelytra: Green throughout, except red veins in membrane, with vein uniting 2 cells pale anteriorly; membrane pale. Legs: Yellow.

STRUCTURE: Head: Vertex flattened in dorsal view, frons and clypeus projected anteriorly with both visible from above; posterior margin of head capsule slightly carinate, slight sulcus medially in vertex, maxillary plate swollen; bucculae almost reaching posterior margin of head. Pronotum: Anterior margin slightly rounded and weakly sinuate; calli evident and weakly raised; disc flat to slightly rounded. Mesoscutum: Exposed and sometimes strongly rounded, sometimes sulcate medially, almost ½ length of scutellum. Scutellum: Flat to slightly raised. Male Genitalia: Right paramere with broad ventral medial process with 5 teeth perpendicular to apophysis with 3 teeth (Figure 33c); aedeagus with spicule of medium width reaching past top of phallotheca; phallotheca with single lobe (Figure 33a); left paramere without basal process (Figure 33b).

Measurements

Males (n=2): BL: 3.755-3.83 (3.79±0.05); BW: 1.21-1.216 (1.21±0.004); LL: 1.094-1.308 (1.20±0.15); PL: 0.397-0.417 (0.41±0.014); PW: 0.964-1.109 (1.04±0.10); AI: 0.455-0.486 (0.47±-0.02); AII: 1.625-1.752 (1.69±0.09); AIII: 0.632; AIV: 0.467; HL: 0.403-0.435 (0.42±0.02); HW: 0.717-0.753 (0.74±0.02); VW: 0.333-0.335 (0.33±0.01); CL: 0.5-0.529 (0.51±0.02).

Females Unknown.

Distribution

P. n. sp. 2 is known from 1 locality in Rurutu and 1 locality in Tubuai in the Austral Islands (Figure 34).

Plant Affiliation

The specimen from Rurutu was collected from a mix of ferns and *Metrosideros collina* (Myrtaceae), and the specimen from Tubuai was collected on *M. collina.*

Remarks

Along with P. n. sp. 16 from the island of Rimatara, this species represents the first record of *Pseudoloxops* in the Austral Islands. Despite the considerable distance between Rurutu and Tubuai, the individuals analyzed from these two islands are conspecific.

***Pseudoloxops* n. sp. 3** (Figures 35-37)

Material Examined: Holotype, ♂, French Polynesia: Huahine Is. Mt Pohuarahi, 16.7809°S 150.9763°W, 469 m, 02-06-2009, on *Mangifera indica*, det. by Brad Balukjian, Brad Balukjian, (AMNH_PBI 00384422) (UCB). Paratypes: Mt Pohuarahi, 16.7809°S 150.9763°W, 469 m, 02-06-2009, on *Mangifera indica*, Brad Balukjian, 3 ♂. (AMNH_PBI 00384435, AMNH_PBI 00384456, AMNH_PBI 00384461), 1 ♀ (AMNH_PBI 00384433) (UCB).//Trail to Mt Pohuarahi, 16.7807°S 150.9736°W, 375 m, 02-06-2009, on *Metrosideros collina*, Brad Balukjian, 1 ♀, (AMNH_PBI 00384458) (UCB).//Trail to Mt Pohuarahi, 16.7811°S 150.9724°W, 345 m, 02-06-2009, on *Glochidion* sp., Brad Balukjian, 2 ♀ (AMNH_PBI 00384421, AMNH_PBI 00384434) (UCB).

Diagnosis

This species can be most easily distinguished by the male genitalia, specifically the two large lobes of the phallotheca, the single lobe of the right paramere, and the thickened sensory lobe and apophysis of the left paramere (Figure 36). The species forms a monophyletic group in our phylogeny and can be recognized by the following synapomorphies at node 5 (Figure 7): Base 158: A→G; Base 159: A→G; Base 281: A→G; Base 357: A→G; Base 1034: T→C; Base 1040: C→G; Base 1042: A→C; Base 1043: T→A; Base 1217: A→G; Base 1239: T→C; Base 1307: T→C; Base 1361: T→C; Base 1382: T→C; Base 1415: A→G; Base 1619: C→T; Base 1646: C→T; Base 1661: A→G; Base 1724: A→G; Base 1745: A→G; Base 1892: T→G.

Description

COLORATION: Head: Completely green. Antennae: AI-IV yellow-green. Pronotum: All green, faint red stripes in lateral thirds. Mesoscutum: Green. Scutellum: Green, sometimes with faint red medial longitudinal stripe. Hemelytra: Green, cuneus with red dot at junction with medial wing membrane vein, cuneus with dark red at apex, red dot in posterior corner of larger membrane cell, wing veins green. Legs: Yellow-green.

STRUCTURE: Head: Vertex flat to slightly sulcate, posterior margin slightly carinate and rectilinear, frons projected and swollen, collar present. Pronotum: Anterior margin carinate and sinuate, calli evident, disc pretty flat. Mesoscutum: Slightly elevated laterally or with transverse ridge. Scutellum: Flat. Male Genitalia: Right paramere with single lobe with 2 teeth on one side and 3 teeth on the other (Figure 36c); aedeagus with single thick spicule; phallotheca with two large lobes of about equal size and concave medially (Figure 36a); left paramere with thickened sensory lobe and apophysis and sensory lobe lacking basal process (Figure 36b).

Measurements

Males (n=4): BL: 3.055-4.128 (3.62±0.44); BW: 1.127-1.447 (1.27±0.15); LL: 1.08-1.255 (1.17±0.07); PL: 0.353-0.418 (0.39±0.03); PW: 1.048-1.181 (1.09±0.06); AI: 0.439-0.501 (0.46±0.03); AII: 1.251-1.673 (1.54±0.20); AIII: 0.537-0.761 (0.68±0.10); AIV: 0.545; HL: 0.31-0.49 (0.39±0.08); HW: 0.726-0.797 (0.75±0.03); VW: 0.326-0.42 (0.37±0.04); CL: 0.418-0.507 (0.47±0.04).

Femlaes (n=3): BL: 3.616-3.832 (3.71±0.11); BW: 1.028-1.394 (1.27±0.21); LL: 1.093-1.239 (1.19±0.08); PL: 0.37-0.399 (0.39±0.2); PW: 0.993-1.104 (1.03±0.06); AI: 0.514; AII: 1.146; AIII: 0.677; AIV: N/A; HL: 0.435-0.474 (0.45±0.02)' HW: 0.667-0.722 (0.70±0.03); VW: 0.369-0.408 (0.39±0.02); CL: 0.402-0.491 (0.45±0.05).

Distribution

This species is known from 3 localities on the island of Huahine (Figure 37).

Plant Affiliation

We collected this species from 3 plants, including the European introduction *Mangifera indica* (Anacardiaceae) and the natives *Glochidion* sp. (Euphorbiaceae) and *Metrosideros collina* (Myrtaceae).

Remarks

This is one of several species in the radiation with simple green-yellow coloring, and is endemic to Huahine. It appears to use both native and introduced plants, as we collected multiple specimens from *Mangifera indica* and *Glochidion* sp. It is sister to n. sp. 4, which is known from the nearby islands of Raiatea and Maupiti.

***Pseudoloxops* n. sp. 4** (Figures 38-40)

Material Examined: Holotype: ♂, French Polynesia: Raiatea Is. Baie Faaroa, 16.8383°S 151.4205°W, 16 m, 09-03-2009, *Persea americana*, det. by Brad Balukjian, Brad Balukjian, (AMNH_PBI 00384448) (UCB). Paratypes: Baie Faaroa, 16.8329°S 151.4206°W, 8 m, 09-03-2009, on *Inga feuillei*, Brad Balukjian, 1 ♀, (AMNH_PBI 00384479) (UCB).//Circle-Island Road, 16.8892°S 151.4586°W, 12 m, 10-03-2009, on *Inocarpus fagifer*, Brad Balukjian, 1 ♂ (AMNH_PBI 00384449) (UCB).

Diagnosis

This species can be recognized by the shape and structure of the male genitalia, specifically the shape of the left paramere, the three-lobed phallotheca, and the single lobe of the right paramere (Figure 39). The species forms a monophyletic group in our phylogeny and can be recognized by the following synapomorphies at the node containing the clade with putative species 6 and 7 (Figure 7): Base 239: T→A; Base 339: A→G.

Description

COLORATION: Head: Yellowish throughout. Antennae: AI yellow, AII-IV brownish. Pronotum: Yellowish anteriorly, more green posteriorly, faint hint of red anteriorly in lateral thirds. Mesoscutum: Yellow. Scutellum: Yellowish, sometimes with faint red medial longitudinal stripe. Hemelytra: Clavus green, corium green, cuneus with red dot at posterior margin where it meets medial vein of wing membrane; dark red/brown at apex of cuneus,

membrane pale with green or pale veins, red dot at posterior junction of two membrane veins. Legs: Yellow.

STRUCTURE: Head: Posterior margin slightly carinate and rectilinear, vertex grooved in bird's foot pattern, frons projected and striated and swollen. Eyes are slightly wider than anterior margin of pronotum; collar evident. Pronotum: Anterior margin slightly sinuate, calli evident, disc mostly flat; posterior margin slightly convex. Mesoscutum: Slightly elevated laterally. Scutellum: Flat. Male Genitalia: Right paramere with single lobe with 6 teeth (Figure 39c); aedeagus with medium-width spicule; phallotheca with three lobes, one large, one medium-sized, one very thin (Figure 39a); left paramere with sensory lobe lacking basal process (Figure 39b),

Measurements

Males (n=2): BL: 3.871-4.057 (3.96±0.13); BW: 1.398-1.434 (1.42±0.03); LL: 1.187-1.296 (1.24±0.08); PL: 0.411-0.449 (0.43±0.03); PW: 1.092-1.147 (1.12±0.04); AI: 0.467-0.524 (0.5±0.04); AII: 1.435-1.566 (1.50±0.09); AIII: 0.667-0.691 (0.68±0.02); AIV: 0.597; HL: 0.434-0.491 (0.46±0.04); HW: 0.777-0.793 (0.79±0.01); VW: 0.359-0.37 (0.36±0.008); CL: 0.445-0.527 (0.49±0.06).

Females (n=2): BL: 3.514-3.722 (3.62±0.15); BW: 1.207-1.413 (1.31±0.15); LL: 1.167-1.243 (1.21±0.05); PL: 0.37-0.385 (0.38±0.01); PW: 0.997-1.059 (1.03±0.04); AI: 0.427-0.492 (0.46±0.05); AII: 1.154-1.596 (1.38±0.31); AIII: 0.587-0.703 (0.65±0.08); AIV: 0.49-0.586 (0.54±0.07); HL: 0.372-0.471 (0.42±0.07); HW: 0.698-0.702 (0.7±0.003); VW: 0.392-0.401 (0.40±0.006); CL: 0.445-0.543 (0.49±0.07).

Distribution

This species is known from three localities on Raiatea and one locality on Maupiti (Figure 40).

Plant Affiliation

This species was collected from *Persea americana* (Lauraceae), *Inga feuillei* (Mimosaceae), and *Inocarpus fagifer* (Fabaceae).

Remarks

This species superficially resembles its sister species, *Pseudoloxops* n. sp. 3, but varies greatly in the shape and structure of the aedeagus and left paramere. This is one of the few species found at sea level, and has only been collected from introduced plants.

***Pseudoloxops* n. sp. 5** (Figures 41-42)

Material Examined: Holotype, ♀, French Polynesia: Tahiti Is. Mt. Aorai, 17.59367°S 149.50056°W, 1449 m, 21-06-2011, on *Weinmannia parviflora*, det. by Ravahere Taputuarai, Brad Balukjian, (AMNH_PBI 00384530) (UCB). Paratype: Plateau Taravao, 17.79851°S

149.23677°W, 1215 m, 08-06-2011, on *Ascarina polystachya*, Brad Balukjian, 1 ♀, (AMNH_PBI 00384548) (UCB).

Diagnosis

This species can be recognized by its complete lack of red markings and its first antennal segment colored red on one side and yellow on the other. The species forms a monophyletic group in our phylogeny and can be recognized by the following synapomorphies at node 8 (Figure 7): Base 136: G→A; Base 242: A→G; Base 264: A→T; Base 269: T→C; Base 274: A→T; Base 277: T→A; Base 1013: A→G; Base 1190: T→C; Base 1250: T→C; Base 1328: C→T; Base 1457: A→G; Base 1508: T→C; Base 1526: A→G; Base 1661: A→G; Base 1760: T→A; Base 1832: T→A; Base 1857: A→G; Base 1889: T→C; Base 1913: A→G; Base 1922: C→T; Base 1925: C→T; Base 1928: A→G.

Description

COLORATION: Head: Completely yellow. Antennae: AI red on one side yellow on the other; AII-IV uniformly yellow. Pronotum: Yellow. Mesoscutum: Yellow. Scutellum: Yellow. Hemelytra: Pale green; wing membrane veins green. Legs: Yellow.

STRUCTURE: Head: Vertex slightly rounded with medial sulcus, frons swollen, both frons and clypeus visible from above. Pronotum: Anterior margin slightly sinuate and carinate, with calli visible; disc slightly rounded. Mesoscutum: Raised medially. Scutellum: Flat.

Measurements

No males known.

Females (n=2): BL: 3.449-4.821 (4.14±0.97); BW: 0.862-1.482 (1.17±0.44); LL: 1.189-1.457 (1.32±0.19); PL: 0.515-0.532 (0.52±0.01); PW: 1.298-1.326 (1.31±0.02); AI: 0.51-0.532 (0.52±0.02); AII: 1.721-1.901 (1.81±0.13); AIII: 0.896-0.951 (0.92±0.04); AIV: 0.664-0.674 (0.67±0.007); HL: 0.459-0.466 (0.46±0.005); HW: 0.858-0.859 (0.859±0.001); VW: 0.484-0.487 (0.49±0.002); CL: 0.415.

Distribution

This species is known from two localities on the island of Tahiti (Figure 42).

Plant Affiliation

This species is known from 2 species: *Ascarina polystachya* (Chloranthaceae) and *Weinmannia parviflora* (Cunoniaceae).

Remarks

This is one of several species with simple yellow-green coloration and lacking any red markings. It is confined to high elevation cloud forest on Tahiti, although its distribution is quite disjunct. Only females are known.

***Pseudoloxops* n. sp. 6** (Figures 43-44)

Material Examined: Holotype, ♀, French Polynesia: Tahiti Is. Pic Vert, 17.59093°S 149.54143°W, 1097 m, 12-06-2011, on *Vaccinium cereum*, det. by Ravahere Taputuarai, Brad Balukjian, (AMNH_PBI 00384549) (UCB). Paratypes: Pic Vert, 17.59177°S 149.54047°W, 1121 m, 01-10-2008, on *Myrsine* sp., det. by Ravahere Taputuarai, Brad Balukjian, 1 ♀, (AMNH_PBI 00384475) (UCB).//Pic Vert, 01-10-2008, Kari Roesch Goodman, 1 ♀ (AMNH_PBI 00384462) (UCB).

Diagnosis

This species can be recognized by its uniform yellow/green color and black or red markings at the apex of the cuneus. It forms a monophyletic group in our phylogeny and can be recognized by the following synapomorphies at node 9 (Figure 7): Base 274: A→G; Base 1042: A→G; Base 1238: A→C; Base 1244: T→A; Base 1286: T→C; Base 1412: C→T; Base 1466: T→C; Base 1526: A→T; Base 1610: T→C; Base 1619: C→T; Base 1670: T→C; Base 1754: T→C; Base 1820: A→G; Base 1832: T→C.

Description

COLORATION: Head: Completely pale yellow. Antenna: AI-AIV pale yellow. Pronotum: Yellow. Scutellum: Yellow. Hemelytra: Yellow, more transparent medially; cuneus yellow with black or red at apex; wing membrane veins pale yellow or green. Legs: Yellow.

STRUCTURE: Head: Vertex flat with medial sulcus, frons swollen and projected forward; maxillary plate swollen. Pronotum: Anterior margin carinate and sinuate; calli evident; eyes wider than anterior margin of pronotum; disc flat to slightly rounded. Mesoscutum: Exposed, almost as long as scutellum; slightly elevated or raised medially. Scutellum: Flat.

Measurements

No males known.

Females (n=3): BL: 4.985-5.215 (5.09±0.12); BW: 1.583-1.786 (1.70±0.11); LL: 1.099-1.263 (1.21±0.09); PL: 0.473-0.53 (0.50±0.03); PW: 1.241-1.325 (1.29±0.04); AI: 0.364-0.655 (0.54±0.15); AII: 1.835-1.973 (1.91±0.07); AIII: 0.858-1.205 (1.0±0.18); AIV: 0.266-0.797 (0.58±0.28); HL: 0.503-0.557 (0.52±0.03); HW: 0.791-0.835 (0.81±0.02); VW: 0.422-0.441 (0.43±0.01); CL: 0.623-0.733 (0.69±0.06).

Distribution

This species is only known from Pic Vert on Tahiti (Figure 44).

Plant Affiliation

This species is known from two species: *Myrsine* sp. (Myrsinaceae) and *Vaccinium cereum* (Ericaceae).

Remarks

This is one of the largest species of *Pseudoloxops* in French Polynesia, with a mean body length of 5.09 mm. It is confined to the high-elevation cloud forest of Pic Vert on Tahiti, and is one of several species with plain green/yellow coloration.

***Pseudoloxops* n. sp. 7** (Figure 45-46)

Material Examined: Holotype, ♀, French Polynesia: Tahiti Is. Pic Vert, 17.59177°S 149.54047°W, 1121 m, 01-10-2008, on Myrsine sp., det. by Ravahere Taputuarai, Brad Balukjian, (AMNH_PBI 00384464) (UCB).

Diagnosis
This species is very similar in appearance to n. sp. 6, but lacks any color in the cuneus. It is known from a single specimen (Z51), which can be recognized in our phylogeny by the following synapomorphies (Figure 7): Base 1040: C→T; Base 1223: C→T; Base 1241: A→G; Base 1277: A→G; Base 1313: T→C; Base 1331: C→T; Base 1427: C→T; Base 1547: A→C; Base 1628: T→C; Base 1745: A→G; Base 1760: T→C; Base 1781: T→C; Base 1817: T→C; Base 1916: A→G; Base 1949: A→G.

Description

COLORATION: Head: Completely pale yellow. Antenna: AI pale yellow; AII-III pale yellow with some brown apically; AIV missing. Pronotum: Yellow. Scutellum: Yellow. Hemelytra: Yellow, more transparent in middle; cuneus yellow; wing membrane veins pale yellow. Legs: Missing.

STRUCTURE: Head: Vertex flattened, frons swollen and projected forward. Pronotum: Anterior margin carinate; calli evident; eyes wider than anterior margin of pronotum. Mesoscutum: Exposed, almost as long as scutellum; slightly elevated. Scutellum: Slightly elevated.

Measurements:

No males known.

Females (n=1): BL: 4.898; BW: 2.136; LL: 1.44, PL: 0.551; PW: 1.304; AI: 0.642; AII: 2.096; AIII: 1.115; AIV: Missing; HL: 0.413; HW: 0.81; VW: 0.442; CL: 0.721.

Distribution

This species is known from a single locality, Pic Vert on Tahiti (Figure 46).

Plant Affiliation

The single specimen was taken from *Myrsine* sp. (Myrsinaceae).

Remarks

Despite their superficial morphological similarity and ecological similarity (both are associated with *Myrsine* sp.), this species and its sister, n. sp. 6, are 2.7% distinct at CO1 and cluster separately in our dendrogram based on continuous morphological traits. This new species is known from only a single female.

***Pseudoloxops* n. sp. 8** (Figures 47-49)

Material Examined: Holotype, ♂, French Polynesia: Moorea Is. Mt Rotui, 17.5074°S 149.8401°W, 822 m, 05-11-2008, collected at blacklight, Brad Balukjian, (AMNH_PBI 00384470) (UCB). Paratypes: Mt Rotui, 17.5074°S 149.8401°W, 822 m, 05-11-2008, at blacklight, Brad Balukjian, 1 ♀ (AMNH_PBI 00384443) (UCB).//Mt Rotui, 17.5087°S 149.83916°W, 876 m, 05-11-2008, on *Metrosideros collina*, Brad Balukjian, 1 ♀ (AMNH_PBI 00384482) (UCB).//Mt Tohiea, 17.55191°S 149.821°W, 1120 m, 23-09-2009, at blacklight, Peter Oboyski, 1 ♂, (AMNH_PBI 00384497) (UCB).//Mt Rotui, 17.5087°S 149.83916°W, 876 m, 05-11-2008, at blacklight, Brad Balukjian, 1 ♂ (AMNH_PBI 00384492) (UCB).// Mt Rotui, 17.50765°S 149.84005°W, 845 m, 05-11-2008, on *Alyxia* sp., Curtis Ewing, 1 ♀ (AMNH_PBI 00384486) (UCB).//Mt Mouaputa, 17.52957°S 149.8031°W, 475 m, 08-11-2008, at blacklight, Curtis Ewing, Light Trap, 1 ♀, (AMNH_PBI 00384485) (UCB).

Diagnosis

This species can be identified by a combination of characters in the male genitalia, specifically the right paramere having no teeth, the aedeagus having a single, thin, curling spicule, and the shape of the left paramere (Figure 48). It forms a monophyletic group in our phylogeny that is defined by node 11 (Figure 7).

Description

COLORATION: Head: Yellowish throughout. Antennae: AI yellow, AII-IV tan, brownish. Pronotum: Yellow-green, with anterior half more yellow, posterior half more green. Mesoscutum: Yellow. Scutellum: Greenish. Hemelytra: Clavus, corium, and cuneus all green; cuneus with dark red/brown at apex; wing membrane pale with green veins. Legs: Yellow-green.

STRUCTURE: Head: Posterior margin slightly carinate and rectilinear, vertex slightly depressed, frons projected and striated and swollen. Eyes are slightly wider than anterior margin

of pronotum; collar slightly evident. Pronotum: Anterior margin rectilinear, calli evident, disc mostly flat; posterior margin slightly convex. Mesoscutum: Flat to transverse ridge. Scutellum: Flat. Male Genitalia: Right paramere with ventral medial process perpendicular to apophysis, neither having any teeth (Figure 48c); aedeagus with curling, thin spicule extending far past the distal margin of the phallotheca; phallotheca with a single lobe (Figure 48a); left paramere with sensory lobe lacking basal process (Figure 48b).

Measurements

Males (n=3): BL: 4.187-4.631 (4.45±0.23); BW: 1.135-1.581 (1.39±0.23); LL: 1.067-1.281 (1.18±0.11); PL: 0.39-0.495 (0.46±0.06); PW: 1.165-1.235 (1.19±0.04); AI: 0.39-0.556 (0.50±0.09); AII: 1.617-1.931 (1.76±0.16); AIII: 0.818-0.944 (0.89±0.06); AIV: 0.517-0.724 (0.62±0.15); HL: 0.358-0.575 (0.46±0.11); HW: 0.827-0.866 (0.84±0.02); VW: 0.413-0.429 (0.42±0.01); CL: 0.509-0.55 (0.53±0.02).

Females (n=4): BL: 4.257-4.645 (4.46±0.18); BW: 1.347-1.708 (1.58±0.16); LL: 1.282-1.402 (1.33±0.05); PL: 0.423-0.497 (0.46±0.03); PW: 1.113-1.313 (1.22±0.09); AI: 0.541-0.561 (0.55±0.01); AII: 1.659-1.797 (1.73±0.07); AIII: 0.767-0.924 (0.87±0.09); AIV: 0.603; HL: 0.328-0.495 (0.42±0.07); HW: 0.767-0.833 (0.79±0.03); VW: 0.448-0.478 (0.46±0.01); CL: 0.458-0.629 (0.56±0.07).

Distribution

This species is known from Mt. Rotui, Mt. Mouaputa, and Mt. Tohiea on the island of Moorea (Figure 49).

Plant Affiliation

Several of the specimens were collected at blacklights, but we did collect one from *Alyxia* sp. (Apocynaceae) and one from M*etrosideros collina* (Myrtaceae).

Remarks

This species is endemic to the island of Moorea, and is found on three of the island's major mountain massifs. Despite the existence of discrete populations on these mountains, there is apparently enough gene flow for this to remain one cohesive species.

***Pseudoloxops* n. sp. 9** (Figures 50-52)

Material Examined: Holotype: ♂, French Polynesia: Tahaa Is. Tapuamu Village, 16.62647°S 151.52383°W, 171 m, 18-06-2011, on *Nephrolepis hirsutula*, det. by Jean-Yves Meyer, Brad Balukjian, (AMNH_PBI 00384711) (UCB). Paratypes: Tahaa Is. Tapuamu Village, 16.62647°S 151.52383°W, 171 m, 18-06-2011, on *Nephrolepis hirsutula*, Brad Balukjian, 2 ♀ (AMNH_PBI 00384710, AMNH_PBI 00384706) (UCB).

Diagnosis

This species can be recognized by its unique pattern of red coloration on the hemleytra and the combination of a thin spicule in the aedeagus and phallotheca with two lobes of equal size (Figure 51). The species forms a monophyletic group in our phylogeny that is defined by node 12 (Figure 7).

Description

COLORATION: Head: Vertex yellow except for medial red line and two parallel red lines bordering eyes, sometimes connecting to form bird's foot pattern; frons yellow with red Fu Manchu mustache shape; clypeus yellow with crossing red hockey stick-shaped stripes meeting in medial longitudinal stripe and transverse medial red stripe with yellow ventrally; dorsal half of mandibular plate red, lower half yellow; most of maxillary plate reddish black except for small spot ventrally. Antennae: AI red; AII yellow with red at base; AIII-IV yellow. Pronotum: Yellow with lateral thirds red/black (black basally). Mesoscutum: Yellow. Scutellum: Yellow. Hemelytra: Clavus red/black and yellowish towards claval suture; corium yellow except for two round red vittae adjacent to posterior part of clavus; cuneus red/black in distal third of cuneus, yellow in anterior two-thirds; red dot in anterior part of cuneus at junction with medial vein of membrane cells; membrane veins red and dusky. Legs: Yellow.

STRUCTURE: Head: Posterior margin rectilinear and slightly carinate; slight medial sulcation in vertex; frons very swollen and projected forward. Pronotum: Collar evident, anterior margin slightly sinuate and calli evident, disc slightly rounded. Mesoscutum: Transverse ridge. Scutellum: Slightly raised. Male Genitalia: Right paramere with ventral medial process with 8 teeth perpendicular to single-lobed apophysis with 5 teeth (Figure 51c); aedeagus with single, sickle-shaped, thin-width spicule; phallotheca with two lobes of equal size (Figure 51a); left paramere's sensory lobe rounded basally (Figure 51b).

Measurements

No measurements available for males (no complete specimens).

Females (n=2): BL: 3.935; BW: 1.202; LL: 1.392-1.469 (1.43±0.05); PL: 0.411-0.425 (0.42±0.01); PW: 0.988-1.025 (1.01±0.03); AI: 0.551-0.587 (0.57±0.03); AII: 1.582-1.586 (1.58±0.002); AIII: 0.522-0.637 (0.58±0.08); AIV: 0.672-0.712 (0.69±0.03); HL: 0.468-0.484 (0.48±0.01); HW: 0.675-0.678 (0.68±0.002); VW: 0.339-0.351 (0.35±0.008); CL: 0.533-0.549 (0.54±0.01).

Distribution

This species is known from two localities on the island of Tahaa (Figure 52).

Plant Affiliation

All three specimens were collected off of the fern *Nephrolepis hirsutula* (Nephrolepidaceae).

Remarks

This species is endemic to the island of Tahaa and has a distinct color pattern on the hemelytra resembling a combination of *Pseudoloxops rubroclavus* and *Pseudoloxops* n. sp. 23.

***Pseudoloxops* n. sp. 10** (Figures 53-55)

Material Examined: Holotype, ♂, French Polynesia: Tahiti Is. Mt. Aorai, 17.60328°S 149.49395°W, 1886 m, 22-06-2011, on *Paesia divaricatissima*, det. by Jean-Yves Meyer, Brad Balukjian, (AMNH_PBI 00384708) (UCB). Paratypes: Tahiti Is. Mt. Aorai, 17.60328°S 149.49395°W, 1886 m, 22-06-2011, on *Paesia divaricatissima*, Brad Balukjian, 1 ♀ (AMNH_PBI 00384540) (UCB).//Mt. Aorai, 17.60365°S 149.49422°W, 1913 m, 22-06-2011, on *Paesia divaricatissima*, Brad Balukjian, 1 ♂, (AMNH_PBI 00384712) (UCB).

Diagnosis

This species can be recognized by the coloration of the hemelytra, with red to black covering the corium except for two large yellow areas posteriorly; it is superficially identical to n. sp. 12, but can be distinguished using molecular characters. This species forms a monophyletic group in our phylogeny that is defined by node 13 (Figure 7).

Description

COLORATION: Head: Vertex uniformly yellow; frons mostly yellow with some red laterally; clypeus yellow with two dorsal red transverse bands or two medial red dots; dorsal half of mandibular plate covered by red band, yellow ventrally; maxillary plate mostly blackish-red except for some yellow ventrally. Antennae: AI dark red on one side, black on the other or entirely red; AII dark red at base turning reddish then yellow for remainder of length until brown or black at apex; AIII-AIV yellow/brown to black. Pronotum: Yellow, lateral thirds red, black towards lateral margins. Mesoscutum: Yellow, sometimes with red in anterior corners and red medial vitta posteriorly resembling a birds' outstretched wings, sometimes with lateral red stripe in posterior half. Scutellum: Completely red. Hemelytra: Clavus mostly pale yellow with red coloration anteriorly near junction with pronotum; corium red to maroon in anterior two-thirds, sometimes fading from black to red; posterior third of corium yellow turning to red near margin of claval commissure and posterior margin of wing membrane; cuneus pale yellow in anterior lateral quarter, the rest red, sometimes turning to black towards apex of cuneus; membrane veins red; membrane dusky. Legs: Distal two-thirds of metafemora red, the rest yellow.

STRUCTURE: Head: Posterior margin slightly carinate and slightly rectilinear; vertex with broad medial sulcus; frons swollen and visible from above. Pronotum: Anterior margin slightly carinate and sinuate, with visible raised calli; disc slightly raised. Mesoscutum: Lateral medial transverse ridge. Scutellum: Flat. Male Genitalia: Right paramere with ventral medial process with 7-8 teeth perpendicular to apophysis with 1-2 teeth (Figure 54c); aedeagus with single

medium-width spicule; phallotheca with a single lobe and triangular flap towards base (Figure 54a); left paramere with sensory lobe lacking basal process (Figure 54b).

Measurements

Males (n=2): BL: 4.086-4.132 (4.11±0.03); BW: 1.246-1.346 (1.30±0.07); LL: 1.26-1.442 (1.35±0.13); PL: 0.43-0.489 (0.46±0.04); PW: 1.009-1.107 (1.06±0.07); AI: 0.467-0.47 (0.47±0.002); AII: 1.357-1.523 (1.44±0.12); AIII: 0.736-0.761 (0.75±0.02); AIV: 0.325; HL: 0.408-0.481 (0.44±0.05); HW: 0.659-0.682 (0.67±0.02); VW: 0.35-0.357 (0.35±0.005); CL: 0.573-0.576 (0.57±0.002).

Females (n=1): BL: 4.608; BW: 1.524; LL: 1.254; PL: 0.48; PW: 1.137; AI: 0.436; AII: 1.47; AIII: 0.749; AIV: 0.471; HL: 0.55; HW: 0.73; VW: 0.415; CL: 0.547.

Distribution

This species is only known from Mt. Aorai on Tahiti.

Plant Affiliation

This species is known exclusively from the fern *Paesia divaricatissima* (Dennstaedtiaceae).

Remarks

This species is part of a larger clade that is affiliated with ferns. It is endemic to Mt. Aorai on Tahiti, and is found near the peak in cloud forest habitat. It appears to be exclusive to *Paesia divaricatissima*, but more sampling is needed to confirm this.

***Pseudoloxops* n. sp. 11** (Figure 56-58)

Material Examined: Holotype, ♂, French Polynesia: Tahiti Is. Mt. Aorai, 17.59327°S 149.50104°W, 1433 m, 21-06-2011, on *Leptecophylla pomarae*, det. by Jean-Yves Meyer, Brad Balukjian, (AMNH_PBI 00384531) (UCB). Paratypes: Mt. Aorai, 17.59327°S 149.50104°W, 1433 m, 21-06-2011, on *Leptecophylla pomarae*, Brad Balukjian, 2 ♀, (AMNH_PBI 00384533, AMNH_PBI 00384532) (UCB).//Mt. Aorai, 17.61082°S 149.49447°W, 2029 m, 22-06-2011, on *Leptecophylla pomarae*, Brad Balukjian, 1 ♂ (AMNH_PBI 00384524) (UCB).//Mt. Aorai, 17.5957°S 149.4984°W, 1615 m, 21-06-2011, on *Leptecophylla pomarae*, Brad Balukjian, 2 ♀ (AMNH_PBI 00384688, AMNH_PBI 00384715), 1 ♂ (AMNH_PBI 00384687) (UCB).

Diagnosis

This species can be recognized by the shape of the left paramere and the structure of the aedeagus (similar to n. sp. 10 but lacking the triangular flap near the base; Figure 57). It forms a monophyletic group in our phylogeny that is defined by node 14 (Figure 7).

Description

COLORATION: Head: Vertex and frons universally yellow; clypeus pale yellow; mandibular plate and maxillary plate yellow. Antennae: AI red, sometimes only on one side; AII-AIII yellow sometimes with brown at apex; AIV yellow. Pronotum: Yellow, lateral thirds faint red. Mesoscutum: Yellow-green. Scutellum: Yellow-green throughout. Hemelytra: Entire region pale green; wing membrane pale; membrane veins pale. Legs: Yellow, apex of metafemora brown.

STRUCTURE: Head: Vertex slightly sulcate, frons projected forward, slightly swollen and visible in dorsal view; clypeus not visible from above; posterior margin slightly sinuate and carinate; maxillary plate only slightly swollen. Pronotum: Anterior margin slightly sinuate and carinate; calli barely evident; disc slightly rounded; posterior margin slightly excavate. Mesoscutum: Raised medially, sloping sharply towards scutellum. Scutellum: Flat to elevated. Male Genitalia: Right paramere with ventral medial process with 3, 5, or 8 teeth perpendicular to apophysis with 2-4 teeth (Figure 57c); aedeagus with single medium-width spicule; phallotheca with a single lobe (Figure 57a); left paramere with sensory lobe lacking basal process (Figure 57b).

Measurements

Males (n=3): BL: 3.867-4.196 (4.05±0.17); BW: 1.161-1.289 (1.20±0.07); LL: 1.037-1.268 (1.15±0.12); PL: 0.445-0.553 (0.51±0.06); PW: 1.082-1.143 (1.10±0.03); AI: 0.422-0.494 (0.45±0.04); AII: 1.285-1.379 (1.33±0.05); AIII: 0.552-0.627 (0.59±0.04); AIV: 0.454-0.563 (0.53±0.06); HL: 0.423-0.497 (0.46±0.04); HW: 0.665-0.745 (0.70±0.04); VW: 0.369-0.41 (0.39±0.02); CL: 0.573-0.645 (0.60±0.04).

Females (n=4): BL: 3.934-4.195 (4.10±0.14); BW: 1.122-1.343 (1.24±0.11); LL: 1.2-1.499 (1.35±0.14); PL: 0.356-0.486 (0.44±0.06); PW: 0.994-1.138 (1.08±0.06); AI: 0.366-0.481 (0.42±0.05); AII: 0.956-1.46 (1.29±0.24); AIII: 0.591-0.694 (0.63±0.04); AIV: 0.361-0.52 (0.43±0.08); HL: 0.408-0.444 (0.42±0.02); HW: 0.639-0.686 (0.67±0.02); VW: 0.372-0.402 (0.39±0.01); CL: 0.482-0.588 (0.55±0.06).

Distribution

This species is known only from Mt. Aorai on the island of Tahiti (Figure 58).

Plant Affiliation

All specimens of these species were collected from the angiosperm *Leptecophylla pomarae* (Ericaceae).

Remarks

Despite being most closely related to species affiliated with ferns, this species appears to be specialized on the cloud forest angiosperm *Leptecophylla pomarae*, representing a shift back to

angiosperms from ferns. This species superficially resembles n. sp. 19, with its green hemelytra, and yellowish pronotum with red stripes in the lateral thirds. It is found at the summit of Mt. Aorai, but is only known from this one massif on Tahiti.

***Pseudoloxops* n. sp. 12** (Figures 59-60)

Material Examined: Holotype, ♀, French Polynesia: Tahiti Is. Mt. Aorai, 17.6018°S 149.4937°W, 1873 m, 22-06-2011, on *Paesia divaricatissima*, det. by Jean-Yves Meyer, Brad Balukjian, (AMNH_PBI 00384709) (UCB). Paratype: Tahiti Is. Mt. Aorai, 17.6018°S 149.4937°W, 1873 m, 22-06-2011, on *Paesia divaricatissima*, Brad Balukjian, 1 ♀ (AMNH_PBI 00384689) (UCB).

Diagnosis

This species superficially resembles n. sp. 10 in the coloration of the pronotum and hemelytra. However it forms a monophyletic group in our phylogeny and can be recognized by the following molecular synapomorphies at node 14 (Figure 7): Base 136: G→A; Base 1295: C→A; Base 1412: T→C; Base 1443: C→T; Base 1505: C→T; Base 1517: C→T; Base 1610: T→C.

Description

COLORATION: Head: Generally yellow; frons and vertex uniformly yellow except for red vittae behind eyes; clypeus yellow except for red transverse band ventrally; most of mandibular plate covered by red band, yellow ventrally; maxillary plate mostly blackish-red except for yellow ventrally. Antennae: AI dark red on one side, black on the other; AII red at base and then yellow flecked with red for most of the length ending with black apically; AIII-AIV yellow/brown/black. Pronotum: Yellow, lateral thirds red. Mesoscutum: Yellow with a medial red vitta in posterior portion. Scutellum: Completely red except in very anterior corners. Hemelytra: Clavus mostly pale yellow with red coloration anteriorly near junction with pronotum; corium red to maroon in anterior two-thirds except for medial yellow section, posterior third of corium yellow except for red along medial and posterior margins; cuneus pale yellow anteriorly and red posteriorly; wing membrane veins red; membrane dusky. Legs: Distal two-thirds of metafemora red, the rest yellow.

STRUCTURE: Head: Vertex flattened in dorsal view, frons and clypeus projected anteriorly with both visible from above; posterior margin of head capsule slightly carinate and rectilinear, slight sulcus medially in vertex, maxillary plate swollen. Pronotum: Anterior margin slightly carinate and sinuate, with visible raised calli; disc slightly raised. Mesoscutum: Lateral medial transverse ridge or rounded. Scutellum: Flat.

Measurements

Males unknown.

Females (n=2): BL: 4.14-4.342 (4.24±0.14); BW: 1.145-1.379 (1.26±0.17); LL: 1.254-1.317 (1.29±0.04); PL: 0.458-0.461 (0.460±0.002); PW: 1.037-1.105 (1.07±0.05); AI: 0.475-0.508 (0.49±0.02); AII: 1.418-1.475 (1.45±0.04); AIII: 0.736-0.79 (0.76±0.04); AIV: 0.689-0.719 (0.70±0.02); HL: 0.43-0.467 (0.45±0.03); HW: 0.667-0.697 (0.68±0.02); VW: 0.361-0.395 (0.38±0.02); CL: 0.591-0.614 (0.60±0.02).

Distribution

This species is known from a single locality on Mt. Aorai, Tahiti (Figure 60).

Plant Affiliation

The two specimens collected of this species were both found on the fern *Paesia divaricatissima* (Dennstaedtiaceae).

Remarks

While this species is sympatric with n. sp. 10 and affiliated with the same species of fern, it forms a monophyletic group separated from n. sp. 10 by n. sp. 11. We consider this a cryptic species given the lack of morphological, geographic, or ecological evidence distinguishing it from n. sp. 10, but the two can be diagnosed by their respective molecular synapomorphies.

***Pseudoloxops* n. sp. 13** (Figures 61-63)

Material Examined: Holotype, ♂, French Polynesia: Tahiti Is. Mt. Aorai, 17.59596°S 149.49832°W, 1629 m, 21-06-2011, on *Dicranopteris linearis*, det. by Brad Balukjian, Brad Balukjian, (AMNH_PBI 00384714) (UCB). Paratypes: Tahiti Is. Mt. Aorai, 17.59596°S 149.49832°W, 1629 m, 21-06-2011, on *Dicranopteris linearis*, Brad Balukjian, 1 ♂, (AMNH_PBI 00384529), 1 ♀ (AMNH_PBI 00384713) (UCB).//Lava Tubes, 17.6289°S 149.34993°W, 717 m, 30-06-2011, on *Dicranopteris linearis*, Brad Balukjian, 1 ♀ (AMNH_PBI 00384501), 1 ♂ (AMNH_PBI 00384518) (UCB).// Mt Marau, 17.61171°S 149.53122°W, 1426 m, 29-06-2011, on *Dicranopteris linearis*, Brad Balukjian, 1 ♂ (AMNH_PBI 00384521), 1 ♀ (AMNH_PBI 00384536) (UCB).//Mt Marau, 17.60744°S 149.53719°W, 1396 m, 29-06-2011, on *Blechnum orientale*, Brad Balukjian, 1 ♂, (AMNH_PBI 00384514) (UCB).//Mt. Aorai, 17.59429°S 149.50005°W, 1490 m, 21-06-2011, on *Paesia divaricatissima*, Brad Balukjian, 1 ♂, (AMNH_PBI 00384545) (UCB).//Lava Tubes, 17.6289°S 149.34993°W, 716 m, 2011, on *Blechnum orientale*, Brad Balukjian, 1 ♂, (AMNH_PBI 00384432) (UCB).//Moorea Is. Mt Tohiea, 17.552°S 149.82°W, 1015 m, 25-09-2009, at blacklight, Peter Oboyski, 1 ♀ (AMNH_PBI 00384495) (UCB).

Diagnosis

This species can be recognized by the large triangular projection at the apical end of the phallotheca of the male genitalia (Figure 62). It forms a monophyletic group in our phylogeny

and can be recognized by the following molecular synapomorphies at the node containing nodes 16-20 (Figure 7): Base 363: T→A; Base 1373: T→C; Base 1484: A→G; Base 1571: A→G.

Description

COLORATION: Head: Generally yellow; frons and vertex pale yellow; clypeus pale yellow except for red transverse medial stripe or red medial dot, sometimes mostly red; dorsal half of mandibular plate covered by red band, the rest yellowish; maxillary plate mostly blackish-red, except for medial yellow spot ventrally. Antennae: AI jet black; AII dark red at base turning to reddish tint, then yellow, sometimes completely yellow; AIII uniformly yellow sometimes with brown tint at apex; AIV yellow. Pronotum: Yellow, lateral thirds red, sometimes with black coloration apically and red coloration basally, sometimes with medial teardrop-shaped red vitta originating at posterior margin and reaching halfway to anterior margin. Mesoscutum: Usually completely yellow, paler anteriorly, sometimes with red in anterior corners, sometimes red in anterior half and yellow in posterior half. Scutellum: Sometimes yellow throughout, sometimes completely red with yellow in anterior corners, sometimes with medial red vitta slightly faded and yellow medially, separating vitta into two parts, sometimes yellow with two red longitudinal stripes medially. Hemelytra: Clavus mostly pale yellow with red markings anteriorly near junction with pronotum, and sometimes with red markings on posterior edge of claval commissure; corium red on anterior half, yellow on posterior half with some red markings on medial edges, also red dot on posterior margin near junction of cuneus and medial wing membrane vein; posterior third of cuneus light red, anterior two thirds of cuneus pale yellow; wing membrane veins red; membrane dusky. Legs: Distal half of metafemora red.

STRUCTURE: Head: Posterior margin rectilinear and slightly carinate, vertex sulcate medially, frons swollen and projected, clypeus visible from above. Pronotum: Collar evident, anterior margin carinate and sinuate; calli evident; disc slightly elevated; posterior margin slightly convex. Mesoscutum: Sometimes elevated, sometimes elevated laterally and sulcate medially. Scutellum: Flat to elevated. Male Genitalia: Right paramere with ventral medial process with 2-5 teeth perpendicular to apophysis with 1, 3, 4, or 6 teeth (Figure 62c); aedeagus with single medium-width spicule; phallotheca with a single lobe and a large triangular projection apically (Figure 62a); left paramere with sensory lobe lacking basal process (Figure 62b).

Measurements

Males (n=7): BL: 3.278-3.789 (3.45±0.19); BW: 0.912-1.253 (1.11±0.11); LL: 1.037-1.145 (1.11±0.04); PL: 0.334-0.404 (0.36±0.02); PW: 0.835-0.958 (0.90±0.04); AI: 0.373-0.471 (0.41±0.03); AII: 0.862-1.307 (1.11±0.15); AIII: 0.52-0.622 (0.58±0.04); AIV: 0.432-0.572 (0.51±0.05); HL: 0.361-0.51 (0.42±0.06); HW: 0.589-0.627 (0.60±0.01); VW: 0.314-0.346 (0.33±0.01); CL: 0.413-0.568 (0.48±0.06).

Females (n=4): BL: 3.331-4.146 (3.64±0.35); BW: 1.049-1.452 (1.21±0.18); LL: 1.078-1.172 (1.12±0.04); PL: 0.354-0.444 (0.39±0.04); PW: 0.883-1.171 (0.98±0.13); AI: 0.352-0.443 (0.40±0.05); AII: 1.226-1.631 (1.42±0.20); AIII: 0.553-0.613 (0.58±0.04); AIV: 0.29-0.363 (0.33±0.05); HL: 0.399-0.437 (0.42±0.02); HW: 0.591-0.697 (0.63±0.05); VW: 0.339-0.366 (0.35±0.01); CL: 0.483-0.617 (0.53±0.06).

Distribution

This species is known from three main localities on Tahiti and 1 locality on Moorea (Figure 63).

Plant Affiliation

This species was collected from three different species of ferns: *Blechnum orientale* (Blechnaceae), *Dicranopteris linearis* (Gleicheneaceae), and *Paesia divaricatissima* (Dennstaedtiaceae).

Remarks

This species is exclusive to ferns and endemic to the islands of Tahiti and Moorea. One specimen (Z73) from Moorea superficially resembles n. sp. 10 and 12, but forms a monophyletic group with the rest of the individuals comprising this species. There is a fair amount of color plasticity within this species complex, so other lines of evidence, specifically the male genitalia and molecular characters, can be used to tell species apart.

***Pseudoloxops* n. sp. 14** (Figures 64-66)

Material Examined: Holotype, ♂, French Polynesia: Society Is. Raiatea Is. Temehani Plateau, 660 m, 01 Sep 1977, W. C. Gagne, *Astronia saccata* (Melastomataceae), (AMNH_PBI 00042804) (BPBM). Paratypes: Raiatea Is. Temehani rahi plateau, 16.7749°S 151.4537°W, 661 m, 08-03-2009, on *Myrsine* sp., Brad Balukjian, 2 ♂, (AMNH_PBI 00384481, AMNH_PBI 00384510) (UCB).//Temehani rahi plateau, 16.7794°S 151.4502°W, 722 m, 08-03-2009, on *Myrsine* sp., Brad Balukjian, 1 ♀, (AMNH_PBI 00384444) (UCB); 08-03-2009, on *Myrsine* sp., Brad Balukjian, 2 ♀, (AMNH_PBI 00384427, AMNH_PBI 00384480) (UCB).//Temehani rahi plateau, 16.77269°S 151.471°W, 227 m, 11-03-2009, on *Glochidion* sp., Peter Oboyski, 1 ♂, (AMNH_PBI 00384509) (UCB).

Diagnosis

This species can be recognized by its unique coloration on the pronotum and hemelytra and the aedeagus lacking an endosomal spicule (Figure 65). It forms a monophyletic group in our phylogeny that is defined by node 21 (Figure 7).

Description

COLORATION: Head: Medial longitudinal red stripe running the length of vertex, sometimes connecting to two red stripes paralleling eyes to form bird's foot pattern; frons yellow, sometimes with lateral red stripe, sometimes with red Fu Manchu mustache pattern; clypeus yellow, sometimes with some red dots, sometimes with transverse red band ventrally; dorsal half of mandibular plate and maxillary plate red, ventral half yellow. Antennae: AI red on one side,

yellow on the other side; AII-IV yellow. Pronotum: Lateral thirds and medial vertical stripe red, the rest yellow. Mesoscutum: Yellow, sometimes with some medial red markings. Scutellum: Almost entirely red except for yellow in anterior corners. Hemelytra: Clavus yellow except for red in anterior corners near junction with pronotum, in posterior corners, and thin red stripe along claval suture; distal two-thirds of corium yellow, interior third red extending all the way to base of claval commissure; also red vitta on cuneus medially where junction with wing membrane occurs (at junction with membrane vein connecting two membrane cells); apex of cuneus red; membrane veins red. Legs: Yellow.

STRUCTURE: Head: Vertex flattened, frons slightly swollen, clypeus visible from above; collar distinct. Pronotum: Anterior margin slightly concave and carinate, calli evident; disc mostly flat, posterior margin sinuate. Mesoscutum: Sulcate to slightly rounded. Scutellum: Flattened to slightly elevated. Male Genitalia: Right paramere with ventral medial process with 4-5 teeth perpendicular to apophysis without teeth (Figure 65c); aedeagus without any spicules; phallotheca with a single lobe (Figure 65a); left paramere with sensory lobe lacking basal process (Figure 65b).

Measurements

Males (n=4): BL: 3.703-4.091 (3.88±0.19); BW: 1.339-1.508 (1.40±0.08); LL: 1.155-1.228 (1.19±0.03); PL: 0.375-0.501 (0.42±0.06); PW: 1.047-1.175 (1.12±0.05); AI: 0.438-0.516 (0.49±0.04); AII: 1.306-1.596 (1.49±0.13); AIII: 0.619-0.858 (0.71±0.10); AIV: 0.658; HL: 0.451-0.504 (0.48±0.02); HW: 0.726-0.75 (0.74±0.01); VW: 0.37-0.384 (0.38±0.01); CL: 0.466-0.574 (0.52±0.04).

Females (n=3): BL: 3.403-4.066 (3.74±0.33); BW: 1.364-1.52 (1.43±0.08); LL: 1.187-1.239 (1.22±0.03); PL: 0.329-0.434 (0.38±0.05); PW: 1.074-1.144 (1.11±0.04); AI: 0.462-0.622 (0.52±0.09); AII: 1.271-1.557 (1.43±0.14); AIII: 0.672-0.701 (0.69±0.02); AIV: 0.434-0.708 (0.57±0.19); HL: 0.411-0.465 (0.44±0.03); HW: 0.663-0.731 (0.69±0.03); VW: 0.377-0.405 (0.39±0.01); CL: 0.533-0.561 (0.55±0.01).

Distribution

This species is endemic to the Temehani rahi plateau on Raiatea (Figure 66).

Plant Affiliation

This species was collected from three angiosperm species: *Astronidium saccatum* (Melastromataceae), *Glochidion* sp. (Euphorbiaceae), and *Myrsine* sp. (Myrsinaceae).

Remarks

This species is endemic to the Temehani rahi plateau of Raiatea and is easily recognized by its distinct coloration.

***Pseudoloxops* n. sp. 15** (Figures 67-69)

Material Examined: Holotype, ♂, French Polynesia: Moorea Is. Mt Atiati, 17.5369°S 149.86831°W, 449 m, 14-11-2008, on grasses and herbs, Brad Balukjian, (AMNH_PBI 00384491) (UCB).

Diagnosis

This species can be identified by the following molecular autapomorphies for specimen Z77 in our molecular phylogeny (Figure 7): Base 244: T→C; Base 859: T→G; Base 907: G→A; Base 1034: T→C; Base 1040: C→T; Base 1042: A→G; Base 1052: T→C; Base 1066: T→A; Base 1099: A→G; Base 1107: T→A; Base 1184: A→G; Base 1208: A→G; Base 1211: A→G; Base 1256: A→T; Base 1328: C→T; Base 1352: A→G; Base 1370: A→C; Base 1379: A→G; Base 1398: T→C; Base 1481: A→G; Base 1527: C→T; Base 1577: A→G; Base 1683: A→G; Base 1691: A→G; Base 1718: C→T; Base 1730: A→T; Base 1742: A→G; Base 1754: T→C; Base 1799: A→G; Base 1904: T→C; Base 1913: A→G.

Description

COLORATION: Head: Yellowish throughout. Antennae: AI-II yellow; AII-IV missing. Pronotum: Yellow in anterior half, greenish in posterior half. Mesoscutum: Yellow. Scutellum: Greenish. Hemelytra: Clavus, corium, and cuneus all green; wing membrane pale with green veins. Legs: Missing.

STRUCTURE: Head: Posterior margin slightly carinate and slightly convex, vertex slightly depressed medially, frons projected and striated and swollen. Eyes are slightly wider than anterior margin of pronotum; collar evident. Pronotum: Anterior margin carinate and sinuate, calli evident, disc mostly flat; posterior margin slightly convex. Mesoscutum: Slightly rounded. Scutellum: Flat. Male Genitalia: Right paramere with ventral medial process with 3 teeth perpendicular to apophysis with 2 teeth (Figure 68b); aedeagus missing; left paramere with sensory lobe lacking basal process (Figure 68a).

Measurements

Males (n=1): BL: 3.289; BW: 1.017; LL: 0.98; PL: 0.403; PW: 0.957; AI: 0.371; AII: 1.105; AIII: N/A; AIV: N/A; HL: N/A; HW: N/A; VW: 0.316; CL: 0.461.

Females Unknown.

Distribution

This species is known from a single specimen on Moorea (Figure 69).

Plant Affiliation

The single specimen collected was taken from a mix of grasses and herbs.

Remarks

This species is known from a single specimen that is genetically highly divergent from its closest relatives (Table 12). While we are reluctant to describe a new species on the basis of a single specimen, it is preferable that this biodiversity be documented so that it can be tested in the future using additional data.

***Pseudoloxops* n. sp. 16** (Figures 70-72)

Material Examined: Holotype, ♂, French Polynesia: Austral Is. Rimatara Is. Amaru, 22.6566°S 152.7993°W, 17-04-2009, on *Hibiscus tiliaceus*, det. by Brad Balukjian, Brad Balukjian, (AMNH_PBI 00384420) (UCB).

Diagnosis

This species is characterized by its uniformly pale green coloration, bright red eyes, pale green antennae, lack of coloration in the cuneus and membrane portion of the wing veins, and structure of the male genitalia (Figure 71). It can be identified by the following molecular autapomorphies for specimen Z16 in our molecular phylogeny (Figure 7): Base 170: T→C; Base 172: T→C; Base 189: A→G; Base 230: A→G; Base 233: A→G; Base 235: A→G; Base 276: T→A; Base 277: T→A; Base 280: T→C; Base 309: T→C; Base 419: T→C; Base 1175: A→G; Base 1187: A→C; Base 1340: T→C; Base 1346: C→T; Base 1358: A→G; Base 1379: A→T; Base 1385: A→G; Base 1409: A→G; Base 1415: A→G; Base 1430: T→C; Base 1472: T→C; Base 1511: A→T; Base 1571: A→T; Base 1598: T→C; Base 1652: A→G; Base 1664: A→T; Base 1728: T→A; Base 1729: C→G; Base 1733: G→T; Base 1751: A→T; Base 1754: T→C; Base 1757: T→C; Base 1760: T→A; Base 1913: A→G; Base 1925: C→T; Base 1949: A→G.

Description

COLORATION: Head: Pale green throughout, except for bright red compound eyes. Antennae: AI and AII pale green; AIII and AIV missing. Pronotum: Pale green. Mesoscutum: Pale green. Scutellum: Pale green. Hemelytron: Pale green; wing membrane veins clear. Legs: Missing.

STRUCTURE: Head: Vertex flat and medially sulcate; frons swollen and projected forward. Pronotum: Calli evident; disc slightly rounded. Mesoscutum: Slightly depressed. Scutellum: Flat. Male genitalia: Unable to recover aedeagus; right paramere with ventral medial process with 3 teeth perpendicular to single-lobed apophysis curling forward with 3 teeth (Figure 71b); left paramere with sensory lobe lacking basal process and relatively thin apophysis curving down distally (Figure 71a).

Measurements

Males (n=1): BL: 3.23; BW: 0.929; LL: 1.148; PL: 0.35; PW: 0.85 mm; AI: N/A; AII: N/A; AIII: N/A; AIV: N/A; HL: 0.431; HW: 0.555; VW: 0.297; CL: 0.471.

Females unknown.

Distribution

This species is known from a single locality on Rimatara Is. in the Austral Islands (Figure 72).

Plant Affiliation

The single male specimen was collected from the shrub *Hibiscus tiliaceus* (Malvaceae), a common native plant at low elevations in French Polynesia.

Remarks

P. rimataraensis is the first record of the genus from Rimatara; congeners are also known from Tubuai and Rurutu in the Austral Islands. Although the lead author's collecting time on Rimatara was limited, it does not appear to be common, as no specimens were collected by the Bishop Museum's southeast Polynesian expedition in the early 1930s or by any subsequent collecting expeditions. This is likely due to the almost complete anthropogenic disturbance of natural habitat on the island, with only pockets of uplifted limestone remaining relatively pristine.

***Pseudoloxops* n. sp. 17** (Figures 73-74)

Material Examined: Holotype, ♀, French Polynesia: Society Is. Huahine Is. Mt. Pohuarahi, 16.78064°S 150.97458°W, 414 m, 30-07-2011, on *Glochidion temehaniense* det. by David Hembry, Erica Newman, (AMNH_PBI 00384731) (UCB).

Diagnosis

This species superficially resembles n. sp. 9, but can be distinguished on the basis of molecular characters. It can be identified by the following molecular autapomorphies for specimen Z212 in the molecular phylogeny (Figure 7): Base 229: T→A; Base 252: G→A; Base 281: A→T; Base 328: T→A; Base 1164: T→C; Base 1169: C→T; Base 1253: T→C; Base 1274: C→T; Base 1275: C→T; Base 1286: T→C; Base 1289: T→C; Base 1295: A→C; Base 1298: T→C; Base 1307: T→C; Base 1319: A→G; Base 1334: A→G; Base 1422: G→A; Base 1424: A→T; Base 1436: A→C; Base 1439: A→T; Base 1457: A→G; Base 1499: T→C; Base 1502: A→G; Base 1505: T→C; Base 1529: A→T; Base 1550: A→T; Base 1556: C→T; Base 1568: T→C; Base 1635: T→A; Base 1637: A→C; Base 1646: C→T; Base 1674: A→G; Base 1675: C→T; Base 1700: A→C; Base 1725: T→C; Base 1739: T→A; Base 1796: T→C; Base 1820: A→G; Base 1844: T→C; Base 1859: T→C; Base 1874: C→T; Base 1937: T→C.

Description

COLORATION: Head: Vertex yellow except for medial red line and two parallel red lines bordering eyes; frons yellow with red Fu Manchu mustache pattern; clypeus yellow with red crossing hockey-stick pattern meeting in medial longitudinal stripe and transverse medial red stripe with yellow ventrally; dorsal half of mandibular plate black/red, ventral half yellow; most

of maxillary plate reddish black except for small spot ventrally. Antennae: AI red; AII red at base then yellow; AIII yellow; AIV missing. Pronotum: Lateral thirds red/black (black basally, red apically); yellow in between. Mesoscutum: Yellow. Scutellum: Yellow. Hemelytra: Clavus red/black and yellowish towards claval suture; corium yellow except for two round red vittae adjacent to posterior part of clavus; cuneus red/black in distal third of cuneus, yellow in anterior two-thirds; red dot in anterior part of cuneus at junction with medial vein of wing membrane cells; membrane veins red; membrane dusky. Legs: Yellow.

Head: Posterior margin rectilinear and slightly carinate; vertex with slight medial sulcation, frons very swollen and projected forward. Pronotum: Collar evident, anterior margin slightly sinuate and calli evident, disc slightly rounded. Mesoscutum: Transverse ridge. Scutellum: Flat.

Measurements

Males unknown.

Femaes (n=1): BL: 3.9; BW: N/A; LL: N/A; PL: 0.436; PW: 1.062; AI: 0.608; AII: 1.716; AIII: 0.693; AIV: N/A; HL: 0.434; HW: 0.706; VW: 0.367; CL: 0.579.

Distribution

This species is known from one locality on the island of Huahine (Figure 74).

Plant Affiliation

The single specimen known of this species was collected from the angiosperm *Glochidion temehaniense* (Euphorbiaceae).

Remarks

Like n. sp. 15, this species is known from a single specimen that is genetically highly divergent from its closest relatives (Table 12). While we are reluctant to describe a new species on the basis of a single specimen, it is preferable that this biodiversity be documented so that it can be tested in the future using additional data. This species superficially resembles n. sp. 9 from Tahaa Is., but is highly divergent genetically and is found on an angiosperm (n. sp. 9 was collected from ferns).

***Pseudoloxops* n. sp. 18** (Figures 75-77)

Material Examined: Holotype, ♂, French Polynesia: Tahiti Is. Mille Sources, 17.58718°S 149.46644°W, 1119 m, 13-06-2011, on *Weinmannia parviflora* det. by Ravahere Taputuarai, Brad Balukjian, (AMNH_PBI 00384526) (UCB). Paratypes: Tahiti Is. Mille Sources, 17.58718°S 149.46644°W, 1119 m, 13-06-2011, on *Parasponia andersonii*, Brad Balukjian, 2 ♂, (AMNH_PBI 00384547, AMNH_PBI 00384681) (UCB).//Mille Sources Trail, 17.58718°S 149.46644°W, 1119 m, 13-06-2011, on *Parasponia andersonii*, Brad Balukjian, 1 ♂

(AMNH_PBI 00384705) (UCB).//Plateau Taravao, 17.78678°S 149.24748°W, 792 m, 09-06-2011, on *Metrosideros collina*, Brad Balukjian, 1 ♂ (AMNH_PBI 00384694) (UCB).

Diagnosis

This species can be recognized by its dark green coloration on the hemelytra and lack of red markings (aside from some occasional red in the membrane veins), its grey, dusky wing membrane, and the male genitalia. The aedeagus and phallotheca resemble its sister species, n. sp. 19, except n. sp. 19 has a small triangular flap towards the base of the phallotheca. The shape of the left parameres are also quite different in the two species (Figure 76). The species forms a monophyletic group in our molecular phylogeny, defined by node 25 (Figure 7).

Description

COLORATION: Head: Completely yellow everywhere, sometimes with faint red or grey spot on maxillary plate. Antennae: AI light tan; AII-IV brown or pale yellow. Pronotum: Anterior half yellow, posterior half darker green. Mesoscutum: Yellow. Scutellum: Darker green. Hemelytra: Clavus dark green; corium dark green; cuneus yellow with black at apex; membrane dusky with blackish patches; membrane veins brown or red. Legs: Yellow to green.

STRUCTURE: Head: Vertex flat with medial sulcus, frons and clypeus anterioprojected and visible from dorsal view, frons swollen; posterior margin rectilinear; maxillary plate swollen. Pronotum: Anterior margin sinuate and carinate; calli slightly evident and raised; disc slightly rounded; posterior margin slightly excavate. Mesoscutum: Rugose, with medial process/carina. Scutellum: Flat. Male Genitalia: Right paramere with ventral medial process with 5-7 teeth perpendicular to single-lobed apophysis with 2-4 teeth (Figure 76c); aedeagus with single spicule; phallotheca with two lobes (one large, one small; Figure 76a); left paramere with rounded sensory lobe basally and lacking basal process (Figure 76b).

Measurements

Males (n=5): BL: 3.951-4.551 (4.20±0.24); BW: 1.244-1.397 (1.30±0.06); LL: 1.082-1.203 (1.14±0.03); PL: 0.443-0.517 (0.48±0.01); PW: 1.12-1.279 (1.18±0.07); AI: 0.457-0.492 (0.48±0.01); AII: 1.554-1.639 (1.60±0.03); AIII: 0.545-0.812 (0.74±0.11); AIV: 0.519-0.686 (0.61±0.07); HL: 0.46-0.514 (0.49±0.02); HW: 0.77-0.828 (0.79±0.02); VW: 0.343-0.372 (0.36±0.01); CL: 0.449-0.649 (0.55±0.09).

Females unknown.

Distribution

P. n. sp. 18 is endemic to the island of Tahiti and is known from two localities in two different parts of the island (Figure 77).

Plant Affiliation

Specimens were collected from three different angiosperms: *Metrosideros collina* (Myrtaceae), *Parasponia andersonii* (Ulmaceae), and *Weinmannia parviflora* (Cunoniaceae).

Remarks

This species appears to be confined to native cloud forests at high elevations on the island of Tahiti. Its distribution overlaps with its sister species, P. n. sp. 18 at both localities where it was found and is associated with two of the same plant species.

***Pseudoloxops* n. sp. 19** (Figures 78-80)

Material Examined: Holotype: ♂, French Polynesia: Tahiti Is. Mt Aorai Trail, 17.57915°S 149.51849°W, 1023 m, 12-09-2008, on *Weinmannia parviflora* det.by Ravahere Taputuarai, Brad Balukjian, 1 ♂ (AMNH_PBI 00384465) (UCB). Paratypes: Moorea Is Mt Tohiea, 17.55518°S 159.81239°W, 480 m, 29-04-2010, on *Alyxia* sp., April Yang, 1 ♂ (AMNH_PBI 00384507) (UCB).//Tahiti Is. Hitiaa Lava Tubes, 17.62883°S 149.34806°W, 696 m, 30-06-2011, on *Metrosideros collina*, Brad Balukjian, 2 ♀ (AMNH_PBI 00384513, AMNH_PBI 00384535) (UCB).//Massif du Pic Vert, 01-10-2008, Kari Roesch Goodman, 1 ♀ (AMNH_PBI 00384463) (UCB).//Massif du Pic Vert, 17.59201°S 149.5402°W, 1131 m, 01-10-2008, on *Weinmannia parviflora*, Brad Balukjian, 1 ♂ (AMNH_PBI 00384442) (UCB).// Mille Sources, 17.58718°S 149.46644°W, 1119 m, 13-06-2011, on *Weinmannia parviflora*, *Metrosideros collina*, Brad Balukjian, 1 ♂ (AMNH_PBI 00384682), 1 ♀ (AMNH_PBI 00384680) (UCB).// Mt Aorai Trail, 17.57946°S 149.51831°W, 1043 m, 12-09-2008, on *Metrosideros collina*, Brad Balukjian, 1 ♀ (AMNH_PBI 00384476) (UCB).//Mt Aorai Trail, 17.57981°S 149.5179°W, 1060 m, 12-09-2008, on *Weinmannia parviflora*, Brad Balukjian, 2 ♀ (AMNH_PBI 00384441, AMNH_PBI 00384474) (UCB).// Mt Aorai Trail, 17.57998°S 149.51767°W, 1049 m, 12-09-2008, on *Weinmannia parviflora*, Brad Balukjian, 1 ♀ (AMNH_PBI 00384466) (UCB).//Mt Aorai Trail, 17.57928°S 149.51843°W, 1019 m, 12-09-2008, on *Weinmannia parviflora*, Brad Balukjian, 1 ♀ (AMNH_PBI 00384426) (UCB).//Mt Aorai Trail, 17.5792°S 149.51844°W, 1024 m, 12-09-2008, on *Metrosoderos collina*, Brad Balukjian, 1 ♂ (AMNH_PBI 00384469), 1 ♀ (AMNH_PBI 00384467) (UCB).// Mt Marau, 17.60631°S 149.53967°W, 1328 m, 29-06-2011, on *Weinmannia parviflora*, Brad Balukjian, 1 ♂ (AMNH_PBI 00384512) (UCB).//Mt Marau, 17.61235°S 149.53074°W, 1443 m, 29-06-2011, on *Weinmannia parviflora*, Brad Balukjian, 1 ♀ (AMNH_PBI 00384520) (UCB).//Mt Marau, 17.61288°S 149.53053°W, 1449 m, 29-06-2011, on *Weinmannia parviflora*, Brad Balukjian, 1 ♀ (AMNH_PBI 00384498) (UCB).//Plateau Taravao, 17.78815°S 149.24885°W, 837 m, 08-06-2011, on *Metrosideros collina*, Brad Balukjian, 1 ♀ (AMNH_PBI 00384686) (UCB).//Plateau Taravao, 17.78678°S 149.24748°W, 792 m, 09-06-2011, on *Metrosideros collina*, Brad Balukjian, 7 ♀ (AMNH_PBI 00384543, AMNH_PBI 00384685, AMNH_PBI 00384703, AMNH_PBI 00384702, AMNH_PBI 00384697, AMNH_PBI 00384696, AMNH_PBI 00384695), 5 ♂ (AMNH_PBI 00384704, AMNH_PBI 00384701, AMNH_PBI 00384700, AMNH_PBI 00384698, AMNH_PBI 00384693) (UCB).//Plateau Taravao, 17.784°S 149.24729°W, 711 m, 23-02-2009, at blacklight, Peter Oboyski, 1 ♂ (AMNH_PBI 00384428) (UCB).//Plateau Taravao, 17.78346°S 149.2482°W, 760 m, 09-06-2011, on *Metrosideros collina*, Brad Balukjian, 1 ♂ (AMNH_PBI 00384546) (UCB).

Diagnosis

This species can be diagnosed by the following combination of characters: Lateral thirds of pronotum red, the rest yellow; one side of AI red, the other side yellow; membrane veins red posteriorly; right paramere with bi-lobed apophysis; phallotheca with two lobes and triangular flap near base; left paramere with distinct shape (Figure 79). The species forms a monophyletic group in our molecular phylogeny, defined by the node that includes putative species 26-30 (Figure 7).

Description

COLORATION: Head: Vertex yellow with red medial stripe sometimes forming bird's foot pattern, two longitudinal red stripes (sometimes faint) paralleling eyes, sometimes red faint enough that vertex appears almost completely yellow; frons yellow, sometimes with red Fu-Manchu mustache pattern, sometimes with just two longitudinal red vittae; clypeus extremely variable, sometimes with two lateral red vittae ventrally, sometimes with two medial red dots, sometimes with transverse medial red band and red "v" shape in the dorsal region; dorsal half of mandibular plate usuallywith red band, the rest yellowish, occasionally completely yellowish; most of maxillary plate usually red, ventral area yellow, sometimes yellow with a bit of red in corner towards eye. Antennae: AI yellow on one side, red on the other; AII-IV yellow. Pronotum: Lateral thirds of pronotum red, the rest yellow. Mesoscutum: Yellow. Scutellum: Yellow. Hemelytra: Greenish, ususally with red at apex of cuneus; membrane veins red posteriorly, vein connecting two cells pale. Legs: Metafemora sometimes red at apex, sometimes green with red dots.

STRUCTURE: Head: Posterior margin slightly convex to rectilinear, sometimes slightly carinate; frons swollen and striated; vertex sulcate medially; eyes slightly wider than anterior margin of pronotum. Pronotum: Calli evident, anterior margin slightly carinate and sinuate, disc pretty flat; posterior margin convex. Mesoscutum: Slightly rounded to carinate. Scutellum: Flat. Male Genitalia: Right paramere with ventral medial process with 3-4 teeth perpendicular to bi-lobed apophysis with 1-3 teeth on upper lobe (Figure 79c); aedeagus with single spicule; phallotheca with two lobes (one large, one small) and small triangular flap towards base (Figure 79a); left paramere with rounded sensory lobe basally and lacking basal process (Figure 79b).

Measurements

Males (n=12): BL: 3.457-4.55 (3.99±0.31); BW: 1.231-1.648 (1.40±0.12); LL: 1.116-1.478 (1.31±0.11); PL: 0.354-0.681 (0.47±0.08); PW: 1.123-1.323 (1.18±0.06); AI: 0.402-0.523 (0.46±0.03); AII: 1.089-1.73 (1.59±0.18); AIII: 0.508-0.809 (0.69±0.08); AIV: 0.435-0.763 (0.61±0.11); HL: 0.326-0.565 (0.46±0.08); HW: 0.676-0.825 (0.79±0.04); VW: 0.351-0.427 (0.39±0.02); CL: 0.416-0.608 (0.51±0.06).

Females (n=18): BL: 3.639-4.857 (4.16±0.3); BW: 1.145-1.711 (1.43±0.15); LL: 1.094-1.564 (1.31±0.14); PL: 0.361-0.54 (0.43±0.04); PW: 0.854-1.298 (1.18±0.09); AI: 0.286-0.535 (0.46±0.05); AII: 1.088-1.833 (1.61±0.15); AIII: 0.488-0.8 (0.72±0.07); AIV: 0.369-0.742 (0.61±0.11); HL: 0.318-0.602 (0.47±0.09); HW: 0.602-0.806 (0.74±0.05); VW: 0.318-0.46 (0.41±0.04); CL: 0.383-0.671 (0.53±0.08).

Distribution

This species is distributed across several high-elevation mountain ridges in Tahiti and one locality in Moorea (Figure 80).

Plant Affiliation

A long series of individuals was collected from both *Metrosideros collina* (Myrtaceae) and *Weinmannia parviflora* (Cunoniaceae), which we consider to be true host plants. A single specimen was taken from *Alyxia* sp. (Apocynaceae) and is likely a sitting record.

Remarks

This species was locally abundant at several localities and shows a strong affinity for both *M. collina* and *W. parviflora.* The bright red markings on the lateral thirds of the pronotum, together with the yellow of the head, scutellum, and mesoscutum, and the green of the hemelytra provide good camouflage when sitting on the red flowers of *M. collina*. The species was usually taken on flowers or young leaves, and its coloration could be a form of crypsis from avian predators such as birds. The species is confined to mid- to high-elevations and is often found in cloud forest habitat where *M. collina* and *W. parviflora* are among the dominant vegetation.

***Pseudoloxops* n. sp. 20** (Figure 81-82)

Material Examined: Holotype, ♀, French Polynesia, Society Is. Huahine Is. Mt. Turi, 16.72113°S 151.01583°W, 419 m, 26-07-2011, on *Metrosideros collina*, det. by Erica Newman, Erica Newman, (AMNH_PBI 00384707) (UCB).

Diagnosis

This species superficially resembles n. sp. 21, but can be distinguished on the basis of molecular characters. It can be identified by the following molecular autapomorphies for specimen Z211 in the molecular phylogeny (Figure 7): Base 715: T→C; Base 1223: C→T; Base 1262: A→G; Base 1427: T→C; Base 1607: T→C; Base 1637: A→G; Base 1830: C→T; Base 1838: C→A; Base 1856: T→C; Base 1901: A→T.

Description

COLORATION: Head: Vertex greenish, except for red bird's foot pattern connecting with two red lateral stripes bordering eyes (but bird's foot lacks the usual medial longitudinal stripe originating at posterior margin of head) forming a large red vitta; frons striated and black, with lateral stripes that create a horseshoe crab pattern and also red Fu Manchu mustache pattern; clypeus with longitudinal red medial stripe connecting to transverse red stripe ventrally and crossing hockey-stick-pattern dorsally, yellow/green ventrally; dorsal half of mandibular plate

red, ventral half greenish/yellow; dorsal half of maxillary plate dark red/blackish, ventral half greenish yellow. Antennae: AI completely dark red/black; AII-IV yellow. Pronotum: Yellow-green. Mesoscutum: Yellow-green. Scutellum: Yellow-green. Hemelytra: Clavus and corium light green, including cuneus; wing membrane veins very light green. Legs: Light green.

STRUCTURE: Head: Posterior margin rectilinear and slightly raised, vertex sulcate medially; frons striated and slightly swollen projecting forward. Pronotum: Collar evident; anterior margin sinuate and slightly carinate; calli evident; disc slightly rounded. Mesoscutum: Transverse ridge but depressed medially. Scutellum. Flat.

Measurements

Males unknown.

Females (n=1): BL: 3.77; BW: 1.356; LL: 1.166; PL: 0.439; PW: 1.224; AI: 0.461; AII: 1.527; AIII: 0.707; AIV: 0.541; HL: 0.416; HW: 0.711; VW: 0.339; CL: 0.555.

Distribution

This species is known from a single locality on Huahine Is. (Figure 82).

Plant Affiliation

The single known specimen of this species was collected from *Metrosideros collina* (Myrtaceae).

Remarks

This species superficially resembles P. n. sp. 21, but is found on the island of Huahine. It is known from a single specimen, and is considered a cryptic species given the lack of morphological differentiation between it and its sister species, n. sp. 21.

***Pseudoloxops* n. sp. 21** (Figures 83-85)

Material Examined: Holotype, ♂, French Polynesia, Society Is. Moorea Is. Uufau Pass, 17.536°S 149.8697°W, 420 m, 15-03-2009, collected at blacklight, Peter Oboyski, (AMNH_PBI 00384429) (UCB). Paratypes: Uufau Pass, 17.536°S 149.8697°W, 420 m, 15-03-2009, collected at blacklight, Peter Oboyski, 1 ♀, (AMNH_PBI 00384508) (UCB).//Atiati Trail, 17.53639°S 149.8697°W, 420 m, 25-09-2009, on *Alstonia costata*, Peter Oboyski, 1 ♂ (AMNH_PBI 00384496) (UCB).// Mt Mouaputa, 17.52664°S 149.80336°W, 790 m, 16-09-2009, on ferns, Peter Oboyski, 1 ♀, (AMNH_PBI 00384472) (UCB).//Tiura Ridge, 17.5258°S 149.875°W, 490 m, 03-06-2010, at blacklight, Peter Oboyski, 2 ♀, (AMNH_PBI 00384506, AMNH_PBI 00384505) (UCB).// Belvedere, 17.542°S 149.8267°W, 236 m, 2009, at blacklight, Peter Oboyski, 1 ♀ (AMNH_PBI 00384493) (UCB).//Uufau Pass, 17.536°S 149.8697°W, 420 m, 15-03-2009, at blacklight, Peter Oboyski, 1 ♂, (AMNH_PBI 00384488) (UCB).

Diagnosis

This species can be recognized by the combination of the following characters: dark red vertex, dark red/black first antennal segment, the slight basal process on the sensory lobe of the left paramere, and molecular characters. The species forms a monophyletic group in our molecular phylogeny and can be diagnosed by the following synapomorphies at the node that includes nodes 46-48 (Figure 7): Base 260: G→A; Base 1037: G→A; Base 1040: C→T; Base 1241: A→G; Base 1343: C→T; Base 1670: T→C.

Description

COLORATION: Head: Vertex olive green in posterior half and dark red in anterior half with some yellow in between, with red bird's foot pattern and horizontal red striations; frons mostly red with yellow ventrally; clypeus pale yellow with medial longitudinal red stripe reaching horizontal red band ventrally; dorsal half of mandibular plate red, the rest yellow; maxillary plate red dorsally, yellow on ventral half. Antennae: AI black; AII-IV pale yellow. Pronotum: Yellow-green. Mesoscutum: Yellow. Scutellum: Yellow-orange to green. Hemelytra: Entire region pale green; wing membrane veins light green. Legs: Pale yellow.

STRUCTURE: Head: Posterior margin rectilinear; frons striated and slightly swollen projecting forward. Pronotum: Collar evident; anterior margin concave and slightly carinate; calli visible; disc slightly rounded. Mesoscutum: Sometimes with transverse ridge, sometimes raised laterally and sulcate medially. Scutellum: Flat. Male Genitalia: Right paramere with ventral medial process with 2-3 teeth perpendicular to apophysis with 3 teeth (Figure 84b); aedeagus missing; left paramere with slight basal process on sensory lobe (Figure 84a).

Measurements

Males (n=3): BL: 3.392-3.861 (3.58±0.25); BW: 1.251-1.288 (1.27±0.02); LL: 1.027-1.048 (1.04±0.01); PL: 0.416-0.43 (0.42±0.01); PW: 0.935-1.101 (1.04±0.09); AI: 0.433-0.442 (0.44±0.01); AII: 1.589-1.597 (1.59±0.01); AIII: 0.677; AIV: 0.555; HL: 0.329-0.441 (0.39±0.06); HW: 0.755-0.802 (0.78±0.02); VW: 0.266-0.275 (0.27±0.005); CL: 0.467-0.521 (0.50±0.03).

Females (n=5): BL: 3.72-4.212 (3.93±0.20); BW: 1.442-1.641 (1.53±0.07); LL: 1.114-1.216 (1.14±0.04); PL: 0.374-0.489 (0.42±0.04); PW: 1.084-1.289 (1.17±0.08); AI: 0.413-0.463 (0.44±0.02); AII: 1.45-1.66 (1.52±0.08); AIII: 0.657-0.793 (0.70±0.06); AIV: 0.451-0.564 (0.52±0.05); HL: 0.382-0.482 (0.45±0.04); HW: 0.698-0.738 (0.73±0.02); VW: 0.315-0.346 (0.34±0.01); CL: 0.423-0.603 (0.53±0.08).

Distribution

This species is known from several localities on Moorea Is. (Figure 85).

Plant Affiliation

Most of the specimens were collected at blacklights; the only exceptions are a single specimen collected from ferns, and a specimen collected from *Alstonia costata* (Apocynaceae).

Remarks

This species is known from several localities in Moorea, and is sister to a cryptic species (P. n. sp. 20) on Huahine. It is found at mid-elevations habitats with a mix of introduced and native species.

Pseudoloxops rubroclavus (Figures 86-88)

Material Examined: Holotype: ♂, Moorea, Society Islands. A.M. Adamson, Opunohu Valley, two miles from sea. Nov. 30, 1928. Paratypes: Moorea: Opunohu Valley, 2 miles from sea, 30 m, 30-11-1928, A.M. Adamson, 1 ♂, (AMNH_PBI 00191354) (USNM).//Maison de la Nature, 17.5488°S 149.84109°W, 288 m, 17-02-2009, on mix of ferns and *Metrosideros collina*, Brad Balukjian, 1 ♂ (AMNH_PBI 00384490) (UCB).//Mt Atiati North Slope, 17.53601°S 149.87161°W, 470 m, 14-11-2008, on ferns, Curtis Ewing, 1 ♀, (AMNH_PBI 00384487) (UCB).

Diagnosis

This species can be recognized by the unique coloration of the hemelytra and the black first antennal segment. The species forms a monophyletic group in our molecular phylogeny and can be diagnosed by the following synapomorphies at node 31 (Figure 7): Base 1037: G→A; Base 1042: A→G; Base 1745: G→A; Base 1799: A→G; Base 1928: A→G.

Description

COLORATION: Head: Vertex yellow; frons usually completely red, sometimes yellow with red "v" pattern; clypeus usually completely red, sometimes with some yellow ventrally; dorsal half of mandibular plate red; all of maxillary plate red. Antennae: AI black; AII yellow with some red at base; AIII yellow; AIV missing. Pronotum: Yellow with red stripes covering lateral thirds. Mesoscutum: Yellow, with a bit of red in anterior corners. Scutellum: Yellow. Hemelytra: Most of clavus red, except for medial yellow area beginning a third of the way from anterior junction of pronotum and extending to base of scutellum; corium yellow except for anterior third and thin stripe along the claval suture; red dot in cuneus along posterior margin where it intercepts the wing membrane and at junction with medial membrane vein; posterior two-thirds of cuneus red, anterior third yellow; membrane veins red. Legs: Yellow.

STRUCTURE: Head: Vertex flat, posterior margin rectilinear. Pronotum: Collar present, anterior margin rectilinear, calli not conspicuous, disc flat. Mesoscutum: Slightly raised to rounded. Scutellum: Flat. Male Genitalia: Right paramere with ventral medial process with 7 teeth perpendicular to single-lobed apophysis with 6 teeth (Figure 87c); aedeagus with single, medium-width spicule; phallotheca with single lobe and triangular flap near base (Figure 87a); left paramere's sensory lobe rounded basally (Figure 87b).

Measurements

Males (n=2): BL: 3.703-3.78 (3.74±0.05); BW: 1.27-1.471 (1.37±0.14); LL: N/A; PL: 4.24-4.53 (0.44±0.02); PW: 0.978-1.062 (1.02±0.06); AI: 0.534; AII: 1.454; AIII: 0.591; AIV: N/A. HL: 0.352-0.41 (0.381±0.04); HW: 0.67-0.704 (0.69±0.02); VW: 0.293-0.322 (0.31±0.02); CL: 0.402-0.529 (0.47±0.09).

Females (n=1): BL: 3.764; BW: 1.527; LL:1.109; PL: 0.427; PW: 0.966; AI: 0.541; AII: 1.445; AIII: 0.733; AIV: N/A; HL: 0.351; HW: 0.648; VW: 0.335; CL: 0.557.

Distribution

This species is endemic to the island of Moorea, and is known from 3 localities (Figure 88).

Plant Affiliation

This species was taken from ferns, with one individual taken from a mix of ferns and *Metrosideros collina* (Myrtaceae). Ferns were not identified to species.

Remarks

This species occurs at the base of a fern-associated clade, and is endemic to Moorea. It was originally described by Knight (1937), and our analysis confirms it as a distinct species.

Pseudoloxops tahiticus (Figures 89-91)

Material Examined: Holotype, ♂, Tahiti, Society Islands, A.M. Adamson, Hitiaa, alt. 1,000 ft., 3 miles from sea. Paratypes: Massif du Pic Vert, 17.58917°S 149.54218°W, 1059 m, 01-10-2008, on *Metrosideros collina*, Brad Balukjian, 1 ♂ (AMNH_PBI 00384438) (UCB).//Mille Sources, 17.57598°S 149.46999°W, 865 m, 13-06-2011, on *Adiantum capillus-veneris*, Brad Balukjian, 1 ♂ (AMNH_PBI 00384684) (UCB).// Mille Sources, 17.55005°S 149.47223°W, 623 m, 13-06-2011, on *Adiantum capillus-veneris*, Brad Balukjian, 1 ♀, (AMNH_PBI 00384537) (UCB).//Mille Sources Trail, 17.58594°S 149.46795°W, 864 m, 13-06-2011, on *Arachniodes aristata*, Brad Balukjian, 1 ♀ (AMNH_PBI 00384683) (UCB).//Mille Sources, 17.58725°S 149.46628°W, 1141 m, 13-06-2011, on *Paesia divaricatissima*, Brad Balukjian, 1 ♀ (AMNH_PBI 00384692) (UCB).// Mt. Aorai, 17.59663°S 149.49806°W, 1663 m, 21-06-2011, on *Paesia divaricatissima*, Brad Balukjian, 1 ♀ (AMNH_PBI 00384544) (UCB).//Mt. Aorai, 17.59429°S 149.50005°W, 1490 m, 21-06-2011, on *Paesia divaricatissima*, Brad Balukjian, 1 ♀ (AMNH_PBI 00384717) (UCB).//Mt. Aorai, 17.601°S 149.49371°W, 1864 m, 22-06-2011, on *Paesia divaricatissima*, Brad Balukjian, 4 ♂ (AMNH_PBI 00384528, AMNH_PBI 00384542, AMNH_PBI 00384538, AMNH_PBI 00384699), 3 ♀ (AMNH_PBI 00384541, AMNH_PBI 00384718, AMNH_PBI 00384716) (UCB).//Mt Marau, 17.60627°S 149.54003°W, 1329 m, 29-06-2011, on *Davallia sp.*, Brad Balukjian, 1 ♀ (AMNH_PBI 00384519) (UCB).//Pic Vert, 17.59206°S 149.54013°W, 1107 m, 12-06-2011, on *Paesia divaricatissima*, Brad Balukjian, 1 ♂

(AMNH_PBI 00384539) (UCB).// Papenoo Valley, 10 km from sea, 150 m, 23-10-1928, A.M. Adamson, 1 ♂, (AMNH_PBI 00191356) (USNM).//Hitiaa Lava Tubes, 17.62898°S 149.33946°W, 553 m, 30-06-2011, on *Dicranopteris linearis*, Brad Balukjian, 2 ♀ (AMNH_PBI 00384522, AMNH_PBI 00384511), 1 ♂ (AMNH_PBI 00384534) (UCB).//Mille Sources, 17.55005°S 149.47223°W, 623 m, 13-06-2011, on *Adiantum capillus-veneris*, Brad Balukjian, 1 ♀ (AMNH_PBI 00384691) (UCB).//Mille Sources, 17.58594°S 149.46795°W, 864 m, 13-06-2011, on *Arachniodes aristata*, Brad Balukjian, 1 ♀ (AMNH_PBI 00384527) (UCB).//Mt Marau, 17.61074°S 149.53191°W, 1411 m, 29-06-2011, on *Dicranopteris linearis*, Brad Balukjian, 1 ♀ (AMNH_PBI 00384517) (UCB).// t Marau, 17.61258°S 149.5306°W, 1452 m, 29-06-2011, on *Dicranopteris linearis*, Brad Balukjian, 1 ♀ (AMNH_PBI 00384515) (UCB).// Mt Marau, 17.61171°S 149.53122°W, 1426 m, 29-06-2011, on *Dicranopteris linearis*, Brad Balukjian, 1 ♂, (AMNH_PBI 00384516) (UCB).//Mille Sources, 17.58594°S 149.46795°W, 864 m, 13-06-2011, on *Davallia denticulata*, Brad Balukjian, 1 ♀, (AMNH_PBI 00384525) (UCB).//Moorea Is. Three Coconuts Trail, 17.54115°S 149.82705°W, 238 m, 25-06-2011, on *Dicranopteris linearis*, Brad Balukjian, 2 ♂, (AMNH_PBI 00384504, AMNH_PBI 00384503), 1 ♀, (AMNH_PBI 00384502) (UCB).

Diagnosis

This species has three distinct color morphs, but can be recognized by the distinct shape of the left paramere. The species forms a monophyletic group in our phylogeny, defined by the node including putative species 33-44 (Figure 7):

Description

COLORATION: Head: Variable, one color morph with completely yellow-green head; vertex variable, sometimes mostly red, sometimes yellow with two longitudinal red to black stripes bordering eyes, sometimes with medial red stripe; frons yellow with red striations or completely red; clypeus, mostly red except for some yellow spots ventrally; mandibular plate red on dorsal half, yellow ventrally; maxillary plate almost entirely red. Antennae: AI black or red; AII sometimes yellow with red at base and a little red at apex, sometimes grayish; AIII-IV yellow to grayish. Pronotum: Variable, one color morph completely greenish, otherwise yellow with red stripes in lateral thirds. Mesoscutum: Yellow. Scutellum: Yellow. Hemelytra: Variable, one color morph completely green, otherwise clavus mostly pale yellow with red coloration anteriorly near junction with pronotum, and red coloration posteriorly to margin of wing membrane edge of claval commissure; corium sometimes yellow except for red in anterior corners and large red region medially that spreads across clavus to form spade-like red shape in middle of dorsum, sometimes entirely red anteriorly with red on interior half posteriorly forming lei-like red band across dorsum and with red vittae on posterior margin near junction of cuneus and medial membrane vein; cuneus pale yellow sometimes with red, black or grey at apex; membrane veins sometimes red, sometimes yellow or pale; membrane slightly dusky. Legs: Yellow.

STRUCTURE: Head: Vertex flattened in dorsal view, frons and clypeus projected anteriorly with both visible from above, frons very swollen; posterior margin of head capsule slightly carinate and rectilinear, slight sulcus medially in vertex, maxillary plate swollen. Pronotum: Anterior margin sinuate and carinate; calli slightly evident and raised; disc slightly rounded;

posterior margin slightly excavate. Mesoscutum: Exposed and sometimes raised medially, sometimes with transverse ridge, sometimes sulcate medially. Scutellum: Slightly raised to flat. Male Genitalia: Right paramere with ventral medial process with 3-5 or 7 teeth perpendicular to single-lobed apophysis with 1-5 or 7 teeth (Figure 90c); aedeagus with single, medium-width spicule; phallotheca with single lobe and triangular flap near base (Figure 90a); left paramere's sensory lobe sometimes rounded basally, sometimes with prominent basal process (Figure 90b).

Measurements

Males (n=15): BL: 2.955-4.126 (3.51±0.41); BW: 0.888-1.345 (1.16±0.14); LL: 0.969-1.294 (1.13±0.11); PL: 0.305-0.563 (0.39±0.06); PW: 0.842-1.086 (0.95±0.08); AI: 0.373-0.581 (0.44±0.05); AII: 0.87-1.663 (1.29±0.18); AIII: 0.468-0.787 (0.62±0.10); AIV: 0.283-0.56 (0.43±0.10); HL: 0.307-0.505 (0.42±0.06); HW: 0.514-0.719 (0.63±0.04); VW: 0.225-0.385 (0.31±0.04); CL: 0.37-0.792 (0.51±0.09).

Females (n=17): BL: 2.986-4.391 (3.71±0.4); BW: 0.956-1.376 (1.20±0.11); LL: 0.849-1.403 (1.11±0.16); PL: 0.292-0.433 (0.37±0.04); PW: 0.843-1.087 (0.96±0.07); AI: 0.308-0.611 (0.46±0.08); AII: 0.755-1.536 (1.25±0.20); AIII: 0.364-0.832 (0.62±0.13); AIV 0.224-0.572 (0.43±0.12); HL: 0.345-0.55 (0.46±0.05); HW: 0.546-0.676 (0.61±0.04); VW: 0.272-0.398 (0.34±0.04); CL: 0.378-0.582 (0.51±0.07).

Distribution

This species is known from several localities on Tahiti and one locality on Moorea (Figure 91).

Plant Affiliation

This species is affiliated almost exclusively with ferns (given the number of individuals collected with ferns, we consider them to be a host plant, and the one specimen collected on *Metrosideros collina* to be a sitting record). There does not seem to be much host specificity within ferns, however, as we collected this species on 5 different species.

Remarks

This species displays significant color polymorphism. We synonymize Knight's (1937) *Pseudoloxops adamsoni*, *Pseudoloxops nigribasicornis*, and consider *Pseudoloxops tahiticus rubromarginatus* to be one of the three color morphs. There is considerable variation in the male genitalia of the color morphs, especially the presence/absence of a basal process in the left paramere. Nonetheless, the shape of the left paramere for all color morphs clusters together in the canonical variates analysis.

***Pseudoloxops* n. sp. 22** (Figures 92-94)

Material Examined: Holotype, ♂, French Polynesia: Tahiti Is. Mt Marau, 17.61171°S 149.53122°W, 1426 m, 29-06-2011, on *Dicranopteris linearis*, det. by Brad Balukjian, Brad

Balukjian, (AMNH_PBI 00384523) (UCB). Paratypes: Mt Marau, 17.61258°S 149.5306°W, 1452 m, 29-06-2011, on *Dicranopteris linearis*, Brad Balukjian, 1 ♂, (AMNH_PBI 00384499) (UCB).//Mille Sources, 17.55005°S 149.47223°W, 623 m, 13-06-2011, on *Adiantum capillus-veneris*, Brad Balukjian, 1 ♂, (AMNH_PBI 00384690) (UCB).

Diagnosis

This species superficially resembles one of the color morphs of *Pseudoloxops tahiticus*, but can be diagnosed by the combination of the hemelytra coloration and the shape of the left paramere (Figure 23). The species forms a monophyletic group in our molecular phylogeny, defined by node 32 (Figure 7).

Description

COLORATION: Head: Vertex variable, sometimes almost completely red with some yellow medially, sometimes with two red or reddish-black longitudinal stripes bordering eyes a and sometimes connecting to red bird's foot pattern; frons completely red, sometimes with yellow specks; clypeus red on dorsal two-thirds, yellow ventrally; mandibular plate red on dorsal half, yellow ventrally; maxillary plate almost entirely red. Antennae: A1 red to black; AII yellow, sometimes with some red at base and apex; AIII-IV yellow. Pronotum: Lateral thirds red, the rest yellow. Mesoscutum: Yellow with some red in lateral corners. Scutellum: Yellow. Hemelytra: Anterior corner of clavus red at junction with pronotum, continuous with anterior red of corium; clavus also red posteriorly connecting to red of corium to form red spadelike pattern; cuneus yellow, sometimes with red dot at intersection with membrane vein connecting two cells, sometimes with red at apex; membrane veins red posteriorly. Legs: Yellow

STRUCTURE: Head: Posterior margin carinate and rectilinear; vertex with medial sulcation; frons swollen and anteriorly projected; maxillary plate swollen. Pronotum: Anterior margin carinate and sinuate with sulcus separating it from calli, which are evident and raised; disc slightly raised; posterior margin rectilinear to concave. Mesoscutum: Sometimes elevated laterally and medially sulcate, sometimes slightly rounded. Scutellum: Flat. Male Genitalia: Right paramere with ventral medial process with 4-5 teeth perpendicular to single-lobed apophysis with 2-3 teeth (Figure 93c); aedeagus with single, medium-width spicule; phallotheca with single lobe and triangular flap near base (Figure 93a); left paramere usually with basal process on sensory lobe, sometimes absent (Figure 93b).

Measurements

Males (n=3): BL: 3.567-3.735 (3.66±0.09); BW: 0.987-1.249 (1.12±0.13); LL: 1.036-1.171 (1.11±0.07); PL: 0.313-0.407 (0.35±0.05); PW: 0.889-1.004 (0.94±0.06); AI: 0.428-0.447 (0.44±0.01); AII: 1.199-1.297 (1.24±0.05); AIII: 0.519-0.575 (0.55±0.04); AIV: 0.356-0.418 (0.38±0.03); HL: 0.306-0.431 (0.37±0.06); HW: 0.589-0.624 (0.61±0.02); VW: 0.271-0.32 (0.30±0.03); CL: 0.511-0.56 (0.53±0.03).

Females unknown.

Distribution

This species is endemic to Tahiti, and is known from Mt. Marau and Mille Sources (see Figure 94).

Plant Affiliation

This species is strictly associated with ferns, and was collected from two different species: *Dicranopteris linearis* (Gleicheneaceae) and *Adiantum capillus-veneris* (Pteridaceae).

Remarks

P. n. sp. 22 is endemic to Tahiti and strictly associated with ferns. It is very similar in appearance to *Pseudoloxops tahiticus*, although its left paramere has a distinct shape (Figure 23). It is limited to mid- to high-elevations.

Pseudoloxops **n. sp. 23** (Figures 95-97)

Material Examined: Holotype: ♂, French Polynesia: Tahiti Is. Plateau Taravao, 17.78678°S 149.24748°W, 792 m, 09-06-2011, on *Metrosideros collina*, det. by Ravahere Taputuarai, Brad Balukjian, (AMNH_PBI 00384698) (UCB). Paratypes: Hitiaa Lava Tubes, 17.6287°S 149.35143°W, 745 m, 30-06-2011, on *Metrosideros collina*, Brad Balukjian, 1 ♀, (AMNH_PBI 00384500) (UCB).//Moorea Is. Mt Tohiea, 17.55352°S 149.81747°W, 840 m, 26-09-2009, at blacklight, Peter Oboyski, 1 ♀, (AMNH_PBI 00384494) (UCB).

Diagnosis

This species can be identified by its bat-shaped red vitta spreading across the clavus and corium and the red coloration in the posterior third of the cuneus.

Description

COLORATION: Head: Vertex pale yellow sometimes with two reddish black longitudinal stripes bordering eyes, sometimes connecting to red bird's foot pattern (but bird's foot lacks the usual medial longitudinal stripe originating at posterior margin of head); frons completely black/red with a spot of yellow medially or with red striations forming horseshoe crab pattern and red Fu Manchu mustache pattern; clypeus entirely red; dorsal half of mandibular plate red, ventral half yellow; maxillary plate almost entirely red or black. Antennae: AI red to black; AII yellow, sometimes with red spots at base and apex; AIII-IV yellow. Pronotum: Lateral thirds blackish red, the rest yellow. Mesoscutum: Yellow, sometimes with red markings in anterior corners. Scutellum: Yellow. Hemelytra: Clavus yellow except for red in anterior corners at junction with pronotum and posteriorly at base of claval commissure, forming a bat-shaped red vitta that spreads into corium; corium also yellow except for red in anterior corners and red vitta that connects to clavus; cuneus red in posterior third, yellow in anterior two-thirds; membrane veins red. Legs: Yellow, except sometimes red in apical two-thirds of metafemora.

STRUCTURE: Head: Posterior margin rectilinear and sometimes carinate, medial sulcus in vertex, frons swollen and projected forward. Pronotum: Collar present; anterior margin slightly carinate and rectilinear to sinuate; calli slightly evident; disc slightly rounded; posterior margin excavate. Mesoscutum: Raised. Scutellum: Flat. Male Genitalia: Right paramere with ventral medial process with 4 teeth perpendicular to single-lobed apophysis with 2 teeth (Figure 96c); aedeagus with single, medium-width spicule; phallotheca with single lobe and triangular flap near base (Figure 96a); left paramere's sensory lobe rounded basally (Figure 96b).

Measurements

Males (n=1): BL: 3.793; BW: 1.275; LL: 1.324; PL: 0.452; PW: 1.092; AI: 0.544; AII: 1.68; AIII: 0.748; AIV: 0.693; HL: 0.489; HW: 0.735; VW: 0.313; CL: N/A.

Females (n=2): BL: 4.6-4.756 (4.68±0.11); BW: 1.434-1.686 (1.56±0.18); LL: 1.27-1.457 (1.36±0.13); PL: 0.446-0.491 (0.47±0.03); PW: 1.064-1.168 (1.12±0.07); AI: 0.516-0.546 (0.53±0.02); AII: 1.747-1.918 (1.83±0.12); AIII: 0.798-0.937 (0.87±0.10); AIV: 0.724-0.726 (0.725±0.001); HL: 0.398-0.541 (0.47±0.10); HW: 0.698-0.772 (0.735±0.05); VW: 0.326-0.375 (0.35±0.03); CL: 0.664-0.68 (0.67±0.01).

Distribution

This species is known from three localities on Tahiti and Moorea, including the trail to the highest peak on Moorea (Mt. Tohiea; Figure 97).

Plant Affiliation

The only plant affiliated with this species is *Metrosideros collina* (Myrtaceae).

Remarks

This is one of the few species which does not comprise a monophyletic group. It is part of a larger clade that is primarily associated with ferns, and its color pattern is similar to one of the color morphs of its close relative, *Pseudoloxops tahiticus*. However, the shape of the left paramere is quite distinctive. This species is found at high elevations in cloud forest.

Discussion

The integration of multiple data sources and analyses greatly improved our ability to discover new biodiversity because we were able to iteratively test species hypotheses against ecological, geographical, morphological, and molecular data. Had we relied on the more traditional approach to species delimitation in entomology, namely the qualitative examination of the morphology of multiple specimens and subsequent groupings into species, we would have come to very different conclusions. For example, none of the cryptic species delimited (n. sp. 1, n. sp. 12, n. sp. 17, n. sp. 20, and n. sp. 22) would have been detected. By sequencing multiple genes and using monophyly and genetic distance as delimitation criteria, we were able to discover this

diversity. Furthermore, by quantifying the shape of the male genitalia (specifically the left paramere) using geometric morphometrics, we were able to detect finer-scale differences (in our canonical variates analysis) that might not be detected by the human eye in the typical qualitative examination process, as inter-specific differences in the left paramere are slight for this radiation. For example, the left paramere of n. sp. 1 has a slightly different shape than its sister species, *P. rubrocuneatus*, which was confirmed in our CVA analysis, but which would have been difficult to detect otherwise. The ability of geometric morphometrics to discriminate between closely related species better than expert taxonomists has been documented in other groups (Mutanen & Pretorius, 2007), and we therefore suggest its widespread adoption in integrative taxonomic studies. In this study, using the "classifier" function in PAST, all 75 specimens examined were correctly assigned to their species 100% of the time, demonstrating the efficacy of this method.

The opposite of cryptic species, polymorphism within species, was also detected using the integrative taxonomy approach. Knight (1937) described the species *P. flavus* from a single male and *P. rubrocuneatus* from a single female. The two look very different in color, with *flavus* yellow throughout and *rubrocuneatus* having multiple red markings. Specimens of both were collected in this study and initially grouped into separate species based on Knight's description. However after examining all of the data, they were found to be conspecific, as they clustered together in the phylogenetic, morphometric, and genetic distance analyses. We therefore relegated *flavus* to a synonym of *rubrocuneatus*. This color polymorphism was also detected for the species *P. tahiticus*, which also led to significant revision of Knight's taxonomy. Knight noted that *tahiticus* and P. *adamsoni* looked very similar to each other, but distinguished between them based on the shape of the left paramere. However, our morphometric analysis revealed that both species have a basal process on the sensory lobe of the left paramere, and that their general shape is indistinguishable. Knight's subspecies, *P. tahiticus rubromarginatus*, with a very different color pattern on the clavus and corium, was also found to be indistinguishable from *adamsoni* and *tahiticus* in our analysis. More surprising, however, was that Knight's *P. nigribasicornis*, with its simple yellow coloration, grouped together ecologically, genetically, and morphologically with these other species as well, which we now consider to be a single, polymorphic species, *P. tahiticus* (*adamsoni* and *nigribasicornis* becoming synonyms, with *tahiticus rubromarginatus* remaining a sub-species, although we do not consider sub-species a meaningful taxonomic rank). These findings underscore the importance of comprehensive sampling when doing taxonomic studies; Knight made his species decisions based on a total of 16 specimens for the entire radiation, and without more material, it is difficult to see the difference between inter- and intraspecific variation. Given the emphasis placed on color as a diagnostic character system in other taxonomic treatments of *Pseudoloxops* (Linnavuori, 1994; Yasunaga, 1997), it was surprising that color was so plastic in several examples in this study. Future taxonomic studies of this genus, and perhaps other genera in the tribe Orthotylini, should be aware of this and treat color characters with caution when making species diagnoses.

The color polymorphism observed here could also inspire future research on its purpose and controlling mechanisms. Polymorphism is common in plant bugs and has been documented in the subfamily Orthotylinae (Blinn, 1988; Wheeler, 2001), but our findings contradict the long-standing (but largely untested) assertion that color is diagnostic at the species level for *Pseudoloxops*. The bright yellow, red, and green colors observed in this radiation closely match the brightly colored flowers of many of the angiosperms with which it is associated (*e.g.*,

Hibiscus tiliaceus, *Metrosideros collina*) as well as the fronds of several ferns. Although purely conjecture at this point, it is possible that the bugs' coloration provides camouflage from visual predators, such as birds. This phenomenon has been observed in other Heteroptera, such as shield bugs (Johansen *et al.*, 2010). Experimental studies are needed to test this hypothesis, as well as much more basic natural history data on the prevalence, genetic basis, and chemistry of color in these organisms. It is interesting to note that while *P. tahiticus* (as now defined based on this study) contains several color morphs, there is some phylogenetic structure differentiating the different morphs. For example, two of the clades (one including Z126, the other including Z108) nested within the larger clade defining this species (Figure 20) contain specimens exclusively with the simple yellow coloration (formerly *P. nigribasicornis*). The basal process of the left paramere's sensory lobe is reduced or absent in the erstwhile *P. nigribasicornis* specimens, providing more evidence of divergence between the brightly colored morphs and the simple yellow morphs. Again, much more natural history and genetic data must be collected in order to document this divergence, including the inclusion of more genetic loci (preferably rapidly evolving ones).

In addition to color polymorphism, there is also some evidence for color convergence in this radiation. When n. sp. 11 was initially collected in the field, we grouped it with n. sp. 19 due to the similarity in coloration, especially the red lateral thirds of the pronotum and red on the first antennal segment (Figures 56, 78). However, a closer look at the morphology and the addition of more lines of evidence revealed them to be two distinct, convergent species. In an informal examination of undescribed *Pseudoloxops* species further west in the Pacific and into Australia and Southeast Asia, we discovered several more examples of convergence in color. For example, Figure 98 shows the remarkable resemblance between an undescribed species from New Caledonia and n. sp. 14 from the French Polynesian island of Raiatea. Clearly, the entire genus needs lots of work, including a full revision and formal test of monophyly. Once we have a better idea of the genus' bounds, we will have the appropriate framework for examining the processes underlying such patterns as convergent color evolution.

While the DNA sequence data we collected contained lots of useful phylogenetic signal, the discrete morphological data was of limited utility. Many of the characters we coded were too plastic to recover much phylogenetic structure on a strict consensus tree, although examining individual most parsimonious trees would provide more resolution (although choosing which of the 100 trees to examine would be arbitrary). The plasticity in morphological data was largely due to many of the characters relating to color, which this study has established as a variable character both within and between species. Our morphological analysis was further weakened by having a small number of characters (21) relative to terminals (176). The challenge with groups such as plant bugs will continue to be finding sufficient phylogenetic characters outside of the male genitalia. Scanning electron microscopy could provide some solutions, as it could be used to discover new character systems in features such as the antennae (Catala, 1997). With regard to phylogenetic signal, it is worth noting that all but 2 of the species delimited and described here are comprised of monophyletic clades. Given that phylogeny provides a representation of the evolution of the tree of life (at least for sexually reproducing organisms), we consider it a good guide for taxonomy; here we used it to come up with our initial species hypotheses in the iterative framework. However, phylogeny (and the criterion of monophyly) is not fool-proof; although *rubrocuneatus* and n. sp. 23 are not monophyletic, for example, we consider them each

to be distinct species due to their separation from their respective sister species according to morphological evidence. The lack of monophyly could be due to a number of processes, but in this case, given the recent nature of this radiation, it is likely incomplete lineage sorting, or perhaps hybridization, which was shown by Mallet (2008) to be more frequent in insects than previously thought.

We found 23 new species of *Pseudoloxops*, confirmed three others, and synonymized three more, for a total of 26 species known from French Polynesia. While this is not a biogeography study, it is worth noting that the diversity patterns found here match species-area expectations (Preston, 1960; MacArthur & Wilson, 1967). Tahiti, by far the largest island examined, has 13 species, 8 of them endemic to the island. The smallest island on which *Pseudoloxops* was found, Rimatara, has a single species, which is endemic to the island. The smallest islands sampled (Mehetia and Tetiaroa) did not support any *Pseudoloxops* species despite their proximity to Tahiti, perhaps suggesting a minimum area requirement for this lineage. More exhaustive sampling of the Leeward Islands is necessary to formally test island biogeography theory for *Pseudoloxops*, especially on the large island of Raiatea, where only 2 species were found (one endemic).

With 26 described endemic species, French Polynesia now contains about 43% of the entire worldwide *Pseudoloxops* fauna, an astounding figure considering its range across the continents of Africa, Asia, and Australia. This is almost certainly an artifact of taxonomic and sampling effort, as at least dozens more species are known from museum collections. However, there is no question that the islands of French Polynesia, specifically the Austral and Society archipelagoes, should be considered hot spots of *Pseudoloxops* biodiversity. Given the lack of basic biodiversity knowledge for the terrestrial invertebrate fauna of these islands, *Pseudoloxops* could serve as an "indicator lineage" of the islands' biodiversity importance and vulnerability as conservation decisions are made. Only 2% of the land area in French Polynesia is officially protected, leaving much room for improvement (Meyer, 2007). While many of the species are found in cloud forest habitat that is not imminently threatened by habitat alteration, several species are found at low- to mid-elevations as well in areas heavily impacted by humans. It is unusual for endemic invertebrates to have survived at such low elevations and in such conditions on remote oceanic islands (Gillespie *et al.*, 2008), but these plant bugs have managed to persist, perhaps through plasticity in their diet. It is important that knowledge of these unique creatures is widely disseminated in the islands in order to increase conservation awareness and to foster local pride in the islands' natural heritage.

Integrative taxonomy allows us to move past tiresome debates over species concepts and headfirst into the daunting task of documenting and describing the planet's biodiversity, especially for such woefully unknown taxa as invertebrates. By considering all of the data available to discriminate between independently evolving lineages, we are able to infer species boundaries and to explain discrepancies between data sources by drawing on our knowledge of biological processes. Using this approach, we delimited 26 species of *Pseudoloxops* plant bugs in French Polynesia, a more accurate number than any single data source would have provided alone. For example, under the monophyletic species concept, 48 species would have been delimited, while under the traditional practice of examining morphology for fixed differences between species, we would not have detected cryptic species, thus under-estimating diversity.

We also emphasize that species are hypotheses in need of future testing. While we used multiple data sources that each have the potential to show evidence of species boundaries, the search for more and better data sources should continue. For example, while the structure and shape of the male genitalia has long been considered a key data source in plant bug taxonomy due to the "lock and key hypothesis" (Shapiro & Porter, 1989), this hypothesis has rarely been tested empirically (Huber, 2003). The male genitalia may be a less important character system than has been assumed. However, other character systems have been largely unexplored in species delimitation of plant bugs but may be of great value, such as the suite of sex pheromones females use to attract males to initiate mating (Aldrich, 1988) and the sensilla on the males' antennae for receiving those pheromones (Graham, 1988). An examination of these characters could provide more useful data in testing species hypotheses and forming new ones for undocumented species.

Finally, we suggest using an integrative taxonomy framework to discover and document biodiversity where it is financially and practically feasible—such an exhaustive approach, while effective, is undoubtedly more expensive and intensive than traditional taxonomic practices. Given the taxonomic impediment for groups such as invertebrates, we encourage taxonomists to continue describing biodiversity using traditional methods in order to have a record of its existence. But we believe an integrative approach provides the best method of accurately delimiting and diagnosing species.

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Chapter 1 Tables and Figures

Table 1: Matrix of discrete morphological characters for ingroup specimens; specimens were assigned a code beginning with the prefix “Z.” The key to the characters is given in Table 2.

	Char 1	Char 2	Char 3	Char 4	Char 5	Char 6	Char 7	Char 8	Char 9	Char 10	Char 11	Char 12	Char 13	Char 14	Char 15	Char 16	Char 17	Char 18	Char 19	Char 20	Char 21
Z5	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	0	0
Z6	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	1	1	0	0
Z7	1	1	2	1	1	2	0	0	0	0	0	?	1	1	1	2	1	1	0	0	0
Z8	2	2	3	1	1	?	0	0	0	0	2	1	1	1	2	0	1	1	2	1	0
Z9	3	3	0	?	1	3	1	2	2	2	3	1	?	?	?	?	?	?	?	2	?
Z10	2	2	3	1	1	3	0	0	0	0	2	1	?	?	?	?	?	?	?	1	?
Z11	0	0	0	0	1	4	0	2	0	0	0	1	1	1	1	0	2	1	0	0	0
Z12	4	0	0	1	1	1	1	1	1	1	1	2	?	?	?	?	?	?	?	3	?
Z13	4	0	0	0	1	?	1	1	1	1	1	1	?	?	?	?	2	1	1	3	?
Z14	0	0	0	0	0	0	0	3	0	0	3	3	0	1	0	0	3	1	3	4	0
Z15	0	0	0	0	0	0	0	0	0	0	3	3	?	?	?	?	?	?	?	4	?
Z16	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	?	?	?	0	0
Z17	4	0	0	0	2	1	1	1	1	1	1	1	1	1	1	1	2	1	1	5	0
Z18	5	0	0	1	1	3	0	2	2	2	3	1	?	?	?	?	?	?	?	2	?
Z19	0	0	0	0	0	0	0	0	0	0	2	3	?	?	?	?	?	?	?	0	?
Z20	2	?	?	?	?	3	0	0	0	0	2	1	1	1	2	0	?	?	?	1	0
Z24	?	?	?	?	?	1	?	1	1	1	1	1	1	1	1	1	2	1	1	3	0
Z25	?	?	4	1	2	5	0	0	3	4	0	2	1	1	1	1	2	1	0	1	0
Z27	4	0	1	0	1	1	1	1	1	1	1	1	?	?	?	?	?	?	?	0	?
Z28	0	0	0	0	0	0	0	3	0	0	2	3	0	1	0	0	?	?	?	4	0
Z29	0	0	0	0	0	0	0	0	0	0	3	3	?	?	?	?	?	?	?	4	?
Z30	0	0	0	0	0	0	0	3	0	0	3	3	?	?	?	?	?	?	?	4	?
Z31	0	0	0	0	0	0	0	3	0	0	3	3	?	?	?	?	?	?	?	4	?
Z32	4	0	0	1	1	1	1	1	1	1	1	1	?	?	?	?	?	?	?	5	?
Z33	0	0	0	0	0	0	0	3	0	0	3	3	?	?	?	?	?	?	?	4	?
Z34	2	0	0	1	1	1	1	1	1	1	1	1	?	?	?	?	?	?	?	5	?
Z36	4	0	0	1	0	1	1	1	1	1	1	1	?	?	?	?	?	?	?	5	?
Z37	4	0	0	1	1	1	1	1	1	1	1	1	1	1	1	?	2	1	1	3	?
Z38	4	0	0	1	0	1	1	1	1	1	1	1	?	?	?	?	?	?	?	5	?
Z40	0	0	0	0	0	0	0	3	0	0	3	3	?	?	?	0	2	1	4	4	0
Z41	0	0	0	0	0	0	0	3	0	0	3	3	0	1	0	0	2	1	4	4	0
Z42	4	2	5	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	6	0
Z43	2	?	?	1	?	1	1	1	1	1	1	1	1	1	1	1	2	1	1	3	0
Z44	4	?	?	1	2	1	1	1	1	1	1	1	1	1	1	1	2	1	1	3	0
Z45	0	0	0	0	0	0	0	0	0	0	2	3	1	0	1	0	1	1	0	0	0
Z46	2	2	3	1	2	3	0	0	0	0	2	1	1	1	2	0	2	1	2	1	0

	Char 1	Char 2	Char 3	Char 4	Char 5	Char 6	Char 7	Char 8	Char 9	Char 10	Char 11	Char 12	Char 13	Char 14	Char 15	Char 16	Char 17	Char 18	Char 19	Char 20	Char 21
Z47	4	?	?	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	0	0
Z48	5	0	0	0	2	3	0	0	0	0	2	1	?	?	?	?	?	?	?	1	?
Z49	2	2	3	1	2	3	0	0	0	0	2	1	?	?	?	?	?	?	?	1	?
Z50	2	2	3	1	2	3	0	0	0	0	2	1	1	1	2	0	1	1	2	1	0
Z51	0	0	0	0	0	0	0	0	0	0	0	3	?	?	?	?	?	?	?	0	?
Z52	5	2	3	1	2	3	0	0	0	0	2	1	?	?	?	?	?	?	?	1	?
Z53	0	0	0	0	0	3	0	0	0	0	2	3	?	?	?	?	?	?	?	0	?
Z54	0	0	0	0	0	0	0	3	0	0	3	3	?	?	?	?	3	1	3	4	?
Z55	2	2	2	1	2	1	1	1	1	1	1	1	?	?	?	?	?	?	?	5	?
Z56	4	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	0	0
Z57	0	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1	2	1	1	5	0
Z58	0	0	0	0	0	0	0	0	0	0	3	3	?	?	?	?	?	?	?	4	?
Z60	0	0	0	0	0	0	0	0	0	0	2	0	?	?	?	?	?	?	?	0	?
Z61	5	3	0	1	1	3	1	2	2	2	3	1	1	1	1	0	?	?	?	2	0
Z62	5	3	0	1	1	3	1	2	2	2	3	1	?	?	?	?	?	?	?	2	?
Z63	0	0	0	0	0	0	0	0	0	0	2	0	?	?	?	?	?	?	?	0	?
Z64	4	2	2	1	0	1	1	1	1	1	1	1	?	?	?	?	?	?	?	3	?
Z65	0	0	0	0	0	0	0	0	0	0	2	0	?	?	?	?	?	?	?	0	?
Z66	2	2	5	1	2	3	0	0	0	0	2	1	?	?	?	?	?	?	?	1	?
Z67	0	0	0	0	0	0	0	0	0	0	2	3	?	?	?	?	?	?	?	0	?
Z68	2	2	0	1	2	3	0	0	0	0	2	1	?	?	?	?	?	?	?	1	?
Z69	4	0	0	1	2	1	1	1	1	1	1	1	1	1	1	1	2	1	1	3	0
Z70	1	1	1	1	1	2	0	0	0	0	0	3	?	?	?	?	?	?	?	0	?
Z71	0	0	0	0	0	0	0	0	0	0	2	0	1	0	1	0	1	1	0	0	0
Z72	1	1	2	1	1	2	0	0	0	0	0	3	1	1	1	2	1	1	0	0	0
Z73	0	0	4	1	3	5	1	2	1	3	4	1	?	?	?	?	?	?	?	7	?
Z74	6	4	6	1	3	5	0	0	3	4	5	1	?	?	?	?	?	?	?	1	?
Z75	1	1	?	1	1	2	0	0	0	0	0	3	?	?	?	?	?	?	?	0	?
Z76	0	0	0	0	0	0	0	0	0	0	2	3	1	0	1	?	1	1	0	0	?
Z77	0	0	0	0	0	0	0	0	0	0	0	3	1	1	1	0	?	?	?	0	0
Z78	0	5	6	1	3	2	0	0	4	2	6	1	1	1	1	0	2	1	5	1	0
Z79	4	?	?	1	1	1	1	1	1	1	1	1	1	1	1	?	2	1	1	3	?
Z80	1	1	?	1	1	2	0	0	0	0	0	3	1	1	1	2	1	?	0	0	0
Z81	0	5	6	1	3	2	0	0	4	2	6	1	?	?	?	?	?	?	?	1	?
Z82	0	0	0	0	0	0	0	0	0	0	2	3	?	?	?	?	?	?	?	0	?
Z83	0	0	0	0	0	0	0	0	0	0	2	3	?	?	?	?	?	?	?	0	?
Z84	3	3	0	1	1	3	1	2	2	2	3	1	?	?	?	?	?	?	?	2	?
Z85	5	2	3	1	1	3	1	2	2	2	3	1	1	1	1	0	0	0	0	2	0
Z86	1	1	1	1	1	2	0	0	0	0	0	3	?	?	?	?	?	?	?	0	?

	Char 1	Char 2	Char 3	Char 4	Char 5	Char 6	Char 7	Char 8	Char 9	Char 10	Char 11	Char 12	Char 13	Char 14	Char 15	Char 16	Char 17	Char 18	Char 19	Char 20	Char 21
Z94	5	?	?	?	2	3	0	0	0	0	0	1	?	?	?	0	?	?	?	1	0
Z95	1	1	1	1	1	2	0	0	0	0	0	3	?	?	?	?	?	?	?	0	?
Z96	1	1	1	1	1	2	0	0	0	0	0	3	?	?	?	?	?	?	?	0	?
Z97	6	?	?	1	3	5	0	0	3	4	0	2	1	1	1	1	2	1	5	1	0
Z98	6	?	?	1	3	5	0	0	3	4	0	1	1	1	1	1	2	1	5	1	0
Z99	6	?	?	1	3	5	0	0	3	4	2	1	?	?	?	?	?	?	?	1	?
Z100	0	0	5	1	2	2	0	0	5	5	7	1	?	?	?	?	?	?	?	1	?
Z101	2	4	6	1	3	5	0	0	3	4	5	1	?	?	?	?	?	?	?	1	?
Z102	7	5	7	1	3	5	0	0	3	4	8	1	1	1	1	1	2	1	5	1	0
Z103	2	2	0	1	2	3	0	0	0	0	2	1	?	?	?	?	?	?	?	1	?
Z104	2	5	7	1	3	5	0	0	3	4	0	1	1	1	1	1	2	1	5	1	0
Z105	7	5	7	1	3	5	0	0	3	4	8	1	?	?	?	?	?	?	?	1	?
Z106	0	0	5	1	2	2	0	2	5	5	7	1	1	1	1	2	2	1	6	1	0
Z107	5	2	0	0	1	3	0	0	0	0	2	1	?	?	?	?	?	?	?	1	?
Z108	0	0	0	0	1	2	0	0	0	0	2	0	?	?	?	?	?	?	?	0	?
Z109	0	0	5	1	2	2	0	0	5	5	7	1	1	1	1	2	2	1	6	1	0
Z110	7	5	?	1	3	5	0	0	3	4	8	1	?	?	?	?	?	?	?	1	?
Z111	7	5	7	1	3	5	0	0	3	4	3	1	1	1	1	1	2	1	5	1	0
Z112	6	4	7	1	3	5	0	0	3	4	3	1	?	?	?	?	?	?	?	1	?
Z113	0	0	5	1	2	2	0	2	5	5	7	1	1	1	1	2	2	1	6	1	0
Z114	0	0	5	1	2	2	0	0	5	5	7	1	1	1	1	2	2	1	6	1	0
Z115	2	2	0	1	1	3	0	0	0	0	2	1	?	?	?	?	?	?	?	1	?
Z116	2	2	0	1	1	3	0	0	0	0	2	1	1	1	2	0	1	1	2	1	0
Z117	5	6	7	1	3	2	0	0	5	3	2	1	?	?	?	?	?	?	?	1	?
Z118	0	0	0	1	2	2	0	2	5	3	7	1	?	?	?	?	?	?	?	1	?
Z119	5	0	0	1	1	3	0	0	0	0	2	1	?	?	?	?	?	?	?	1	?
Z120	7	6	7	1	2	5	0	0	3	4	8	2	1	1	1	?	2	1	5	1	?
Z121	0	0	0	0	0	5	0	0	0	0	0	0	?	?	?	?	?	?	?	4	?
Z122	0	0	0	0	0	5	0	0	0	0	0	0	?	?	?	?	?	?	?	4	?
Z123	0	0	0	0	0	5	0	0	0	0	0	0	1	1	1	0	2	1	0	4	0
Z124	0	0	0	0	0	3	0	0	0	0	0	3	?	?	?	?	?	?	?	0	?
Z125	0	0	3	1	2	5	0	2	5	3	7	1	1	1	1	?	?	?	?	1	?
Z126	0	0	0	0	1	2	0	0	0	0	2	0	1	1	1	1	2	1	5	0	0
Z127	5	6	4	1	2	5	0	0	3	4	2	1	?	?	?	?	?	?	?	1	?
Z128	0	0	0	0	0	7	0	0	0	0	2	4	1	1	1	0	2	1	7	0	0
Z129	5	6	4	1	3	5	0	0	5	2	3	1	?	?	?	?	?	?	?	1	?
Z130	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	2	1	0	0	0
Z131	0	0	0	0	0	0	0	0	0	0	2	3	?	?	?	?	?	?	?	0	?
Z132	0	0	0	0	0	0	0	0	0	0	0	3	?	?	?	?	?	?	?	0	?

	Char 1	Char 2	Char 3	Char 4	Char 5	Char 6	Char 7	Char 8	Char 9	Char 10	Char 11	Char 12	Char 13	Char 14	Char 15	Char 16	Char 17	Char 18	Char 19	Char 20	Char 21
Z133	0	0	0	0	0	7	0	0	0	0	2	1	1	1	1	0	2	1	7	0	0
Z134	2	2	3	1	1	3	0	0	0	0	2	1	1	1	2	0	2	1	2	1	0
Z135	0	0	3	1	2	5	0	1	5	3	7	1	1	1	1	0	2	1	6	1	0
Z136	0	0	0	0	1	2	0	0	0	0	2	0	?	?	?	?	?	?	?	0	?
Z137	5	2	0	1	1	3	0	0	0	0	2	1	?	?	?	?	?	?	?	1	?
Z138	0	0	0	0	0	2	0	0	0	0	2	0	1	1	1	0	2	1	5	0	0
Z139	0	0	0	0	0	2	0	0	0	0	2	0	?	?	?	?	?	?	?	0	?
Z140	0	0	8	1	2	6	1	2	1	3	4	1	?	?	?	?	?	?	?	1	?
Z141	0	0	0	0	0	0	0	0	0	0	2	0	?	?	?	?	?	?	?	0	?
Z142	0	0	0	0	0	2	0	0	0	0	0	0	?	?	?	1	2	1	5	0	0
Z143	5	6	4	1	3	2	0	0	5	2	3	1	?	?	?	?	?	?	?	1	?
Z144	0	0	0	0	0	2	0	0	0	0	0	0	?	?	?	?	?	?	?	0	?
Z145	5	6	4	1	3	5	0	0	3	4	3	1	?	?	?	?	?	?	?	1	?
Z146	6	6	4	0	3	5	0	0	3	4	2	1	1	1	1	0	?	?	?	1	?
Z147	0	0	3	1	2	5	1	2	1	3	6	1	?	?	?	?	?	?	?	1	?
Z148	0	0	0	0	0	5	0	0	0	0	0	0	?	?	?	?	?	?	?	4	?
Z149	0	0	0	0	0	5	0	0	0	0	0	0	1	1	1	0	2	1	?	4	0
Z150	2	2	3	1	1	3	0	0	0	0	2	1	?	?	?	?	?	?	?	1	?
Z151	5	2	0	0	1	3	0	0	0	0	2	1	?	?	?	?	?	?	?	1	?
Z152	6	5	4	1	3	2	0	0	5	2	7	1	1	1	1	1	2	1	5	1	0
Z153	6	1	4	1	2	2	0	0	5	2	2	1	?	?	?	?	?	?	?	1	?
Z154	2	2	0	1	1	3	0	0	0	0	2	1	1	1	2	?	1	1	2	1	?
Z155	0	0	0	0	0	7	0	0	0	0	2	4	1	1	1	0	2	1	7	0	0
Z156	0	0	0	0	0	3	0	0	0	0	0	1	?	?	?	?	?	?	?	1	?
Z157	0	0	0	0	0	7	0	0	0	0	2	1	1	1	1	0	?	?	?	0	0
Z158	2	2	0	1	2	3	0	0	0	0	2	1	1	1	2	0	2	1	2	1	0
Z159	2	2	5	1	2	3	0	0	0	0	2	1	?	?	?	?	?	?	?	1	?
Z160	5	2	0	1	1	3	0	0	0	0	2	1	?	?	?	?	?	?	?	1	?
Z161	2	2	5	1	2	3	0	0	0	0	2	1	1	1	2	?	2	1	2	1	?
Z162	2	2	0	1	2	3	0	0	0	0	2	1	1	1	2	0	2	1	2	1	0
Z163	0	0	0	0	2	2	0	0	0	0	2	0	1	1	1	1	2	1	5	0	0
Z164	2	6	7	1	3	2	0	0	3	4	5	1	1	1	1	0	2	1	5	1	0
Z165	2	2	5	1	2	3	0	0	0	0	2	1	?	?	?	?	?	?	?	1	?
Z166	2	2	0	1	2	3	0	0	0	0	2	1	?	?	?	?	?	?	?	1	?
Z167	2	2	0	0	1	3	0	0	0	0	2	1	?	?	?	?	?	?	?	1	?
Z168	0	0	0	0	0	7	0	0	0	0	2	1	1	1	1	0	2	1	7	0	0
Z169	5	2	0	1	1	3	0	0	0	0	2	1	1	1	2	0	2	1	2	1	0
Z170	0	0	0	0	0	2	0	0	0	0	2	0	?	?	?	?	?	?	?	0	?
Z171	0	0	0	0	0	2	0	0	0	0	2	0	?	?	?	?	?	?	?	0	?

	Char 1	Char 2	Char 3	Char 4	Char 5	Char 6	Char 7	Char 8	Char 9	Char 10	Char 11	Char 12	Char 13	Char 14	Char 15	Char 16	Char 17	Char 18	Char 19	Char 20	Char 21
Z172	0	0	0	0	1	2	0	0	0	0	2	0	?	?	?	?	?	?	?	0	?
Z173	0	0	0	0	0	5	0	0	0	0	0	0	?	?	?	?	?	?	?	4	?
Z201	0	0	5	1	2	2	0	2	5	5	7	1	1	1	1	0	2	1	6	1	0
Z203	0	0	5	1	2	2	0	4	5	5	7	1	?	?	?	?	?	?	?	1	?
Z204	0	0	4	1	2	6	1	2	1	3	4	1	1	1	1	0	2	1	5	1	0
Z205	?	?	?	?	?	?	0	0	6	4	7	1	1	1	1	0	1	1	8	1	0
Z206	5	2	2	1	2	5	0	0	6	4	7	1	?	?	?	?	?	?	?	1	?
Z208	0	0	5	1	2	6	1	2	1	3	4	1	?	?	?	?	?	?	?	1	?
Z210	0	0	7	1	2	5	1	2	1	3	4	1	1	1	1	0	2	1	5	1	0
Z211	1	4	2	1	1	2	0	0	0	0	0	3	?	?	?	?	?	?	?	0	?
Z212	5	2	2	1	2	5	0	0	6	4	7	1	?	?	?	?	?	?	?	1	?
Z213	5	2	2	1	2	5	0	0	6	4	7	1	?	?	?	?	?	?	?	1	?
Z228	0	0	0	0	0	0	0	0	0	0	0	1	?	?	?	0	2	1	0	0	0
Z229	0	0	0	0	0	0	0	0	0	0	2	0	?	?	?	?	?	?	?	0	?
Z230	0	7	4	1	3	2	0	0	4	2	6	1	?	?	?	?	?	?	?	1	?
Z231	4	0	0	0	1	1	1	1	1	1	1	1	?	?	?	?	?	?	?	0	?
Z232	0	1	4	1	3	8	0	0	3	4	2	1	?	?	?	?	?	?	?	1	?
Z233	0	0	0	0	0	2	0	0	0	0	2	3	?	?	?	?	?	?	?	0	?
Z234	6	6	4	1	3	5	0	0	3	4	8	1	?	?	?	?	?	?	?	1	?
Z235	0	3	4	1	3	5	0	0	5	3	2	1	?	?	?	?	?	?	?	1	?
Z220	0	3	4	1	3	?	0	0	4	2	6	1	?	?	?	?	2	1	?	1	?
Z221	0	3	4	1	3	?	0	0	3	4	2	1	1	1	1	1	2	1	?	1	0
Z313	2	0	0	1	1	3	1	2	2	2	3	1	1	1	1	0	0	0	0	2	0

Table 2: Key to character states for morphological matrix.

Character	Character Description	State 0	State 1	State 2	State 3	State 4	State 5	State 6	State 7	State 8
1	Vertex Color	Pale yellow or green	Yellow in posterior half; red in anterior half with red bird's foot pattern connected to two lateral red stripes bordering eyes	Base color yellow, medial red bird's foot pattern; 2 lateral red stripes bordering eyes	Yellow, except for medial red stripe	Base color yellow; medial red dot on posterior margin, sometimes red extends slightly towards anterior end.	Base color yellow; medial red stripe with two lateral red stripes bordering eyes	Base color yellow; lateral red stripes bordering eyes	Almost completely red	
2	Frons Color	Pale yellow or green	Red or black striations with some yellow ventrally	Base color yellow; red stripe in the shape of a Fu-Manchu mustache	Yellow with lateral red stripe	Red and black striations and red stripe in the shape of a Fu-Manchu mustache	Completely red	Mostly red, with some yellow specks	Yellow dorsally, red ventrally	
3	Clypeus Color	Predominantly pale yellow or green with or without 1-2 red dots	Yellow with red longitudinal stripe	Yellow with red longitudinal stripe; lateral red stripe ventrally	Yellow with or without some red dots medially and red lateral stripe ventrally	Mostly red with some yellow spots	Yellow with transverse medial red stripe	Completely red	Dorsal two-thirds red, ventral one-third yellow	Yellow with two red transverse stripes
4	Mandibular Plate Color	Predominantly pale yellow or green with or without specks of red	Dorsal half red; ventral half yellow	Yellow with longitudinal red stripe bordering eye						

Character	Character Description	State 0	State 1	State 2	State 3	State 4	State 5	State 6	State 7	State 8
5	Maxillary Plate Color	Predominantly pale yellow or green with or without specks of red	Dorsal half red, grey, black or brown; ventral half yellow	Mostly brown, grey, black or red	Entirely red, brown or black					
6	Antennal Segment 1 Color	Yellow or green	Yellow with red specks distally	Black	Red on one side, yellow on the other side	Yellow with red longitudinal stripe	Red	Red on one side, black on the other	Brown	Proximal third yellow, distal two-thirds red
7	Mesoscutum Color	Yellow or green	Yellow with some red or brown vittae	Brown						
8	Scutellum Color	Yellow or green	Anterior two-thirds red or brown, posterior third yellow	Almost entirely red, small areas of yellow	Mostly yellow/green, with faint medial reddish stripe	Yellow with two red longitudinal stripes	Brown or yellow in anterior and posterior thirds, red in medial third	Anterior third yellow, posterior third red		
9	Clavus Color	Yellow or green	Yellow with red anteriorly near junction with pronotum	Yellow with red anteriorly near junction with pronotum and posteriorly at claval commisure; also red along distal margin continuing into corium	Yellow with red anteriorly at juncrton with pronotum; red posteriorly continuous with corium to form red spadelike or batlike pattern	Mostly red with yellow stripe starting at medial part of clavus and extending to base of scutellum	Yellow with red at anterior junction with pronotum and red posteriorly near posterior end of claval commisure	Completely red/black, with red proximally and black distally		

Character	Character Description	State 0	State 1	State 2	State 3	State 4	State 5	State 6	State 7	State 8
10	Corium Color	Yellow or green	Yellow/green with red along margin of membranous part of hemelytra, extending into cuneus	Yellow with inner third bordering claval suture red	Red with yellow covering posterior third	Yellow with red anteriorly near junction with pronotum and red continuous with clavus to form spadelilke or batlike pattern	Red in anterior half, yellow in posterior half	Red in anterior quarter, yellow posteriorly; red dot in costal fracture		
11	Cuneus Color	Yellow or green	Yellow with red at apex and basal red vitta continuous with corium	Yellow/green with red/brown/black at apex	Yellow/green with red at apex and red dot along posterior margin at junction with medial wing vein	Red except for yellow in anterior distal corner	Yellow in anterior two-thirds, red in posterior third	Anterior half yellow, posterior half red; red dot along posterior margin at junction with medial wing vein	Yellow in anterior two-thirds, red in posterior third; red dot along posterior margin at junction with medial wing vein	Yellow with red dot along posterior margin at junction with medial wing vein
12	Wing Membrane Vein Color	Pale	Red	Mostly pale with a bit of red	Green/yellow	Brown				
13	Right Paramere General Structure	Single lobe (lacking distinct apophysis and ventral medial process)	Ventral medial process present and perpendicular to apophysis	Ventral medial process present and parallel to apophysis						
14	Right Paramere Teeth	No teeth on ventral medial process or apophysis	Teeth present on ventral medial process and/or apophysis							

Character	Character Description	State 0	State 1	State 2	State 3	State 4	State 5	State 6	State 7	State 8
15	Right Paramere Apophysis Lobe Structure	Apophysis absent	Apophysis present with single lobe	Apophysis present with 2 lobes						
16	Left paramere Basal Process of Sensory Lobe	Absent	Present and prominent	Present and slight						
17	Endosomal Spicule Thickness	Spicules Absent	Thin	Medium	Thick					
18	Number of Endosomal Spicules	None	One	Two	Three					
19	Phallotheca Morphology	Single lobe	Glove-shaped, one large lobe, one small lobe on right side	Two lobes, one large, one very small on right side; triangular flap towards base	Two lobes, both large, concave medially	Three lobes, one large, one medium-sized, one thin	Single lobe with triangular flap towards base on left side	Single lobe with large triangular projection towards top	Two lobes, one large, one small on right side	Two lobes of about equal size
20	Pronotum Color	Green/yellow	Yellow/green, lateral thirds red or black	Yellow/green, with lateral thirds red and medial longitudinal stripe extending the length of pronotum	Yellow/green, with red vittae or stripes in lateral thirds and sometimes red vittae medially	Yellow/green, with faint red stripes in lateral thirds	Brown, somewhat transparent	Mostly red, with some yellow	Lateral thirds red and teardrop-shaped medial red vitta reaching halfway to anterior margin	
21	Left Paramere General Structure	Sensory lobe roughly parallel to apophysis	Sensory lobe roughly perpendicular to apophysis	Single lobe (no distinct sensory lobe and apophysis)						

Table 3: PCR conditions used for amplifying genes 16S, 28S, and CO1.

Gene/Protocol	Reagent	Volume
16S	Water	5.75 uL
	10X Buffer	2.0 uL
Denature: 95° for 2 min	$MgCl_2$	3.5 uL
95° for 1 min	Q Solution	4.0 uL
55° for 1 min	2.5 mM dNTPs	2.0 uL
Extension: 72° for 1 min	1X BSA	1.0 uL
35X	10uM Primer 16Sa	1.25 uL
Final Extension: 72° for 10 min	10uM Primer 16Sb	1.25 uL
12° final hold	Taq	0.25 uL
	DNA template	4.0 uL
	Total	25 uL
28S	Water	12.75 uL
	10X Buffer	2.0 uL
Denature: 95° for 2 min	$MgCl_2$	2.5 uL
95° for 1 min	2.5 mM dNTPs	2.0 uL
58° for 1 min	1X BSA	1.0 uL
Extension: 72° for 1 min	10uM Primer 28SF	1.25 uL
35X	10uM Primer 28SR	1.25 uL
Final Extension: 72° for 10 min	Taq	0.25 uL
12° final hold	DNA template	2.0 uL
	Total volume per sample :	25 uL
CO1	Water	12.25 uL
	10X Buffer	2.5 uL
Denature: 95° for 2 min	$MgCl_2$	2.0 uL
95° for 1 min	2.5 mM dNTPs	1.5 uL
55° for 1 min	1X BSA	1.0 uL
Extension: 72° for 1 min	10uM Primer MTD10	0.75 uL
35X	10uM Primer MTD12	0.75 uL
Final Extension: 72° for 10 min	Taq	0.25 uL
12° final hold	DNA template	4.0 uL
	Total volume per sample :	25 uL

Table 4: Primers used for DNA sequencing.

Gene	Primer	Primer Sequence (5’ to 3’)	Reference
CO1	MTD10	TTGATTTTTTGGTCATCCAGAAGT	Simon *et al.*, 1994
	MTD12	TCCATTGCACTAATCTGCCATATTA	
16S	16Sa	CGCCTGTTTATCAAAAACAT	Xiong & Kocher, 1991
	16Sb	CTCCGGTTTGAACTCAGATCA	
28S	28SD2F	CGGGTTGCTTGAGAGTGC	Weirauch & Munro, 2009
	28SD2R	CTCCTTGGTCCGTGTTTC	

Table 5: Geographic data for islands where *Pseudoloxops* was collected.

Island	Archipelago	Age (ma)	Area (km^2)	Maximum Altitude (m)
Tahiti	Society	0.19-1.37*	1,042	2,241
Moorea	Society	1.72	135	1,207
Huahine	Society	2.65	74.8	670
Raiatea	Society	2.75	171.4	1,017
Maupiti	Society	4.51	12	372
Tahaa	Society	3.4	90.2	590
Rimatara	Austral	28.6-4.78**	8.7	99
Rurutu	Austral	13-0.2**	38.5	389
Tubuai	Austral	10.6-7.23	45	410

*Evidence for multiple phases of volcanism

**Evidence for multiple phases of volcanism and secondary uplift

Table 6: Specimens included in integrative taxonomy study. AMNH refers to the specimen code in the American Museum of Natural History's Plant Bug Planetary Biodiversity Inventory database, beginning AMNH_PBI 00-.

Specimen Code/ GenBank Acc. #	AMNH	Locality	Island	Latitude (°)	Longitude (°)	Elevation (m)	Plant Affiliation	Plant Division	CO 1	16S	28S	Morph.
INGROUP												
Z5	384431	Motu Uta	Tahiti	-17.5342	-149.5774	17.67	*Terminalia catappa*	Angiospermae	X	X	X	X
Z6	384430	Pihaena	Moorea	-17.4894	-149.8472	13.58	N/A	N/A		X	X	X
Z7	384429	Uufau Pass	Moorea	-17.536	-149.8697	420	N/A	N/A	X	X	X	X
Z8	384428	Taravao	Tahiti	-17.784	-149.2473	711	N/A	N/A				X
Z9	384427	Temehani	Raiatea	-16.7794	-151.4502	722.31	*Myrsine* sp.	Angiospermae				X
Z10	384426	Mt. Aorai	Tahiti	-17.5793	-149.51843	1019.36	*Weinmannia parviflora*	Angiospermae	X	X	X	X
Z11	384425	Mt. Taitaa	Tubuai	-23.3702	-149.46973	324.1	*Metrosideros collina*	Angiospermae	X	X	X	X
Z12	384424	Motu Pitiahe	Maupiti	-16.4811	-152.2479	16.95	*Hibiscus tiliaceus*	Angiospermae	X	X	X	X
Z13	384423	Mt. Nuupure	Maupiti	-16.446	-152.2506	133.99	*Triumfetta rhomboidea*	Angiospermae	X	X	X	X
Z14	384422	Mt. Pohuarahi	Huahine	-16.7809	-150.9763	469.49	*Mangifera indica*	Angiospermae	X	X	X	X
Z15	384421	Mt. Pohuarahi	Huahine	-16.7811	-150.9724	345	*Glochidion* sp.	Angiospermae	X	X	X	X
Z16	384420	Amaru	Rimatara	-22.6566	-152.7993	0.75	*Hibiscus tiliaceus*	Angiospermae	X	X	X	X
Z17	384445	Shore road	Huahine	-16.7296	-151.037	7.5	*Hibiscus tiliaceus*	Angiospermae		X	X	X
Z18	384444	Temehani	Raiatea	-16.7794	-151.4502	722.31	*Myrsine* sp.	Angiospermae	X	X	X	X
Z19	384443	Mt. Rotui	Moorea	-17.5074	-149.8401	822	N/A	N/A	X	X	X	X
Z20	384442	Pic Vert	Tahiti	-17.5920	-149.5402	1131.83	*Weinmannia parviflora*	Angiospermae	X	X	X	X
Z21	384441	Mt. Aorai	Tahiti	-17.5798	-149.5179	1060.69	*Weinmannia parviflora*	Angiospermae	X	X	X	
Z22	384440	Pihaena	Moorea	-17.4894	-149.84723	13.58	N/A	N/A		X	X	
Z24	384439	Pihaena	Moorea	-17.4894	-149.84723	13.58	N/A	N/A	X	X	X	X
Z25	384438	Pic Vert	Tahiti	-17.5892	-149.54218	1059.25	*Metrosideros collina*	Angiospermae	X	X	X	X
Z26	384437	Mt. Marau	Tahiti	-17.6142	-149.5297	1441.37	*Weinmannia parviflora*	Angiospermae	X	X	X	
Z27	384436	Pihaena	Moorea	-17.4894	-149.84723	13.58	N/A	N/A	X	X	X	X
Z28	384435	Mt. Pohuarahi	Huahine	-16.7809	-150.9763	469.49	*Mangifera indica*	Angiospermae	X	X	X	X
Z29	384434	Mt. Pohuarahi	Huahine	-16.7811	-150.9724	345	*Glochidion* sp.	Angiospermae	X	X	X	X
Z30	384433	Mt. Pohuarahi	Huahine	-16.7809	-150.9763	469.49	*Mangifera indica*	Angiospermae	X	X	X	X
Z31	384458	Mt. Pohuarahi	Huahine	-16.7807	-150.9736	375.28	*Metrosideros collina*	Angiospermae	X	X	X	X
Z32	384457	Shore road	Huahine	-16.7296	-151.037	7.5	*Hibiscus tiliaceus*	Angiospermae	X	X	X	X
Z33	384456	Mt. Pohuarahi	Huahine	-16.7809	-150.9763	469.49	*Mangifera indica*	Angiospermae	X	X	X	X
Z34	384455	Shore road	Huahine	-16.7331	-151.0008	90.25	*Hibiscus tiliaceus*	Angiospermae	X	X	X	X
Z36	384453	Shore road	Huahine	-16.7331	-151.0008	90.25	*Hibiscus tiliaceus*	Angiospermae	X	X	X	X
Z37	384452	Shore road	Huahine	-16.7331	-151.0008	90.25	*Hibiscus tiliaceus*	Angiospermae	X	X	X	X
Z38	384451	Shore road	Huahine	-16.7331	-151.0008	90.25	*Hibiscus tiliaceus*	Angiospermae		X	X	X
Z40	384449	Shore road	Raiatea	-16.8892	-151.4586	12.86	*Inocarpus fagifer*	Angiospermae	X	X	X	X
Z41	384448	Baie Faaroa	Raiatea	-16.8383	-151.4205	16.47	*Persea americana*	Angiospermae	X	X		X
Z42	384447	Pihaena	Moorea	-17.4894	-149.84723	13.58	N/A	N/A	X	X	X	X
Z43	384446	Pihaena	Moorea	-17.4894	-149.84723	13.58	N/A	N/A	X	X	X	X

Specimen Code/ GenBank Acc. #	AMNH	Locality	Island	Latitude (°)	Longitude (°)	Elevation (m)	Plant Affiliation	Plant Division	CO 1	16S	28S	Morph.
Z44	384471	Pihaena	Moorea	-17.4894	-149.84723	13.58	N/A	N/A	X	X	X	X
Z45	384470	Mt. Rotui	Moorea	-17.5074	-149.8401	822	N/A	N/A	X	X	X	X
Z46	384469	Mt. Aorai	Tahiti	-17.5792	-149.51844	1024.40	*Metrosoderos collina*	Angiospermae	X	X	X	X
Z47	384468	Pihaena	Moorea	-17.4894	-149.84723	13.58	N/A	N/A	X	X	X	X
Z48	384467	Mt. Aorai	Tahiti	-17.5792	-149.51844	1024.40	*Metrosoderos collina*	Angiospermae	X	X	X	X
Z49	384466	Mt. Aorai	Tahiti	-17.58	-149.51767	1049.16	*Weinmannia parviflora*	Angiospermae	X	X	X	X
Z50	384465	Mt. Aorai	Tahiti	-17.5792	-149.51849	1023.44	*Weinmannia parviflora*	Angiospermae	X	X	X	X
Z51	384464	Pic Vert	Tahiti	-17.5918	-149.54047	1120.77	*Myrsine* sp.	Angiospermae	X	X	X	X
Z52	384463	Pic Vert	Tahiti	N/A	N/A	N/A	N/A	N/A	X	X	X	X
Z53	384462	Pic Vert	Tahiti	N/A	N/A	N/A	N/A	N/A	X	X		X
Z54	384461	Mt. Pohuarahi	Huahine	-16.7809	-150.9763	469.49	*Mangifera indica*	Angiospermae	X	X	X	X
Z55	384460	Shore road	Huahine	-16.7296	-151.037	7.5	*Hibiscus tiliaceus*	Angiospermae	X	X	X	X
Z56	384459	Mt. Nuupure	Maupiti	-16.447	-152.2552	361.58	*Allophylus rhomboidalis*	Angiospermae	X	X	X	X
Z57	384484	Motu Pitiahe	Maupiti	-16.4811	-152.2479	16.95	*Hibiscus tiliaceus*	Angiospermae	X	X	X	X
Z58	384483	Shore road	Maupiti	-16.4508	-152.2512	71.51	*Inga feuillei*	Angiospermae		X	X	X
Z60	384482	Mt. Rotui	Moorea	-17.5087	-149.83916	875.88	*Metrosideros collina*	Angiospermae	X	X	X	X
Z61	384481	Temehani	Raiatea	-16.7749	-151.4537	661.03	*Myrsine* sp.	Angiospermae	X	X	X	X
Z62	384480	Temehani	Raiatea	-16.7794	-151.4502	722.31	*Myrsine* sp.	Angiospermae	X	X	X	X
Z63	384479	Baie Faaroa	Raiatea	-16.8329	-151.4206	8.54	*Inga feuillei*	Angiospermae	X	X	X	X
Z64	384478	Motu Uta	Tahiti	-17.5342	-149.5774	17.67	*Terminalia catappa*	Angiospermae	X	X	X	X
Z65	384477	Fare Hape	Tahiti	-17.6424	-149.4429	320.73	*Hibiscus tiliaceus*	Angiospermae	X	X	X	X
Z66	384476	Mt. Aorai	Tahiti	-17.5795	-149.51831	1043.15	*Metrosideros collina*	Angiospermae	X	X	X	X
Z67	384475	Pic Vert	Tahiti	-17.5918	-149.54047	1120.77	*Myrsine* sp.	Angiospermae		X		X
Z68	384474	Mt. Aorai	Tahiti	-17.58	-149.5179	1060.69	*Weinmannia parviflora*	Angiospermae	X	X	X	X
Z69	384473	Pihaena	Moorea	-17.4894	-149.84723	13.58	N/A	N/A	X	X	X	X
Z70	384472	Mt. Mouaputa	Moorea	-17.5266	-149.80336	790	N/A	Pteridophyta	X	X	X	X
Z71	384497	Mt. Tohiea	Moorea	-17.5519	-149.821	1120	N/A	N/A	X	X	X	X
Z72	384496	Mt. Atiati	Moorea	-17.5364	-149.8697	420	*Alstonia costata*	Angiospermae	X	X	X	X
Z73	384495	Mt. Tohiea	Moorea	-17.552	-149.82	1015	N/A	N/A	X	X	X	X
Z74	384494	Mt. Tohiea	Moorea	-17.5535	-149.81747	840	N/A	N/A	X	X	X	X
Z75	384493	Belvedere	Moorea	-17.542	-149.8267	240	N/A	N/A	X	X	X	X
Z76	384492	Mt. Rotui	Moorea	-17.5087	-149.83916	822	N/A	N/A		X	X	X
Z77	384491	Mt. Atiati	Moorea	-17.5369	-149.86831	449.8	Grasses	Angiospermae	X	X	X	X
Z78	384490	3 Cocos Trail	Moorea	-17.5488	-149.84109	287.6	Ferns	Pteridophyta	X	X	X	X
Z79	384489	Pihaena	Moorea	-17.4894	-149.84723	13.6	*Terminalia catappa*	Angiospermae	X	X	X	X
Z80	384488	Mt. Atiati	Moorea	-17.536	-149.8697	420	N/A	N/A				X
Z81	384487	Mt. Atiati	Moorea	-17.5360	-149.87161	470	Ferns	Pteridophyta	X	X	X	X
Z82	384486	Mt. Rotui	Moorea	-17.5077	-149.84005	845	*Alyxia* sp.	Angiospermae		X	X	X
Z83	384485	Mt. Mouaputa	Moorea	-17.5296	-149.8031	475	N/A	N/A		X	X	X
Z84	384510	Temehani	Raiatea	-16.7749	-151.4537	661	*Myrsine* sp.	Angiospermae				X
Z85	384509	Temehani	Raiatea	-16.7727	-151.471	227	*Glochidion* sp.	Angiospermae		X		X

Specimen Code/ GenBank Acc. #	AMNH	Locality	Island	Latitude (°)	Longitude (°)	Elevation (m)	Plant Affiliation	Plant Division	CO 1	16S	28S	Morph.
Z86	384508	Mt. Atiati	Moorea	-17.536	-149.8697	420	N/A	N/A		X	X	X
Z94	384507	Mt. Tohiea	Moorea	-17.5552	-159.81239	480	*Alyxia* sp.	Angiospermae	X	X	X	X
Z95	384506	Tiura Ridge	Moorea	-17.5258	-149.875	490	N/A	N/A	X	X	X	X
Z96	384505	Tiura Ridge	Moorea	-17.5258	-149.875	490	N/A	N/A	X	X	X	X
Z97	384504	Belvedere	Moorea	-17.5412	-149.82705	237.8	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z98	384503	Belvedere	Moorea	-17.5412	-149.82705	237.8	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z99	384502	Belvedere	Moorea	-17.5412	-149.82705	237.8	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z100	384501	Lava Tubes	Tahiti	-17.6289	-149.34993	716.5	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z101	384500	Lava Tubes	Tahiti	-17.6287	-149.35143	744.9	*Metrosideros collina*	Angiospermae	X	X	X	X
Z102	384499	Mt. Marau	Tahiti	-17.6126	-149.5306	1451.5	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z103	384498	Mt. Marau	Tahiti	-17.6129	-149.53053	1448.6	*Weinmannia parviflora*	Angiospermae	X	X	X	X
Z104	384523	Mt. Marau	Tahiti	-17.6117	-149.53122	1425.5	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z105	384522	Lava Tubes	Tahiti	-17.629	-149.33946	553.1	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z106	384521	Mt. Marau	Tahiti	-17.6117	-149.53122	1425.5	*Dicranopteris linearis*	Pteridophyta		X	X	X
Z107	384520	Mt. Marau	Tahiti	-17.6124	-149.53074	1443.3	*Weinmannia parviflora*	Angiospermae	X	X	X	X
Z108	384519	Mt. Marau	Tahiti	-17.6063	-149.54003	1328.7	*Davallia* sp.	Pteridophyta	X	X	X	X
Z109	384518	Lava Tubes	Tahiti	-17.6289	-149.34993	716.5	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z110	384517	Mt. Marau	Tahiti	-17.6107	-149.53191	1411.3	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z111	384516	Mt. Marau	Tahiti	-17.6117	-149.53122	1425.5	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z112	384515	Mt. Marau	Tahiti	-17.6126	-149.5306	1451.5	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z113	384514	Mt. Marau	Tahiti	-17.6074	-149.53719	1395.9	*Blechnum orientale*	Pteridophyta	X	X	X	X
Z114	384432	Lava Tubes	Tahiti	-17.6289	-149.34993	716.5	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z115	384513	Lava Tubes	Tahiti	-17.6288	-149.34806	696.4	*Metrosideros collina*	Angiospermae	X	X	X	X
Z116	384512	Mt. Marau	Tahiti	-17.6063	-149.53967	1327.7	*Weinmannia parviflora*	Angiospermae	X	X	X	X
Z117	384511	Lava Tubes	Tahiti	-17.629	-149.33946	553.1	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z118	384536	Mt. Marau	Tahiti	-17.6117	-149.53122	1425.5	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z119	384535	Lava Tubes	Tahiti	-17.6288	-149.34806	696.4	*Metrosideros collina*	Angiospermae	X	X	X	X
Z120	384534	Lava Tubes	Tahiti	-17.629	-149.33946	553.1	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z121	384533	Mt. Aorai	Tahiti	-17.5933	-149.50104	1433	*Leptecophylla pomarae*	Angiospermae	X	X	X	X
Z122	384532	Mt. Aorai	Tahiti	-17.5933	-149.50104	1433	*Leptecophylla pomarae*	Angiospermae	X	X	X	X
Z123	384531	Mt. Aorai	Tahiti	-17.5933	-149.50104	1433	*Leptecophylla pomarae*	Angiospermae	X	X	X	X
Z124	384530	Mt. Aorai	Tahiti	-17.5937	-149.50056	1448.8	*Weinmannia parviflora*	Angiospermae	X	X	X	X
Z125	384529	Mt. Aorai	Tahiti	-17.596	-149.49832	1628.6	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z126	384528	Mt. Aorai	Tahiti	-17.601	-149.49371	1863.9	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z127	384527	Mille Sources	Tahiti	-17.5859	-149.46795	863.6	*Arachniodes aristata*	Pteridophyta	X	X	X	X
Z128	384526	Mille Sources	Tahiti	-17.5872	-149.46644	1119.3	*Weinmannia parviflora*	Angiospermae	X	X		X
Z129	384525	Mille Sources	Tahiti	-17.5859	-149.46795	863.6	*Davallia denticulata*	Pteridophyta	X	X	X	X
Z130	384524	Mt. Aorai	Tahiti	-17.6108	-149.49447	2028.5	*Leptecophylla pomarae*	Angiospermae	X	X	X	X
Z131	384549	Pic Vert	Tahiti	-17.5909	-149.54143	1096.5	*Vaccinium cereum*	Angiospermae		X	X	X
Z132	384548	Taravao	Tahiti	-17.7985	-149.23677	1215.2	*Ascarina polystachya*	Angiospermae	X	X	X	X

Specimen Code/ GenBank Acc. #	AMNH	Locality	Island	Latitude (°)	Longitude (°)	Elevation (m)	Plant Affiliation	Plant Division	CO 1	16S	28S	Morph.
Z133	384547	Mille Sources	Tahiti	-17.5872	-149.46645	1119.3	*Parasponia andersonii*	Angiospermae	X	X	X	X
Z134	384546	Taravao	Tahiti	-17.7835	-149.2482	760.3	*Metrosideros collina*	Angiospermae	X	X	X	X
Z135	384545	Mt. Aorai	Tahiti	-17.5943	-149.5001	1490.2	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z136	384544	Mt. Aorai	Tahiti	-17.5966	-149.4981	1663.4	*Paesia divaricatissima*	Pteridophyta				X
Z137	384543	Taravao	Tahiti	-17.7868	-149.2475	792	*Metrosideros collina*	Angiospermae	X	X	X	X
Z138	384542	Mt. Aorai	Tahiti	-17.601	-149.49371	1863.9	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z139	384541	Mt. Aorai	Tahiti	-17.601	-149.49371	1863.9	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z140	384540	Mt. Aorai	Tahiti	-17.6033	-149.49396	1885.7	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z141	384539	Pic Vert	Tahiti	-17.5921	-149.54014	1107.1	*Paesia divaricatissima*	Pteridophyta	X		X	X
Z142	384538	Mt. Aorai	Tahiti	-17.601	-149.49371	1863.9	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z143	384537	Mille Sources	Tahiti	-17.5501	-149.47223	623.3	*Adiantum capillus-veneris*	Pteridophyta	X	X	X	X
Z144	384692	Mille Sources	Tahiti	-17.5873	-149.46629	1141	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z145	384691	Mille Sources	Tahiti	-17.5501	-149.47223	623.3	*Adiantum capillus-veneris*	Pteridophyta	X	X	X	X
Z146	384690	Mille Sources	Tahiti	-17.5501	-149.47223	623.3	*Adiantum capillus-veneris*	Pteridophyta	X	X	X	X
Z147	384689	Mt. Aorai	Tahiti	-17.6018	-149.4937	1873	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z148	384688	Mt. Aorai	Tahiti	-17.5957	-149.4984	1615.4	*Leptecophylla pomarae*	Angiospermae	X	X	X	X
Z149	384687	Mt. Aorai	Tahiti	-17.5957	-149.4984	1615.4	*Leptecophylla pomarae*	Angiospermae	X	X	X	X
Z150	384686	Taravao	Tahiti	-17.7882	-149.24886	837.2	*Metrosideros collina*	Angiospermae	X	X	X	X
Z151	384685	Taravao	Tahiti	-17.7868	-149.24749	792	*Metrosideros collina*	Angiospermae	X	X	X	X
Z152	384684	Mille Sources	Tahiti	-17.576	-149.47	864.8	*Adiantum capillus-veneris*	Pteridophyta	X	X	X	X
Z153	384683	Mille Sources	Tahiti	-17.5859	-149.46795	863.6	*Arachniodes aristata*	Pteridophyta	X	X	X	X
Z154	384682	Mille Sources	Tahiti	-17.5872	-149.46644	1119.3	*Weinmannia parviflora*	Angiospermae	X	X	X	X
Z155	384681	Mille Sources	Tahiti	-17.5872	-149.46644	1119.3	*Parasponia andersonii*	Angiospermae	X	X	X	X
Z156	384680	Mille Sources	Tahiti	-17.5872	-149.46644	1119.3	*Metrosideros collina*	Angiospermae	X	X	X	X
Z157	384705	Mille Sources	Tahiti	-17.5872	-149.46644	1119.3	*Parasponia andersonii*	Angiospermae	X	X	X	X
Z158	384704	Taravao	Tahiti	-17.7868	-149.24749	792	*Metrosideros collina*	Angiospermae	X	X	X	X
Z159	384703	Taravao	Tahiti	-17.7868	-149.24749	792	*Metrosideros collina*	Angiospermae	X	X	X	X
Z160	384702	Taravao	Tahiti	-17.7868	-149.24749	792	*Metrosideros collina*	Angiospermae	X	X	X	X
Z161	384701	Taravao	Tahiti	-17.7868	-149.24749	792	*Metrosideros collina*	Angiospermae	X	X	X	X
Z162	384700	Taravao	Tahiti	-17.7868	-149.24749	792	*Metrosideros collina*	Angiospermae	X	X	X	X
Z163	384699	Mt. Aorai	Tahiti	-17.601	-149.49371	1863.9	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z164	384698	Taravao	Tahiti	-17.7868	-149.24749	792	*Metrosideros collina*	Angiospermae	X	X	X	X
Z165	384697	Taravao	Tahiti	-17.7868	-149.24749	792	*Metrosideros collina*	Angiospermae	X	X	X	X
Z166	384696	Taravao	Tahiti	-17.7868	-149.24749	792	*Metrosideros collina*	Angiospermae	X	X	X	X
Z167	384695	Taravao	Tahiti	-17.7868	-149.24749	792	*Metrosideros collina*	Angiospermae	X	X	X	X
Z168	384694	Taravao	Tahiti	-17.7868	-149.24749	792	*Metrosideros collina*	Angiospermae	X	X	X	X
Z169	384963	Taravao	Tahiti	-17.7868	-149.24749	792	*Metrosideros collina*	Angiospermae	X	X	X	X
Z170	384718	Mt. Aorai	Tahiti	-17.601	-149.49371	1863.9	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z171	384717	Mt. Aorai	Tahiti	-17.5943	-149.50006	1490.2	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z172	384716	Mt. Aorai	Tahiti	-17.601	-149.49371	1863.9	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z173	384715	Mt. Aorai	Tahiti	-17.5957	-149.49840	1615.4	*Leptecophylla pomarae*	Angiospermae	X	X	X	X

Specimen Code/ GenBank Acc. #	AMNH	Locality	Island	Latitude (°)	Longitude (°)	Elevation (m)	Plant Affiliation	Plant Division	CO 1	16S	28S	Morph.
Z201	384714	Mt. Aorai	Tahiti	-17.596	-149.49832	1628.6	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z203	384713	Mt. Aorai	Tahiti	-17.596	-149.49832	1628.6	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z204	384712	Mt. Aorai	Tahiti	-17.6037	-149.49423	1913.1	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z205	384711	Tapuamu	Tahaa	-16.6265	-151.52383	171	*Nephrolepis hirsutula*	Pteridophyta		X	X	X
Z206	384710	Tapuamu	Tahaa	-16.6265	-151.52383	171	*Nephrolepis hirsutula*	Pteridophyta	X	X	X	X
Z208	384709	Mt. Aorai	Tahiti	-17.6018	-149.49371	1873	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z210	384708	Mt. Aorai	Tahiti	-17.6033	-149.49396	1885.7	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z211	384707	Mt. Turi	Huahine	-16.7211	-151.0158	419	*Metrosideros collina*	Angiospermae	X	X	X	X
Z212	384731	Mt. Pohuarahi	Huahine	-16.7806	-150.9746	414	*Glochidion temehaniense*	Angiospermae	X	X		X
Z213	384706	Tapuamu	Tahaa	-16.6265	-151.52383	171	*Nephrolepis hirsutula*	Pteridophyta	X	X	X	X
Z220	191354	Opunohu Val.	Moorea	N/A	N/A	30.5	N/A	N/A				X
Z221	191356	Papenoo Val.	Tahiti	N/A	N/A	150	N/A	N/A				X
Z229	N/A	Papenoo Val.	Tahiti	N/A	N/A	150	N/A	N/A				X
Z230	N/A	Opunohu Val.	Moorea	N/A	N/A	N/A	N/A	N/A				X
Z231	N/A	Tuauru River	Tahiti	N/A	N/A	15.2	N/A	N/A				X
Z232	N/A	Papenoo Val.	Tahiti	N/A	N/A	150	N/A	N/A				X
Z233	N/A	Papeari	Tahiti	N/A	N/A	152.4	N/A	N/A				X
Z234	N/A	Hitiaa	Tahiti	N/A	N/A	304.8	N/A	N/A				X
Z235	N/A	Hitiaa	Tahiti	N/A	N/A	304.8	N/A	N/A				X
Z313	N/A	Temehani	Raiatea	N/A	N/A	660	*Astronidium saccatum*	Angiospermae				X
OUTGROUPS												
Z222	17684	Bai de Sapins	N Caledonia	N/A	N/A	0	*Lumnitzera racemosa*	Angiospermae		X		X
Z224	N/A	Archer Pt.	Australia	N/A	N/A	0	N/A	N/A		X	X	X
Z225	N/A	Archer Pt.	Australia	N/A	N/A	0	N/A	N/A		X	X	X
Z226	N/A	Mt. Garnett	Australia	N/A	N/A	673	N/A	N/A		X	X	X
Z227	195389	Mt. Garnett	Australia	N/A	N/A	673	N/A	N/A		X	X	X
Z307	N/A	Suvarnabhum	Thailand	14.3667	100.6	N/A	*Leucaena* sp.	Angiospermae	X	X	X	X
Z308	N/A	Suvarnabhum	Thailand	14.3667	100.6	N/A	*Leucaena* sp.	Angiospermae	X	X	X	X
Z309	N/A	Sakaerat	Thailand	N/A	N/A	N/A	N/A	N/A	X	X	X	X
Z311	N/A	Sakaerat	Thailand	N/A	N/A	N/A	N/A	N/A		X		X
EU683097.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	X			
GQ254018.1	N/A	N/A	Hawaii	N/A	N/A	N/A	N/A	N/A	X			
AY252755.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	X			
GU194600.1	N/A	N/A	Japan	N/A	N/A	N/A	N/A	N/A	X			
AY252849.1	N/A	N/A	USA	N/A	N/A	N/A	N/A	N/A	X			
AY252872.1	N/A	N/A	USA	N/A	N/A	N/A	N/A	N/A	X			
HQ676944.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A			X	
HQ667659.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	X			

Table 7: Interspecific CO1 p-distances between putative species. Distances >1.5% divergent are colored in solid green.

Putative Species Pair	Interspecific p-distance
1-2	0.6%
2-3	3%
3-4	5.5%
5-6	4%
6-7	N/A
8-9	4.4%
9-10	2.7%
10-11	6%
12-13	6.8%
13-14	1.6%
14-15	1.9%
15-16	1.6%
16-17	1.1%
17-18	0.6%
18-19	N/A
19-20	N/A
18-20	1.0%
13-21	7%
23-24	9.1%
22-25	5.9%
25-26	3.5%
26-27	0.4%
27-28	1.2%
28-29	0.7%
29-30	0.7%
31-32	2.2%
32-33	2.6%
33-34	0.4%
34-35	1.4%
35-36	0.6%

Putative Species Pair	Interspecific p-distance
36-37	1.1%
37-38	0.2%
38-39	0.4%
39-40	0.9%
40-41	0.4%
41-42	0.3%
42-43	0.4%
43-44	0%
45-47	1.8%
46-48	0.2%

Table 8: Integrative taxonomy table with results of testing putative species against additional lines of evidence. Y indicates that the data source supported the existence of the putative species; N indicates lack of support for the putative species. Putative species with no additional supporting evidence are colored in solid red in the rightmost column.

Putative Species	Specimens	Node	Discrete Morphology	Continuous Morphology Females	Continuous Morphology Males	Left Parameres	CO1 Distance	Plant Affiliation	Island Distribution	# Additional Lines of Evidence Supporting
sp. 1	Z27, Z43, Z47	1	N	N/A	N	N	N	N/A	Y	1
sp. 2	Z24, Z44, Z79	2	N	N/A	N	N	Y	N/A	Y	2
sp. 3	Z12, Z13, Z17, Z32, Z34, Z36, Z37, Z38, Z55, Z56, Z57	3	N	N	N	N	Y	N	N	1
sp. 4	Z11, Z228	4	N	N/A	N	N	Y	Y	N	2
sp. 5	Z14, Z15, Z28, Z29, Z30, Z31, Z33, Z54	5	N	N	N	Y	Y	N	Y	3
sp. 6	Z40, Z41, Z63	6	N	N/A	N	N/A	Y	N	Y	2
sp. 7	Z58	7	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
sp. 8	Z124, Z132	8	N	N	N/A	N/A	Y	N	Y	2
sp. 9	Z53, Z67, Z131	9	N	Y	N/A	N/A	Y	N	Y	3

Putative Species	Specimens	Node	Discrete Morphology	Continuous Morphology Females	Continuous Morphology Males	Left Parameres	CO1 Distance	Plant Affiliation	Island Distribution	# Additional Lines of Evidence Supporting
sp. 10	Z51	10	N/A	N/A	N/A	N/A	Y	N/A	N/A	1
sp. 11	Z19, Z45, Z60, Z71, Z76, Z82, Z83	11	N	N	N	Y	Y	N	Y	3
sp. 12	Z205, Z206, Z213	12	N	Y	N/A	N/A	Y	Y	Y	4
sp. 13	Z140, Z204, Z210	13	N	N/A	N	N	Y	Y	Y	3
sp. 14	Z121, Z122, Z123, Z130, Z148, Z149, Z173	14	N	N	N	N	Y	Y	Y	3
sp. 15	Z147, Z208	15	N	N	N/A	N/A	Y	Y	Y	3
sp. 16	Z100, Z109, Z114	16	N	N/A	N	N	Y	Y	Y	3
sp. 17	Z125, Z135, Z201, Z203	17	N	N/A	N	N	N	N	Y	1

Putative Species	Specimens	Node	Discrete Morphology	Continuous Morphology Females	Continuous Morphology Males	Left Parameres	CO1 Distance	Plant Affiliation	Island Distribution	# Additional Lines of Evidence Supporting
sp. 18	Z113, Z118	18	N	N/A	N/A	N/A	N	N	Y	1
sp. 19	Z106	19	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
sp. 20	Z73	20	N/A	N/A	N/A	N/A	N	N/A	N/A	0
sp. 21	Z18, Z61, Z62, Z85	21	N	N	N	N	Y	N	Y	2
sp. 22	Z77	22	N/A	N/A	N/A	N/A	Y	N/A	N/A	1
sp. 23	Z16	23	N/A	N/A	N/A	N/A	Y	N/A	N/A	1
sp. 24	Z212	24	N/A	N/A	N/A	N/A	Y	N/A	N/A	1
sp. 25	Z128, Z133, Z155, Z157, Z168	25	N	N/A	N	N	Y	N	Y	2
sp. 26	Z115, Z119	26	N	N	N/A	N/A	Y	Y	Y	3
sp. 27	Z46, Z48, Z66	27	N	N	N/A	N	N	Y	Y	2
sp. 28	Z21, Z26	28	N	N/A	N/A	N/A	N	Y	Y	2
sp. 29	Z49, Z50	29	N	N/A	N/A	N/A	N	Y	Y	2
sp. 30	Z94	30	N/A	N/A	N/A	N/A	N	N/A	N/A	0
sp. 31	Z78, Z81	31	N	N/A	N/A	N/A	Y	Y	Y	3
sp. 32	Z102, Z104, Z146	32	N	N/A	N	N	Y	N	Y	2
sp. 33	Z97, Z98	33	N	N/A	N	N	Y	Y	Y	3
sp. 34	Z99	34	N/A	N/A	N/A	N/A	N	N/A	N/A	0
sp. 35	Z153	35	N	N/A	N/A	N/A	N	N/A	N/A	0

Putative Species	Specimens	Node	Discrete Morphology	Continuous Morphology Females	Continuous Morphology Males	Left Parameres	CO1 Distance	Plant Affiliation	Island Distribution	# Additional Lines of Evidence Supporting
sp. 36	Z111, Z120	36	N	N/A	N	N	N	Y	Y	2
sp. 37	Z144	37	N/A	N/A	N/A	N/A	N	N/A	N/A	0
sp. 38	Z139, Z170, Z171, Z172	38	N	N	N/A	N/A	N	Y	Y	2
sp. 39	Z108	39	N/A	N/A	N/A	N/A	N	N/A	N/A	0
sp. 40	Z126, Z138, Z142, Z163	40	N	N/A	N	N	N	Y	Y	2
sp. 41	Z141	41	N/A	N/A	N/A	N/A	N	N/A	N/A	0
sp. 42	Z127, Z129, Z145, Z152	42	N	N	N/A	N/A	N	N	Y	1
sp. 43	Z117	43	N/A	N/A	N/A	N/A	N	N/A	N/A	0
sp. 44	Z25, Z105, Z110, Z112	44	N	N	N/A	N/A	N	N	Y	1
sp. 45	Z211	45	N/A	N/A	N/A	N/A	Y	N/A	N/A	1
sp. 46	Z86, Z95	46	N	N	N/A	N/A	N	N/A	Y	1
sp. 47	Z75	47	N/A	N/A	N/A	N/A	Y	N/A	N/A	1
sp. 48	Z96	48	N/A	N/A	N/A	N/A	N	N/A	N/A	0

Table 9: PAST classifier and jackknife assignment of individuals to species based on canonical variates analysis.

Specimen	Species	Classification	Jackknifed
Z61	n. sp. 14	n. sp. 14	n. sp. 14
Z85	n. sp. 14	n. sp. 14	n. sp. 10
Z313	n. sp. 14	n. sp. 14	n. sp. 14
Z08	n. sp. 19	n. sp. 19	n. sp. 19
Z20	n. sp. 19	n. sp. 19	n. sp. 18
Z46	n. sp. 19	n. sp. 19	n. sp. 19
Z50	n. sp. 19	n. sp. 19	n. sp. 19
Z94	n. sp. 19	n. sp. 19	n. sp. 19
Z116	n. sp. 19	n. sp. 19	n. sp. 19
Z134	n. sp. 19	n. sp. 19	n. sp. 19
Z158	n. sp. 19	n. sp. 19	n. sp. 19
Z162	n. sp. 19	n. sp. 19	n. sp. 19
Z169	n. sp. 19	n. sp. 19	n. sp. 19
Z17	n. sp. 1	n. sp. 1	*rubrocuneatus*
Z56	n. sp. 1	n. sp. 1	n. sp. 2
Z57	n. sp. 1	n. sp. 1	*rubrocuneatus*
Z14	n. sp. 3	n. sp. 3	n. sp. 1
Z28	n. sp. 3	n. sp. 3	*tahiticus*
Z05	*rubrocuneatus*	*rubrocuneatus*	*rubrocuneatus*
Z06	*rubrocuneatus*	*rubrocuneatus*	n. sp. 8
Z22	*rubrocuneatus*	*rubrocuneatus*	*tahiticus*
Z24	*rubrocuneatus*	*rubrocuneatus*	*rubrocuneatus*
Z42	*rubrocuneatus*	*rubrocuneatus*	n. sp. 1
Z43	*rubrocuneatus*	*rubrocuneatus*	n. sp. 1
Z44	*rubrocuneatus*	*rubrocuneatus*	n. sp. 1
Z47	*rubrocuneatus*	*rubrocuneatus*	n. sp. 1
Z69	*rubrocuneatus*	*rubrocuneatus*	*rubrocuneatus*
Z45	n. sp. 8	n. sp. 8	n. sp. 8
Z71	n. sp. 8	n. sp. 8	n. sp. 8
Z07	n. sp. 21	n. sp. 21	n. sp. 13

Specimen	Species	Classification	Jackknifed
Z72	n. sp. 21	n. sp. 21	n. sp. 21
Z80	n. sp. 21	n. sp. 21	n. sp. 21
Z106	n. sp. 13	n. sp. 13	*rubroclavus*
Z109	n. sp. 13	n. sp. 13	n. sp. 10
Z113	n. sp. 13	n. sp. 13	n. sp. 13
Z114	n. sp. 13	n. sp. 13	n. sp. 11
Z135	n. sp. 13	n. sp. 13	n. sp. 22
Z201	n. sp. 13	n. sp. 13	n. sp. 11
Z78	*rubroclavus*	*rubroclavus*	n. sp. 13
Z220	*rubroclavus*	*rubroclavus*	n. sp. 10
Z25	*tahiticus*	*tahiticus*	*tahiticus*
Z97	*tahiticus*	*tahiticus*	*rubrocuneatus*
Z98	*tahiticus*	*tahiticus*	*tahiticus*
Z111	*tahiticus*	*tahiticus*	*tahiticus*
Z126	*tahiticus*	*tahiticus*	*tahiticus*
Z138	*tahiticus*	*tahiticus*	*tahiticus*
Z142	*tahiticus*	*tahiticus*	*tahiticus*
Z152	*tahiticus*	*tahiticus*	n. sp. 22
Z163	*tahiticus*	*tahiticus*	*rubrocuneatus*
Z221	*tahiticus*	*tahiticus*	*rubroclavus*
Z123	n. sp. 11	n. sp. 11	*rubroclavus*
Z130	n. sp. 11	n. sp. 11	n. sp. 11
Z149	n. sp. 11	n. sp. 11	n. sp. 13
Z204	n. sp. 10	n. sp. 10	n. sp. 13
Z210	n. sp. 10	n. sp. 10	n. sp. 10
Z11	n. sp. 2	n. sp. 2	n. sp. 1
Z228	n. sp. 2	n. sp. 2	n. sp. 18
Z102	n. sp. 22	n. sp. 22	n. sp. 22
Z104	n. sp. 22	n. sp. 22	n. sp. 22
Z146	n. sp. 22	n. sp. 22	n. sp. 13
Z128	n. sp. 18	n. sp. 18	n. sp. 18
Z133	n. sp. 18	n. sp. 18	n. sp. 18

Specimen	Species	Classification	Jackknifed
Z155	n. sp. 18	n. sp. 18	n. sp. 18
Z157	n. sp. 18	n. sp. 18	n. sp. 18
Z168	n. sp. 18	n. sp. 18	n. sp. 18

Table 10: Accuracy of PAST classifier and jackknife analyses in assigning individuals to their correct species.

Species	Classifier Accuracy	Jackknife Accuracy
n. sp. 1	100%	0%
n. sp. 2	100%	0%
n. sp. 3	100%	0%
n. sp. 8	100%	100%
n. sp. 10	100%	50%
n. sp. 11	100%	33.3%
n. sp. 13	100%	16.7%
n. sp. 14	100%	66.7%
n. sp. 18	100%	100%
n. sp. 19	100%	90%
n. sp. 21	100%	66.7%
n. sp. 22	100%	66.7%
rubroclavus	100%	0%
rubrocuneatus	100%	33.3%
tahiticus	100%	60%

Table 11: Distribution and endemism for final *Pseudoloxops* species determinations.

Species	# Specimens	Island Distribution	Archipelago or Single-Island Endemic	Species Elevational Range (m)
rubrocuneatus	15	Moorea, Tahiti	Archipelago	13.6-320.7
n sp. 1	11	Huahine, Maupiti	Archipelago	7.5-361.6
n. sp. 2	2	Rurutu, Tubuai	Archipealgo	324-388
n. sp. 3	8	Huahine	Island	345-469.5
n. sp. 4	4	Maupiti, Raiatea	Archipelago	8.5-16.5
n. sp. 5	2	Tahiti	Island	1215.2-1448.8
n. sp. 6	3	Tahiti	Island	1096.5-1120.8
n. sp. 7	1	Tahiti	Island	1120.8
n. sp. 8	7	Moorea	Island	475-1120
n. sp. 9	3	Tahaa	Island	171
n. sp. 10	3	Tahiti	Island	1885.7-1913.1
n. sp. 11	7	Tahiti	Island	1433-2028.5
n. sp. 12	2	Tahiti	Island	1873
n. sp. 13	11	Moorea, Tahiti	Archipelago	716.5-1628.6
n. sp. 14	7	Raiatea	Archipelago	227-722.3
n. sp. 15	1	Moorea	Island	449.8
n. sp. 16	1	Rimatara	Island	0.8
n. sp. 17	1	Huahine	Island	414
n. sp. 18	5	Tahiti	Island	792-1119.3
n. sp. 19	33	Moorea, Tahiti	Archipelago	480-1448.6

Species	# Specimens	Island Distribution	Archipelago or Single-Island Endemic	Species Elevational Range (m)
rubroclavus	4	Moorea	Island	287.6-470
tahiticus	32	Moorea, Tahiti	Archipelago	237.8-1863.9
n. sp. 20	1	Huahine	Island	419
n. sp. 21	8	Moorea	Island	240-790
n. sp. 22	3	Tahiti	Island	623.3-1451.5
n. sp. 23	3	Moorea, Tahiti	Archipelago	744.9-840

Table 12: CO1 pairwise distances for final *Pseudoloxops* species delineations.

Species Pair	P-Distance
rubrocuneatus- n. sp. 1	3%
n. sp. 1- n sp. 2	5.5%
n. sp. 2- n. sp. 3	7.4%
n. sp. 3- n. sp. 4	4%
n. sp. 4- n. sp. 5	7.8%
n. sp. 5- n. sp. 6	4.4%
n. sp. 6- n. sp. 7	2.7%
n. sp. 7- n. sp. 8	6%
n. sp. 8- n. sp. 9	5.8%
n. sp. 9- n. sp. 10	6.8%
n. sp. 10- n. sp. 11	1.6%
n. sp. 11- n. sp. 12	1.9%
n. sp. 12- n. sp. 13	1.9%
n. sp. 13- n. sp. 14	7.9%
n. sp. 16- n. sp. 17	9.1%
n. sp. 15- n. sp. 18	5.9%
n. sp. 17- n. sp. 19	4.1%
rubroclavus-n. sp. 22	2.2%
n. sp. 22- n. sp. 23	2%
tahiticus- n. sp. 22	2.9%
n. sp. 20- n. sp. 21	1.9%

Table 13: *Pseudoloxops* species richness for islands; number of endemic species are in parentheses.

Island	Number of Species (# of endemics)
Tahiti	13 (8)
Moorea	9 (4)
Huahine	5 (2)
Raiatea	2 (1)
Maupiti	2 (0)
Tahaa	1 (1)
Rimatara	1 (1)
Rurutu	1 (0)
Rurutu	1 (0)

Table 14: Final species assignments for each ingroup individual.

Specimen	Species
Z5	*rubrocuneatus*
Z6	*rubrocuneatus*
Z7	n. sp. 21
Z8	n. sp. 19
Z9	n. sp. 14
Z10	n sp. 19
Z11	n. sp. 2
Z12	n. sp. 1
Z13	n. sp. 1
Z14	n. sp. 3
Z15	n. sp. 3
Z16	n. sp. 16
Z17	n. sp. 1
Z18	n. sp. 14
Z19	n. sp. 8
Z20	n. sp. 19
Z21	n. sp. 19
Z22	*rubrocuneatus*
Z24	*rubrocuneatus*
Z25	*tahiticus*
Z26	n. sp. 19
Z27	*rubeocuneatus*
Z28	n. sp. 3
Z29	n. sp. 3
Z30	n. sp. 3
Z31	n. sp. 3
Z32	n. sp. 1
Z33	n. sp. 3
Z34	n. sp. 1
Z36	n. sp. 1
Z37	n. sp. 1
Z38	n. sp. 1
Z40	n. sp. 4
Z41	n. sp. 4
Z42	*rubrocuneatus*
Z43	*rubrocuneatus*
Z44	*rubrocuneatus*
Z45	n. sp. 8
Z46	n. sp. 19

Specimen	Species
Z47	*rubrocuneatus*
Z48	n. sp. 19
Z49	n. sp. 19
Z50	n. sp. 19
Z51	n. sp. 7
Z52	n. sp. 19
Z53	n. sp. 6
Z54	n. sp. 3
Z55	n. sp. 1
Z56	n. sp. 1
Z57	n. sp. 1
Z58	n. sp. 4
Z60	n. sp. 8
Z61	n. sp. 14
Z62	n. sp. 14
Z63	n. sp. 4
Z64	*rubrocuneatus*
Z65	*rubrocuneatus*
Z66	n. sp. 19
Z67	n. sp. 6
Z68	n. sp. 19
Z69	*rubrocuneatus*
Z70	n. sp. 21
Z71	n. sp. 8
Z72	n. sp. 21
Z73	n. sp. 13
Z74	n. sp. 23
Z75	n. sp. 21
Z76	n. sp. 8
Z77	n. sp. 15
Z78	*rubroclavus*
Z79	*rubrocuneatus*
Z80	n. sp. 21
Z81	*rubroclavus*
Z82	n. sp. 8
Z83	n. sp. 8
Z84	n. sp. 14
Z85	n. sp. 14
Z86	n. sp. 21
Z94	n. sp. 19
Z95	n. sp. 21
Z96	n. sp. 21

Specimen	Species
Z97	*tahiticus*
Z98	*tahiticus*
Z99	*tahiticus*
Z100	n. sp. 13
Z101	n. sp. 23
Z102	n. sp. 22
Z103	n. sp. 19
Z104	n. sp. 22
Z105	*tahiticus*
Z106	n. sp. 13
Z107	n. sp. 19
Z108	*tahiticus*
Z109	n. sp. 13
Z110	*tahiticus*
Z111	*tahiticus*
Z112	*tahiticus*
Z113	n. sp. 13
Z114	n. sp. 13
Z115	n. sp. 19
Z116	n. sp. 19
Z117	*tahiticus*
Z118	n. sp. 13
Z119	n. sp. 19
Z120	*tahiticus*
Z121	n. sp. 11
Z122	n. sp. 11
Z123	n. sp. 11
Z124	n. sp. 5
Z125	n. sp. 13
Z126	*tahiticus*
Z127	*tahiticus*
Z128	n. sp. 18
Z129	*tahiticus*
Z130	n. sp. 11
Z131	n. sp. 6
Z132	n. sp. 5
Z133	n. sp. 18
Z134	n. sp. 19
Z135	n. sp. 13
Z136	*tahiticus*
Z137	n. sp. 19

Specimen	Species
Z138	*tahiticus*
Z139	*tahiticus*
Z140	n. sp. 10
Z141	*tahiticus*
Z142	*tahiticus*
Z143	*tahiticus*
Z144	*tahiticus*
Z145	*tahiticus*
Z146	n. sp. 22
Z147	n. sp. 12
Z148	n. sp. 11
Z149	n. sp. 11
Z150	n. sp. 19
Z151	n. sp. 19
Z152	*tahiticus*
Z153	*tahiticus*
Z154	n. sp. 19
Z155	n. sp. 18
Z156	n. sp. 19
Z157	n. sp. 18
Z158	n. sp. 19
Z159	n. sp. 19
Z160	n. sp. 19
Z161	n. sp. 19
Z162	n. sp. 19
Z163	*tahiticus*
Z164	n. sp. 23
Z165	n. sp. 19
Z166	n. sp. 19
Z167	n. sp. 19
Z168	n. sp. 18
Z169	n. sp. 19
Z170	*tahiticus*
Z171	*tahiticus*
Z172	*tahiticus*
Z173	n. sp. 11
Z201	n. sp. 13
Z203	n. sp. 13
Z204	n. sp. 10
Z205	n. sp. 9
Z206	n. sp. 9
Z208	n. sp. 12

Specimen	Species
Z210	n. sp. 10
Z211	n. sp. 20
Z212	n. sp. 17
Z213	n. sp. 9
Z220	*rubroclavus*
Z221	*tahiticus*
Z229	*rubrocuneatus*
Z230	*rubroclavus*
Z231	*rubrocuneatus*
Z232	*tahiticus*
Z233	*tahiticus*
Z234	*tahiticus*
Z235	*tahiticus*
Z313	n. sp. 14

Figure 1: Map of French Polynesia; inset map shows location of French Polynesia in the Pacific Ocean.

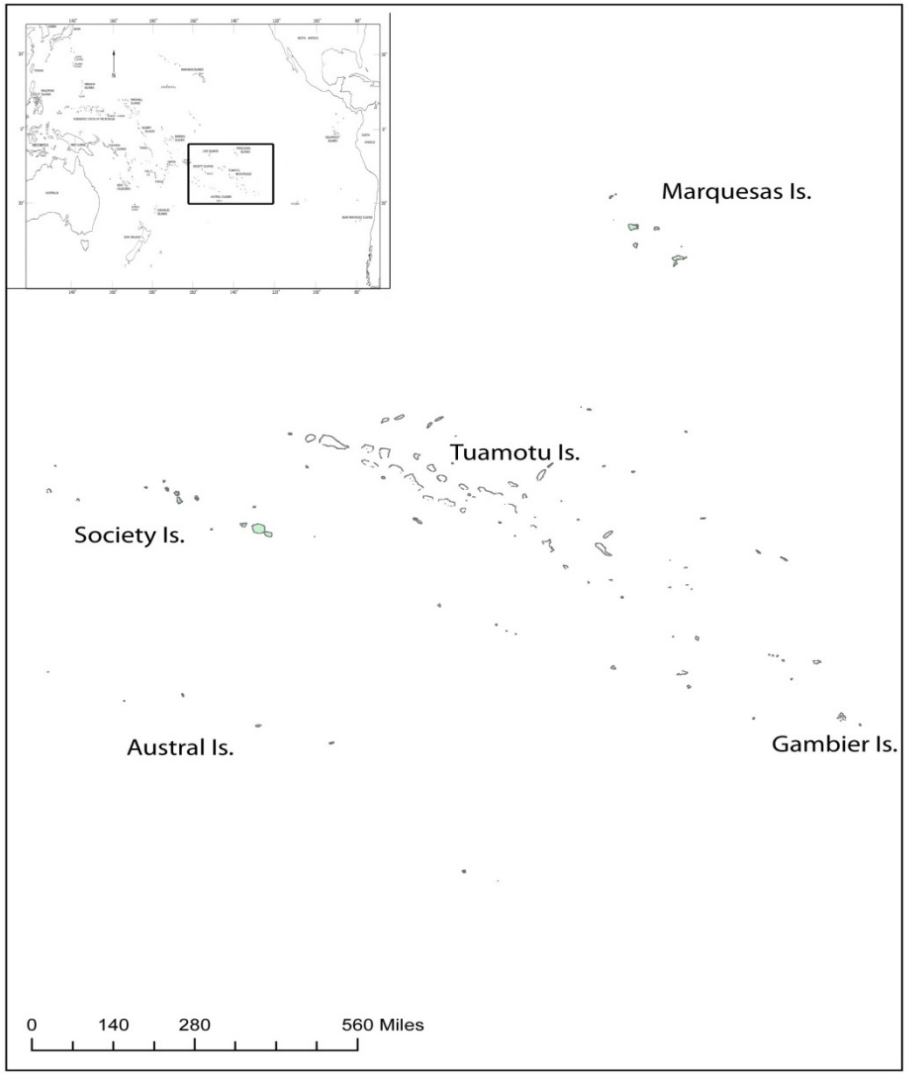


Figure 2: Map of (a) Society and (b) Austral Islands.

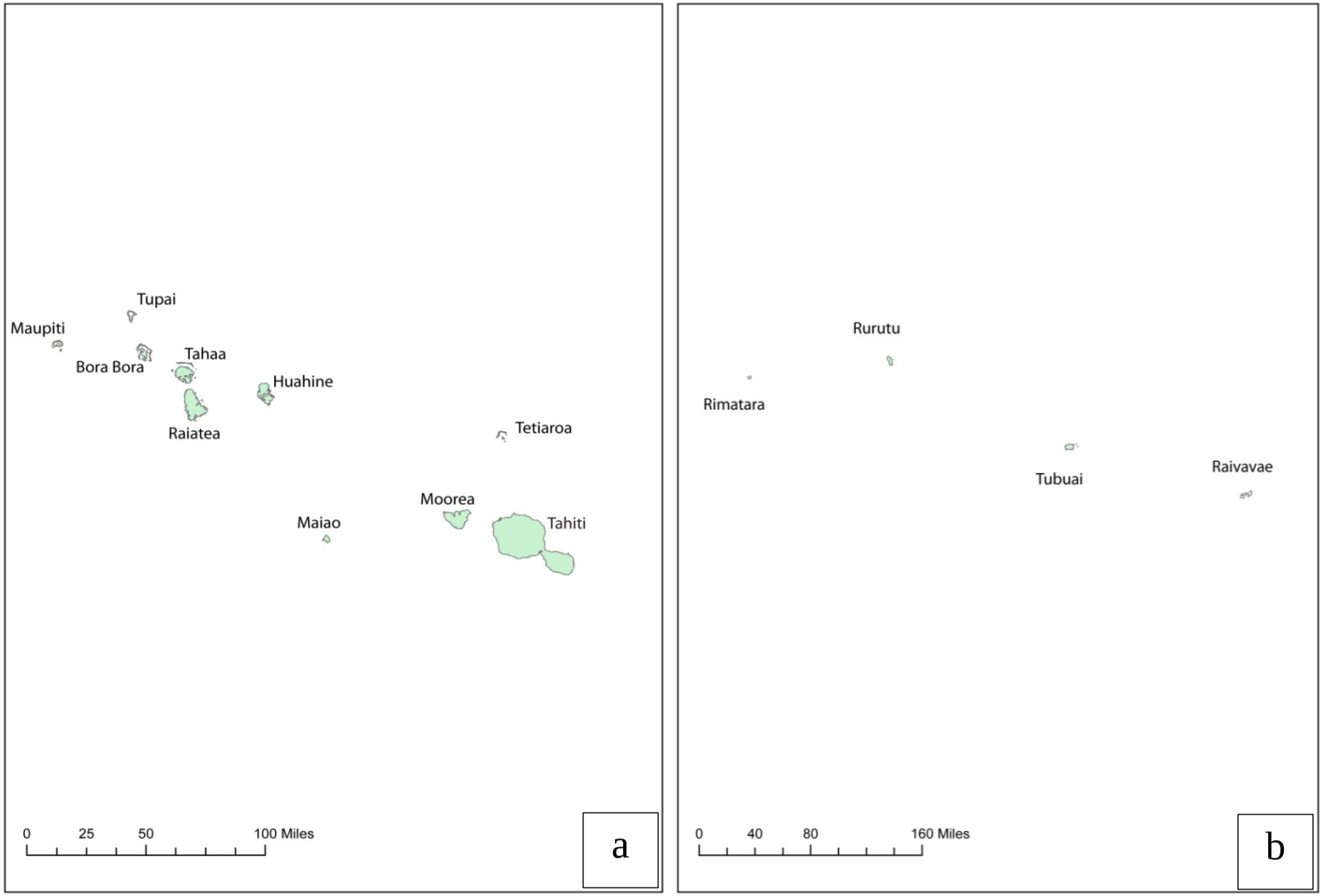


Figure 3 (a-d): Morphological traits measured for integrative taxonomy and species description; (a) AI=Length of antennal segment 1; AII=Length of antennal segment 2; AIII=Length of antennal segment 3; AIV=Length of antennal segment 4; (b) BL2=Second measurement of body length, summed with BL1 for total body length, BL; (c) BL1=First measurement of body length, summed with BL2 for total body length, BL; BW=Body Width; CL=Cuneus Length; (d) HL=Length of head capsule.

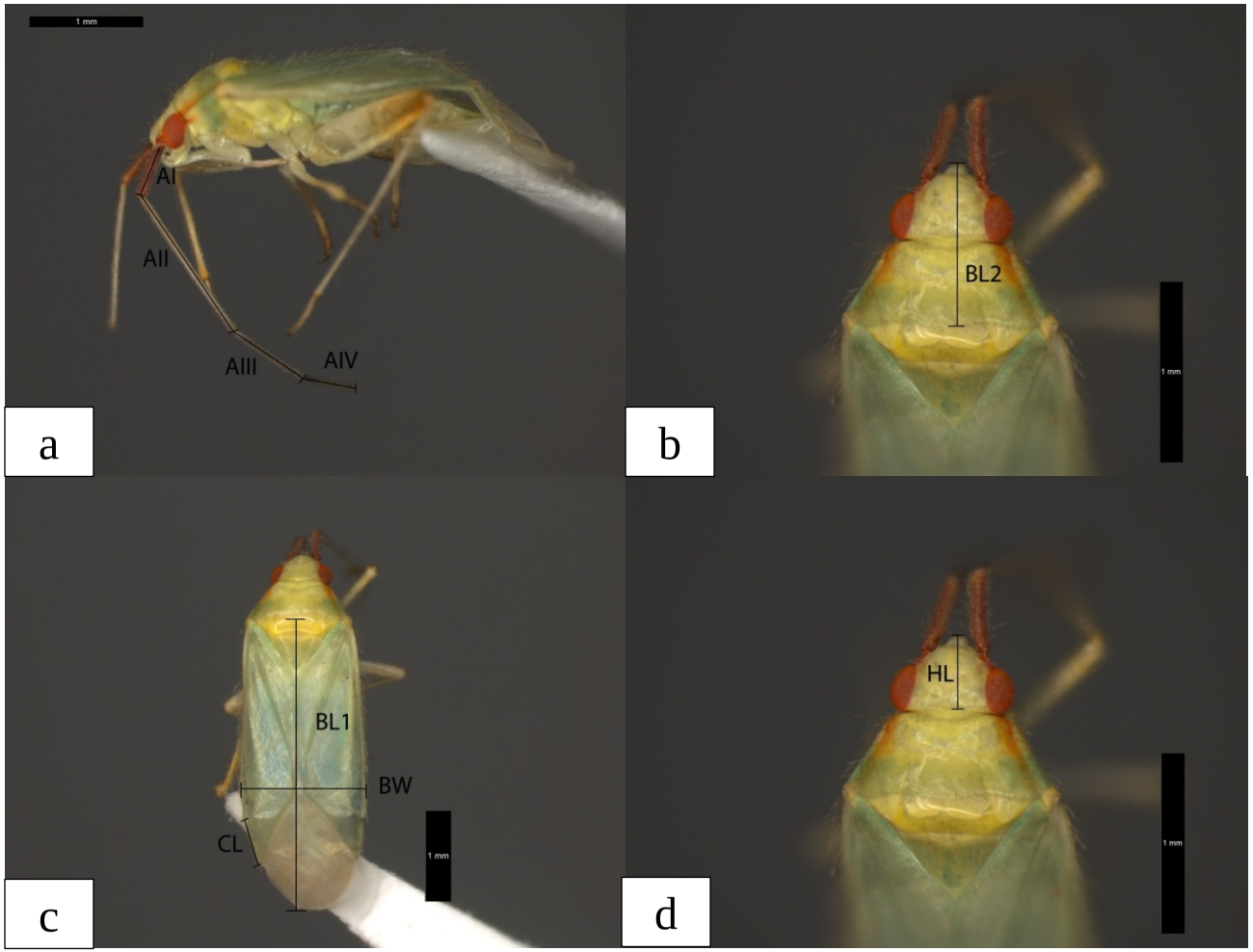


Figure 3 (e-h): Morphological traits measured for integrative taxonomy and species description. Clockwise: (e) HW=Head Width; (f) LL=Labium Length; (g) PW=Pronotal Width; (h) PL=Pronotum Length.

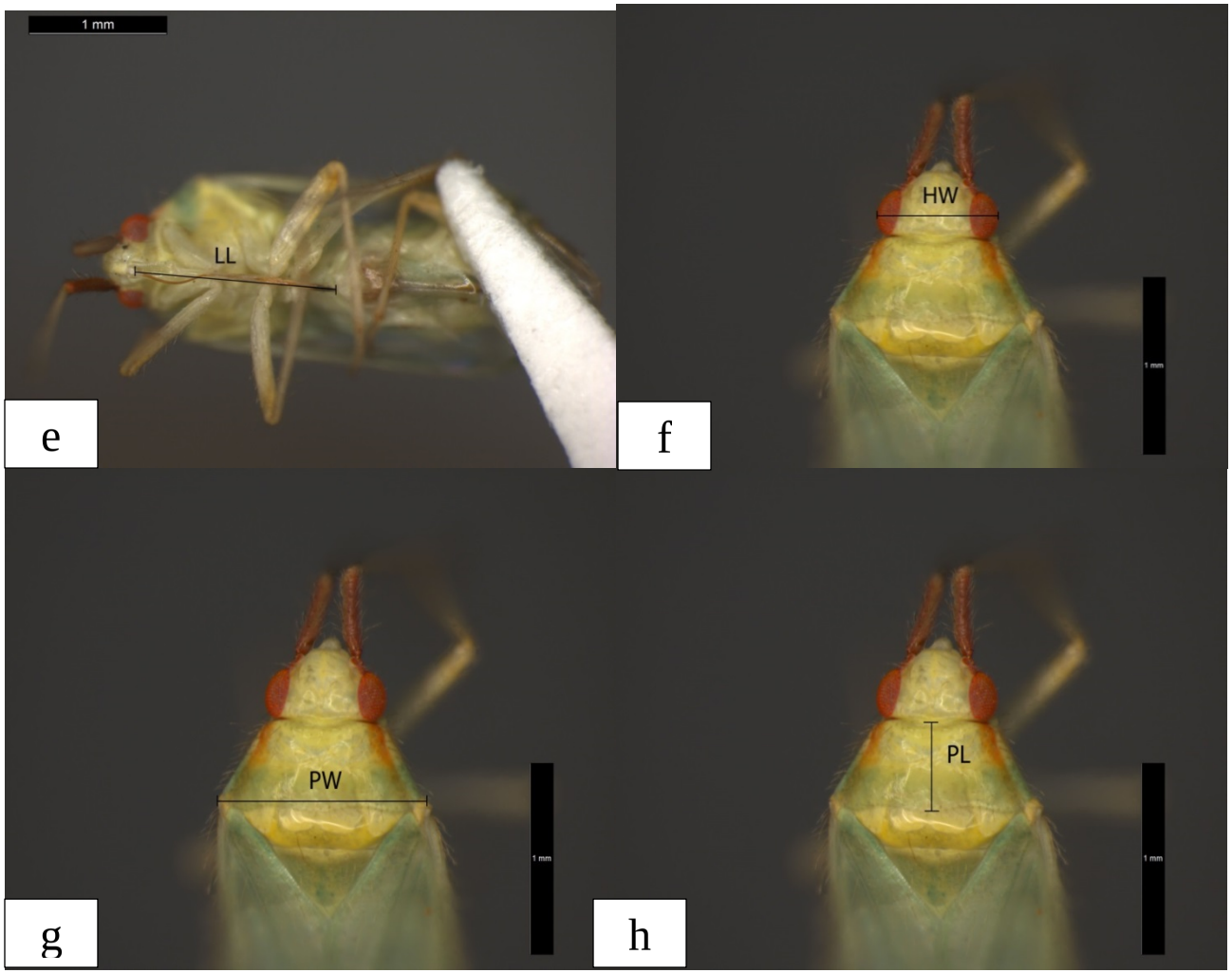


Figure 3 (i): Morphological traits measured for integrative taxonomy and species description. (i) VW=Vertex Width.

Figure 4: Location of landmarks on the left paramere (specimen Z6 pictured below) for geometric morphometric analysis.

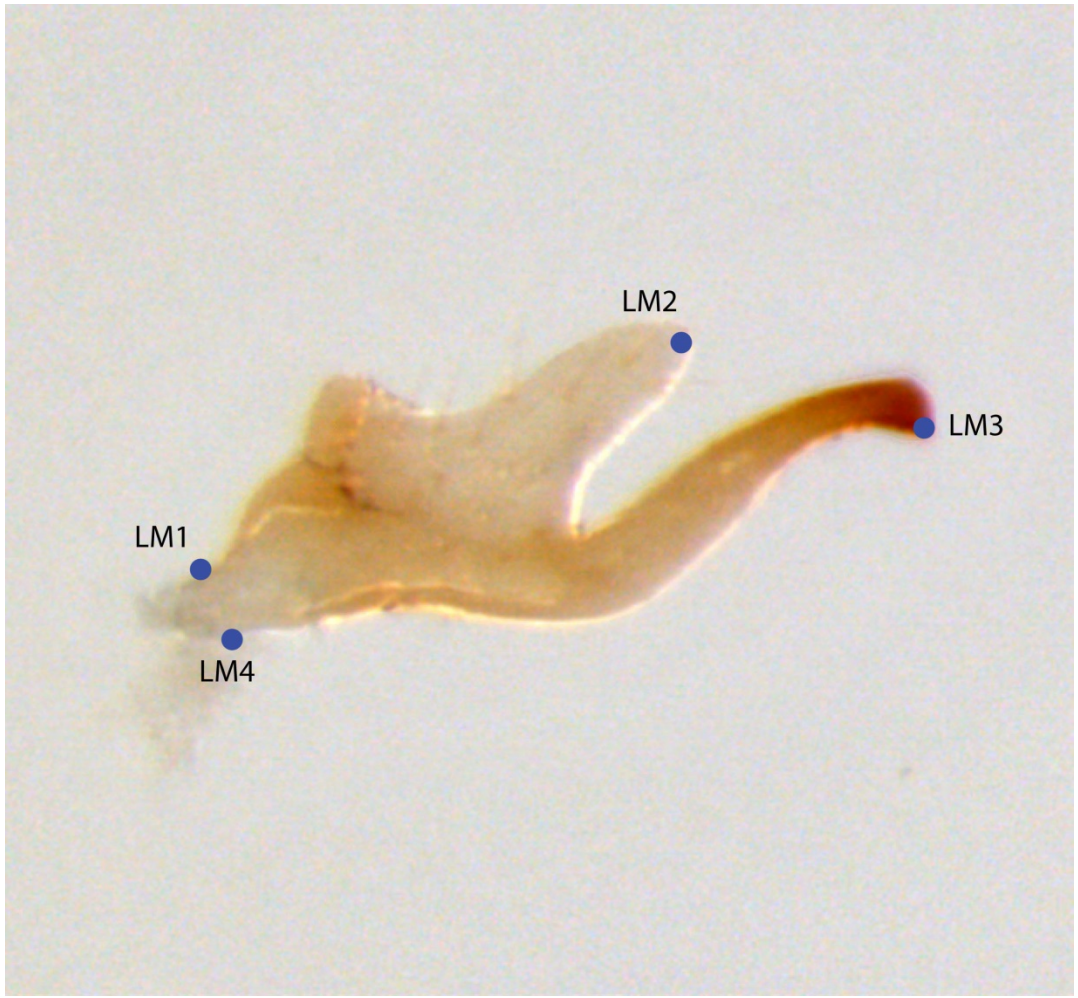


Figure 5: Location of sliding semi-landmarks on left paramere for geometric morphometric analysis.

Figure 6: 50% majority-rules consensus molecular Bayesian tree (3 genes combined) for all ingroup and outgroup specimens. Outgroups are coded with letters as follows: A=*Lopidea bullata*; B=*Pseudoloxops ayutthaya*; C=*Orthotylus sophoroides*; D=*Pseudoloxops sp.*; E=*Pseudopsallus angularis*; F=*Blepharidopteris chlorionis*; G=*Orthotylus rossi*; H=*Pseudopsallus viridicans*; I=*Pseudoloxops takaii*; J=*Pseudoloxops sp.;* K=*Pseudoloxops sp.* Nodes with posterior probability ≥70% are marked with a circle.

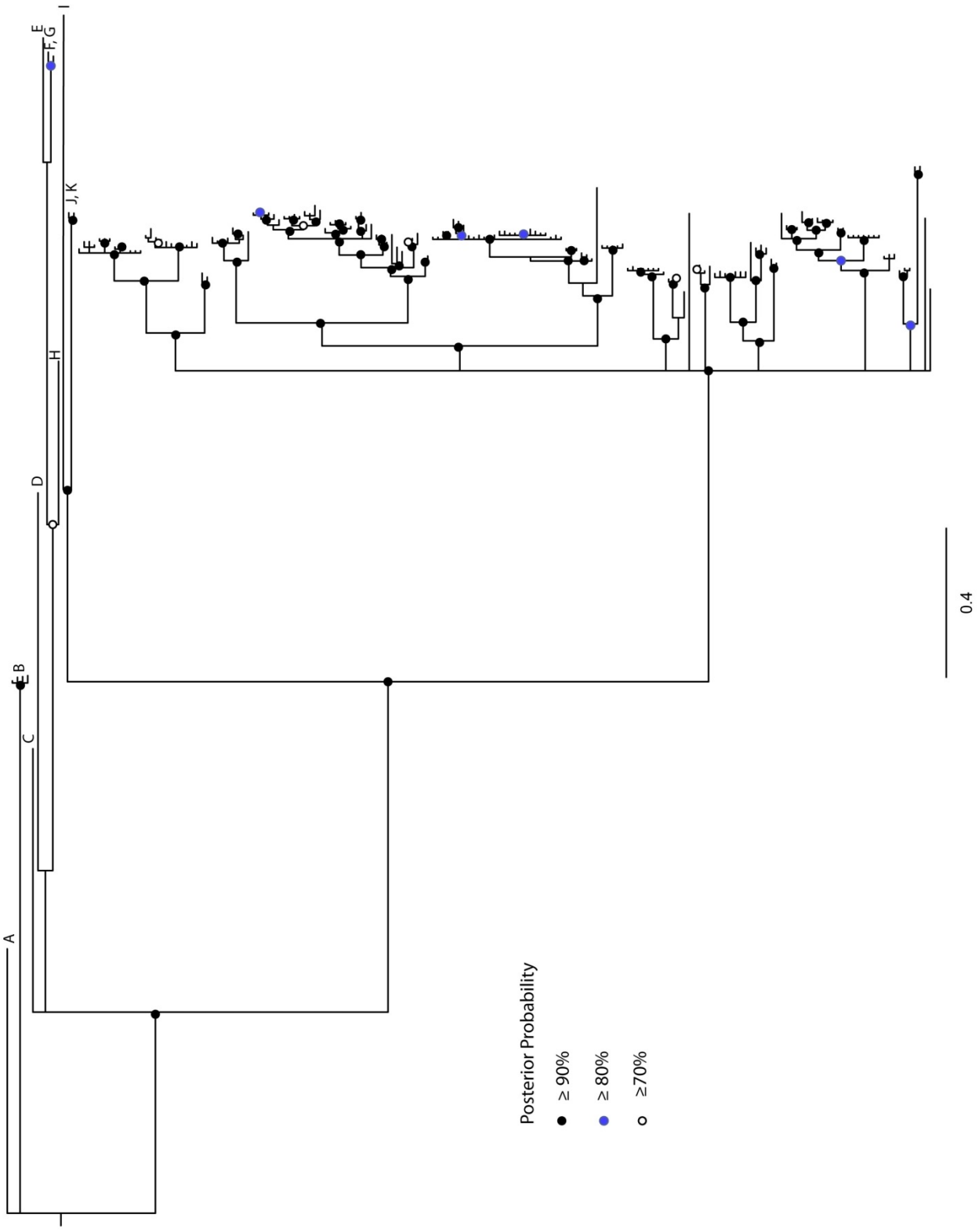

A
B
C
D
H
J, K
F, G
E
I
0.4
Posterior Probability
≥ 90%
≥ 80%
≥70%

Figure 7: 50% majority-rules Bayesian molecular consensus tree (3 genes combined) for all ingroup specimens. The nodes defining putative species are marked with a filled black circle and numbered.

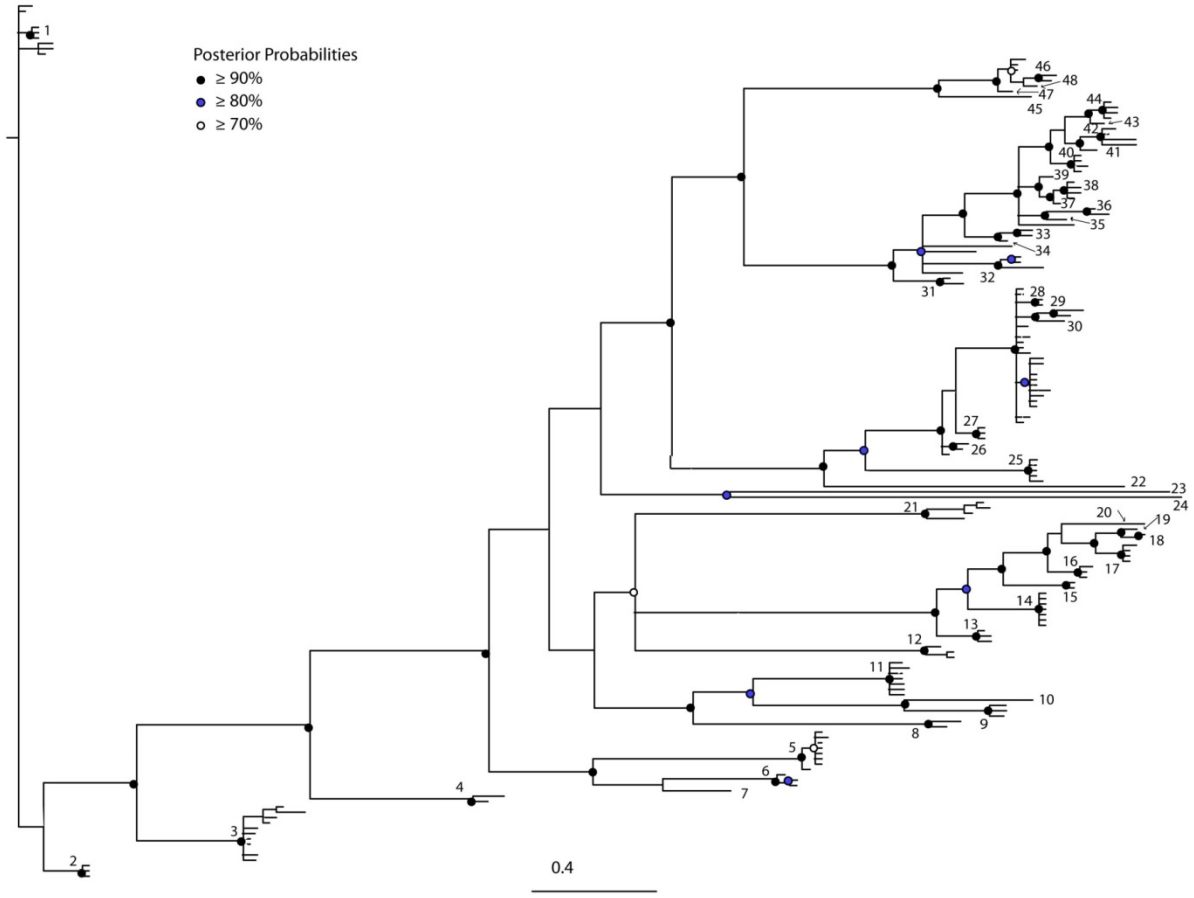


Figure 8: 50% majority-rules Bayesian16S consensus tree for ingroup specimens.

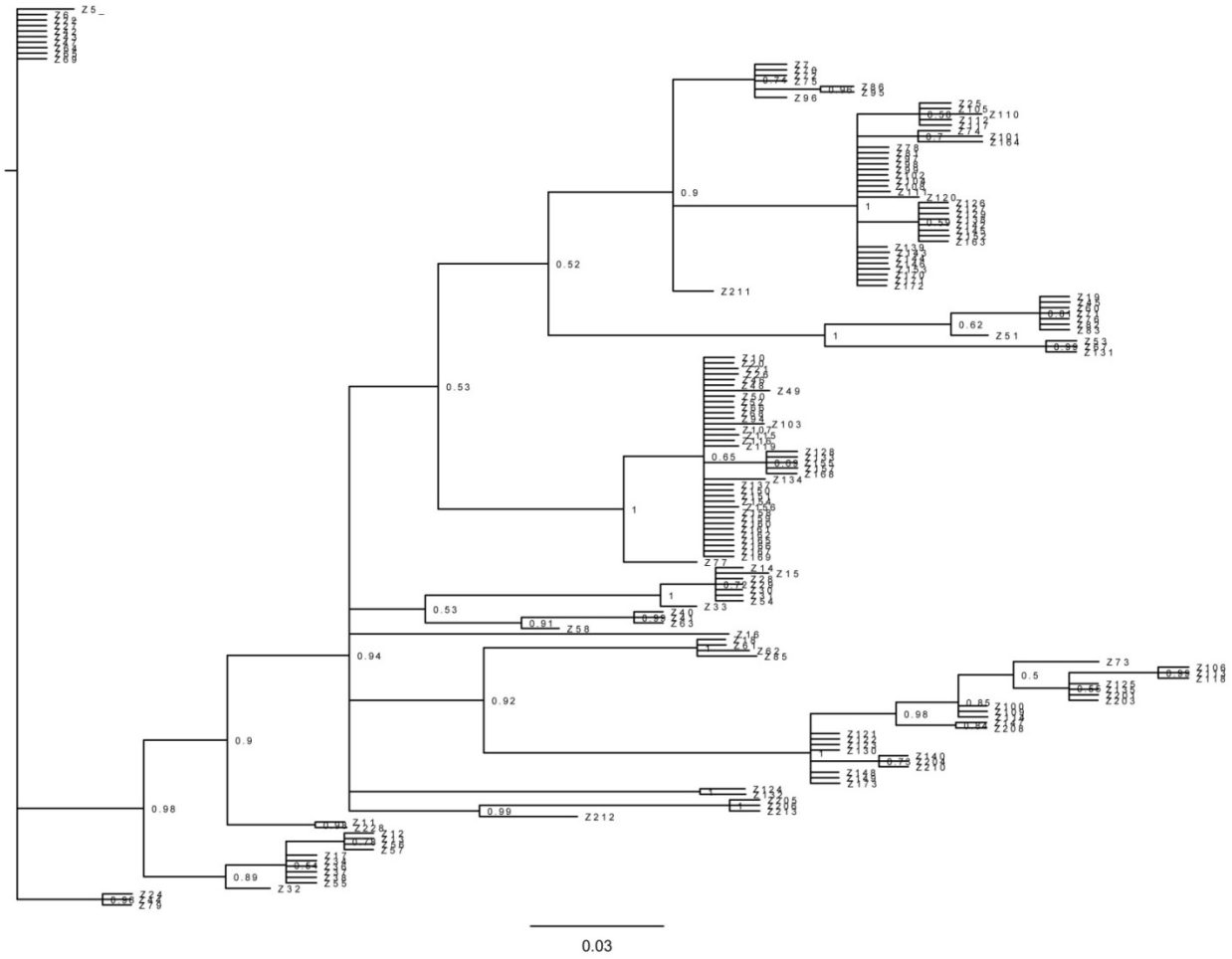


Figure 9: 50% majority-rules Bayesian CO1 consensus tree for ingroup specimens.

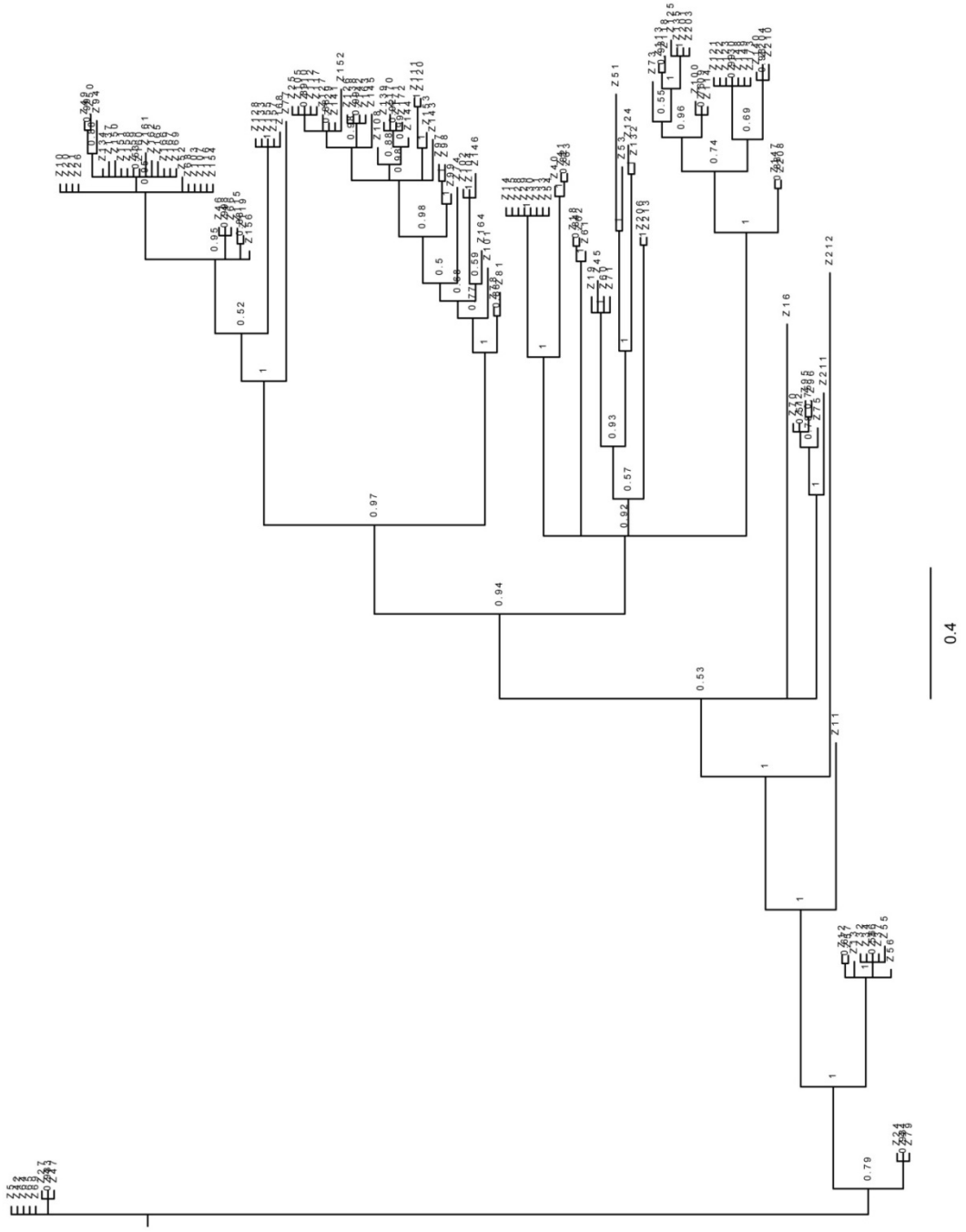


Figure 10: 50% majority-rules Bayesian 28S consensus tree for ingroup specimens.

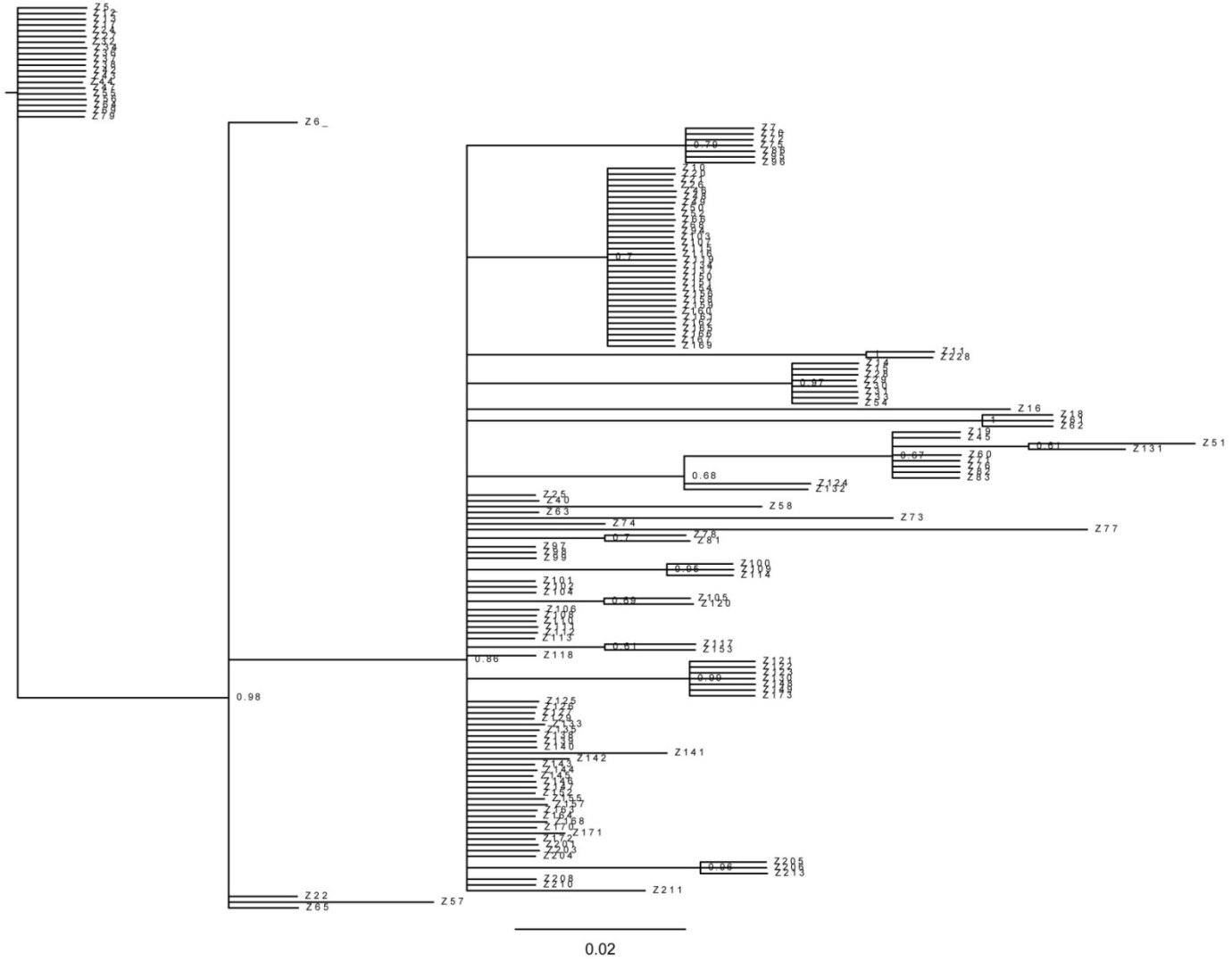


Figure 11: Strict consensus parsimony tree of discrete morphological data, part 1. Shaded blue box indicates region of close-up.

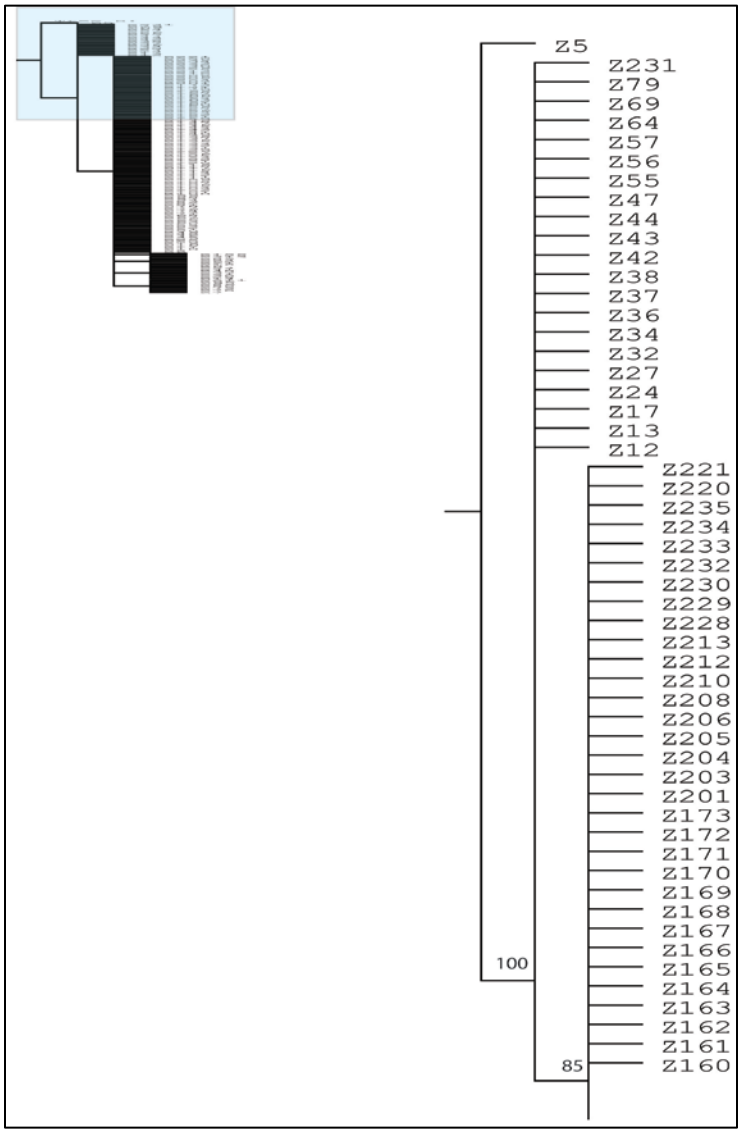


Figure 12: Strict consensus parsimony tree of discrete morphological data, part 2. Shaded blue box indicates region of close-up.

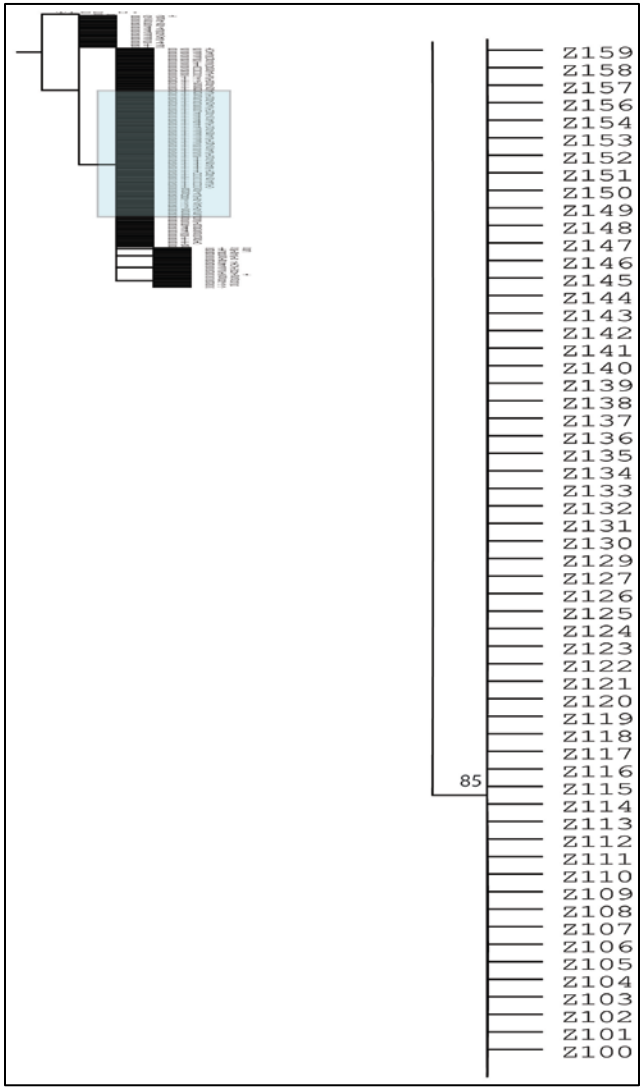


Figure 13: Strict consensus parsimony tree of discrete morphological data, part 3. Shaded blue box indicates region of close-up.

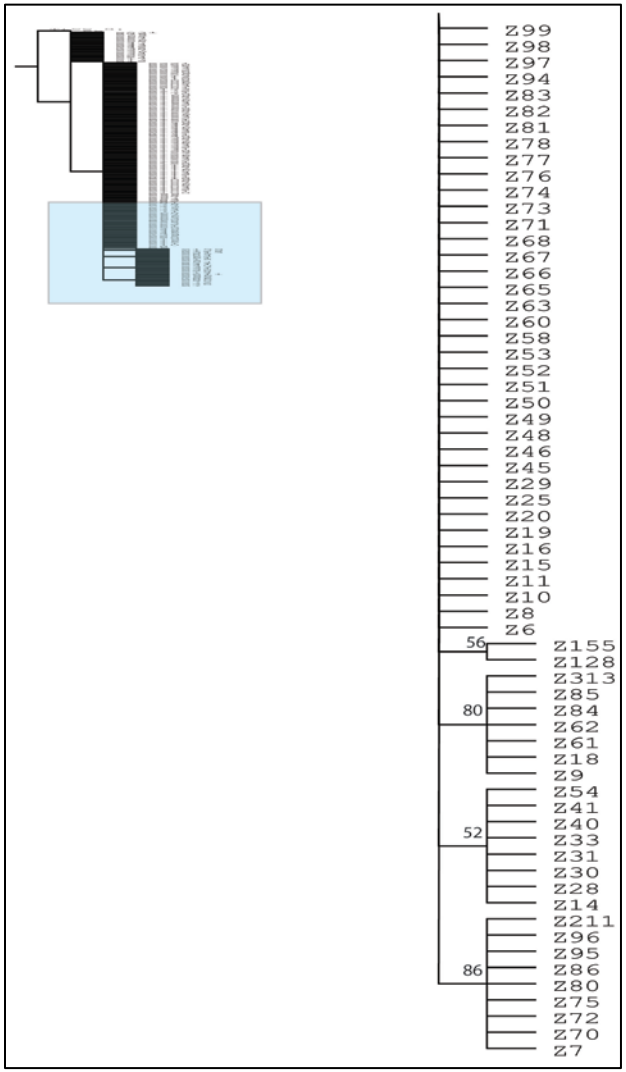


Figure 14: Dendrogram of female ingroup specimens for 11 continuous morphological traits.

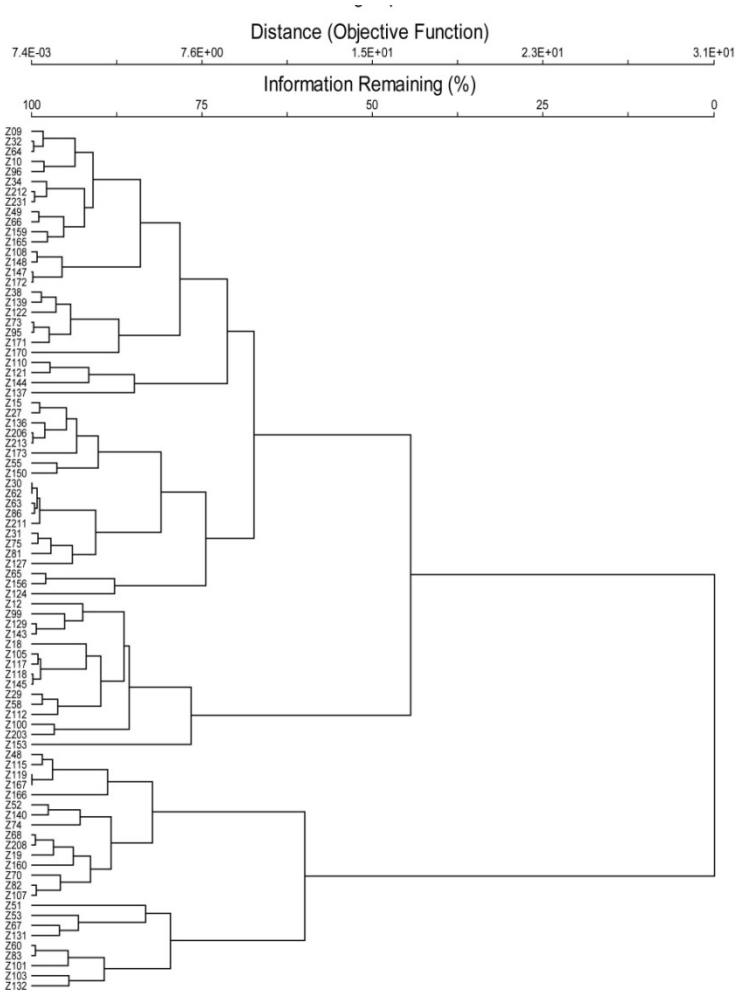


Figure 15: Dendrogram of male ingroup specimens for 11 continuous morphological traits.

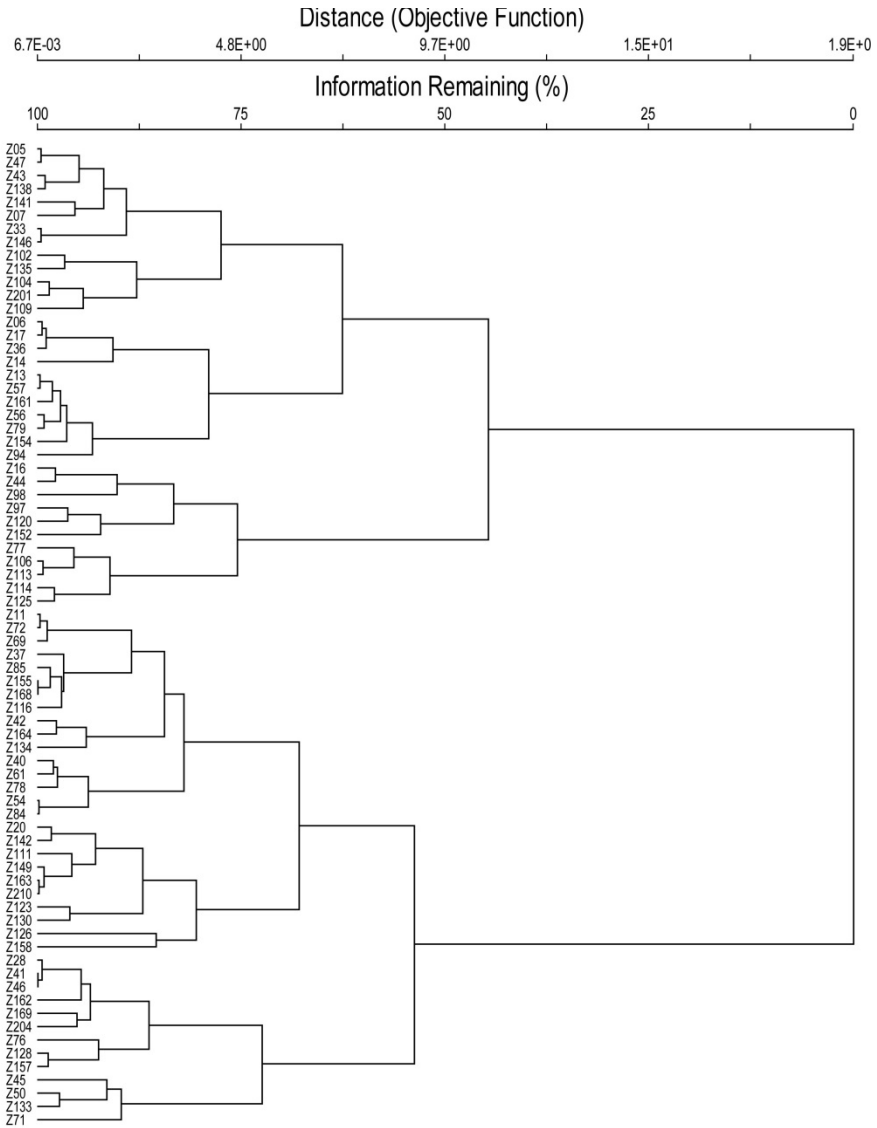


Figure 16: Dendrogram of male ingroup specimens for 74 principal components of left paramere shape.

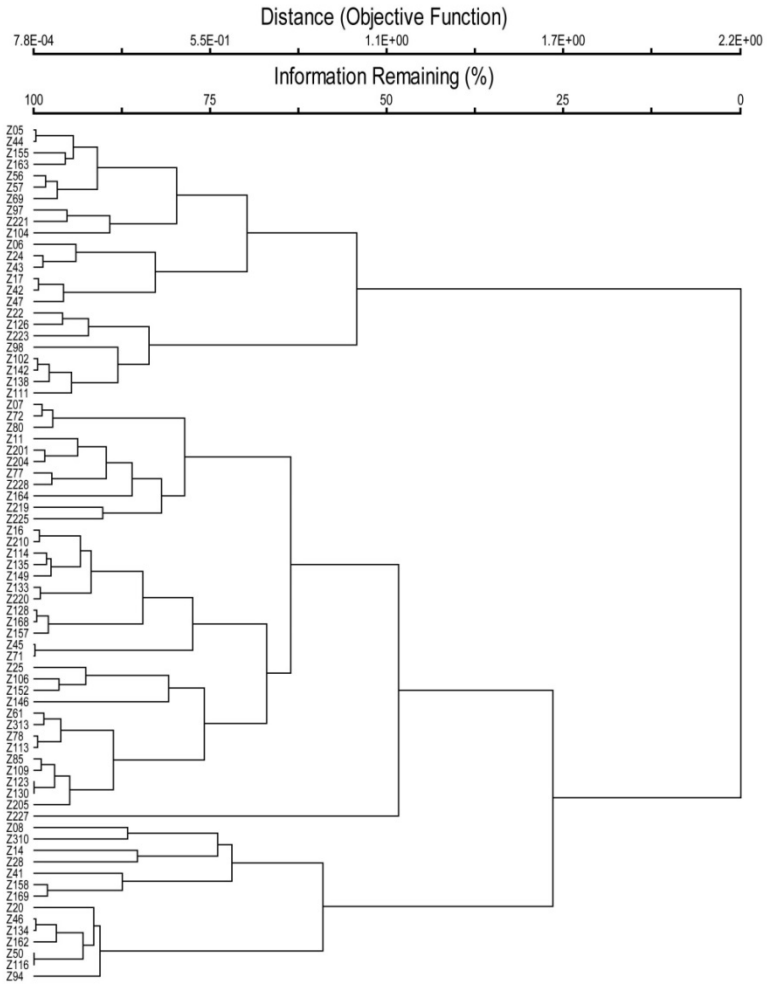


Figure 17: Close-up of combined molecular Bayesian ingroup tree, with putative species nodes marked with a filled black circle and numbered. Shaded blue box indicates region of close-up.

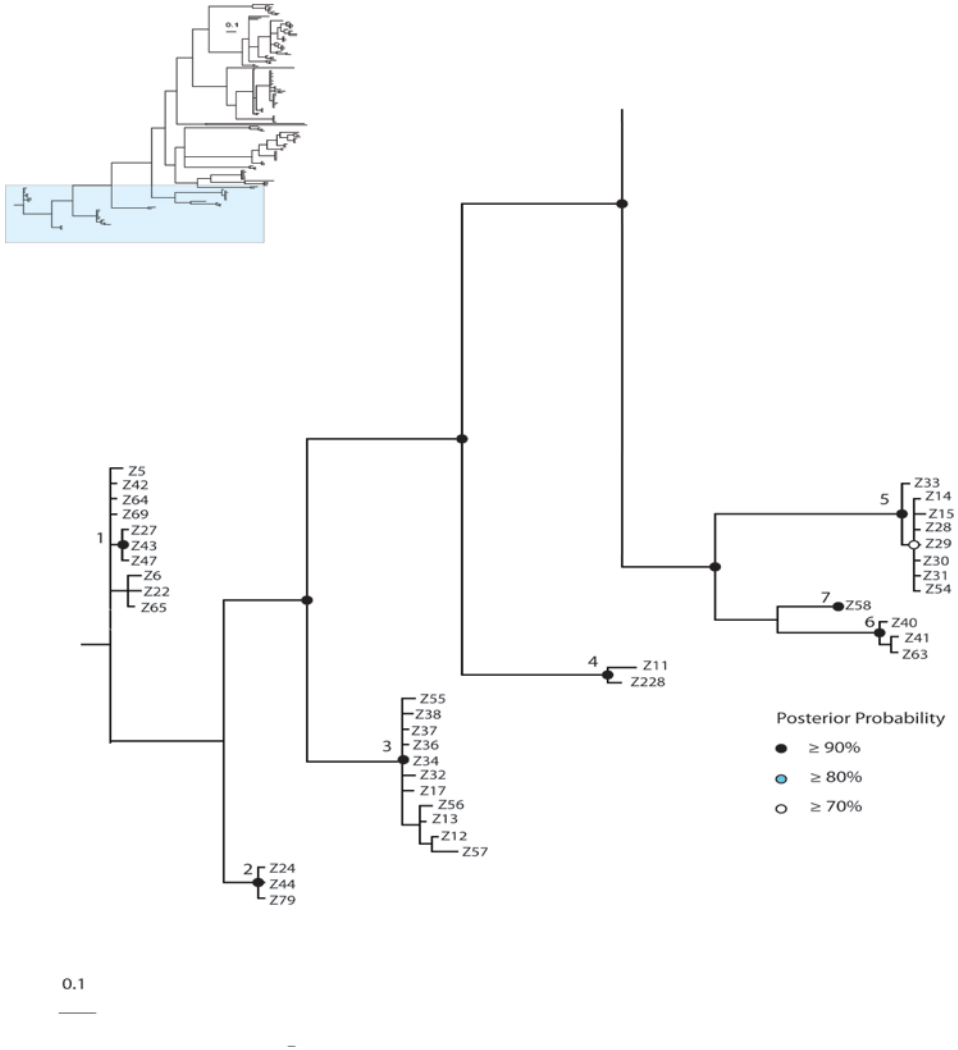


Figure 18: Close-up of combined molecular Bayesian ingroup tree, with putative species nodes marked with a filled black circle and numbered. Shaded blue box indicates region of close-up.

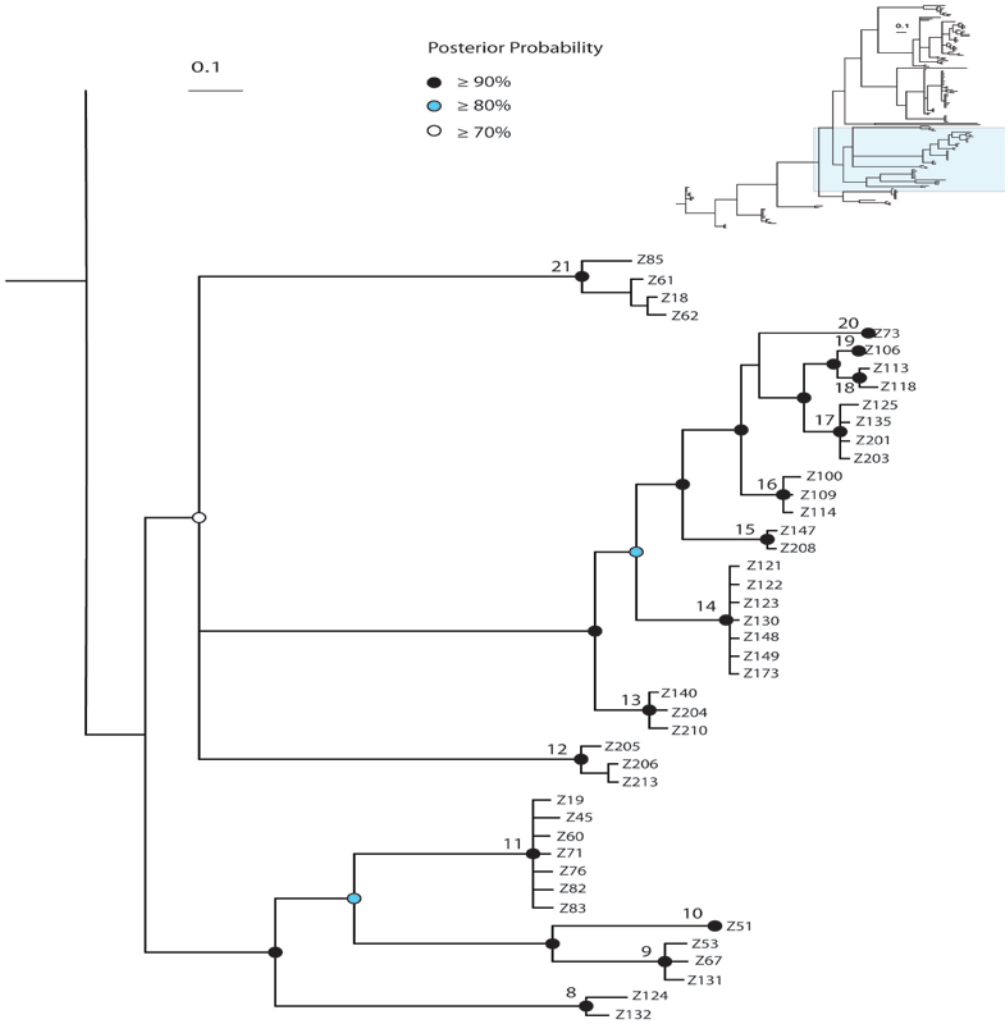


Figure 19: Close-up of combined molecular Bayesian ingroup tree, with putative species nodes marked with a filled black circle and numbered. Shaded blue box indicates region of close-up.

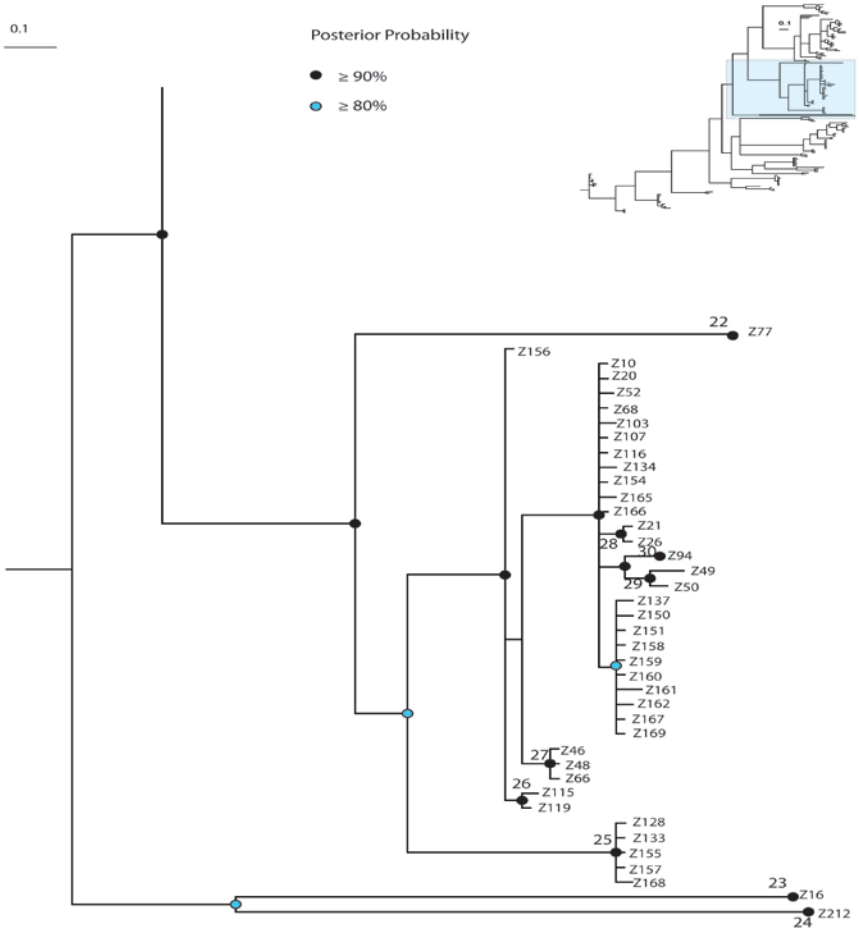


Figure 20: Close-up of combined molecular Bayesian ingroup tree, with putative species nodes marked with a filled black circle and numbered. Shaded blue box indicates region of close-up.

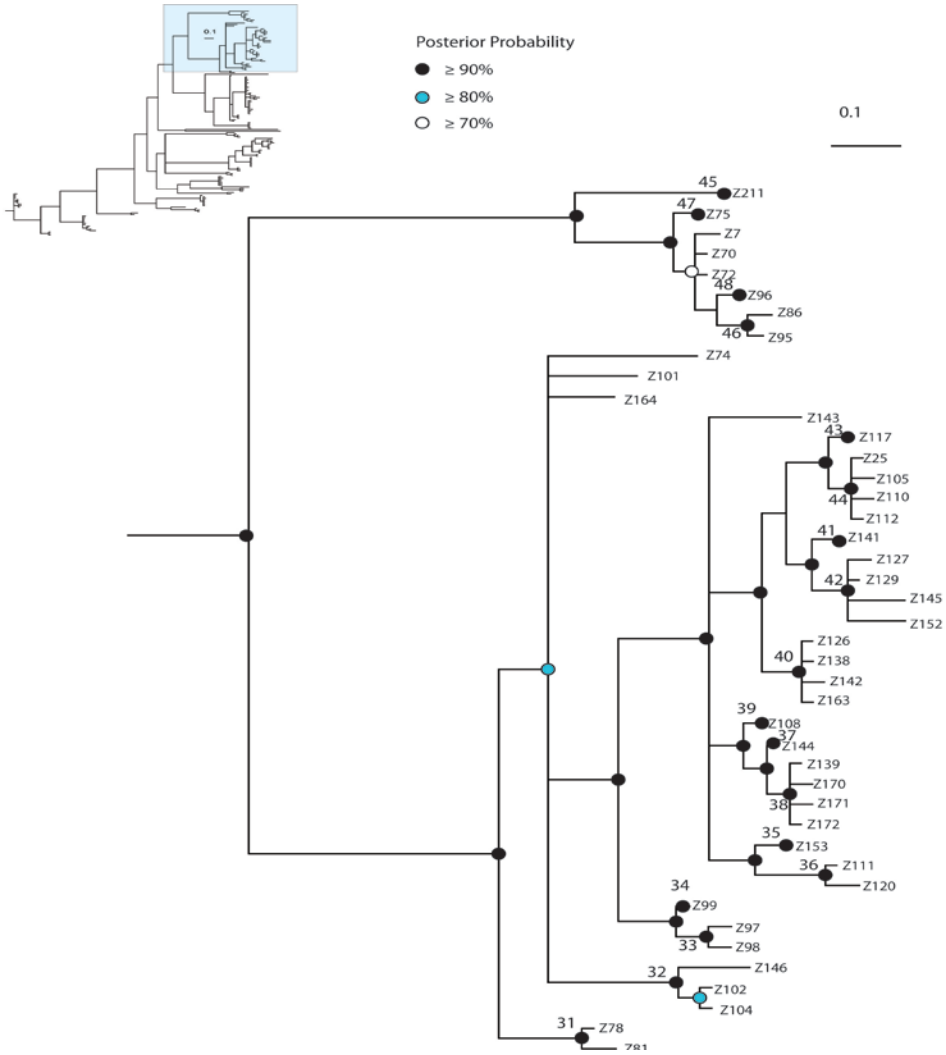


Figure 21: PCA plot of the left paramere shape of ingroup specimens.

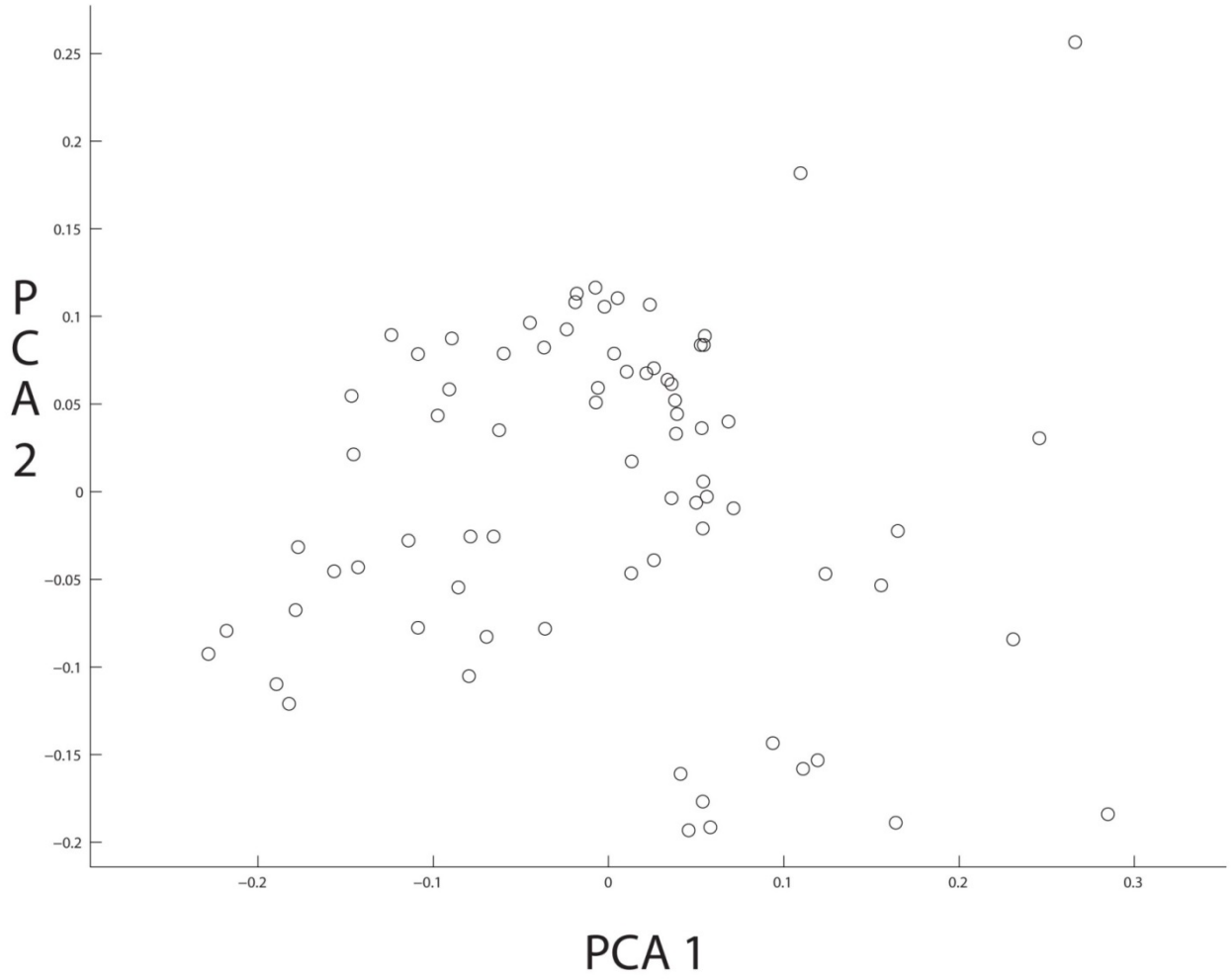


Figure 22 : Scree plot showing the amount of variance accounted for by each principal component of left paramere shape.

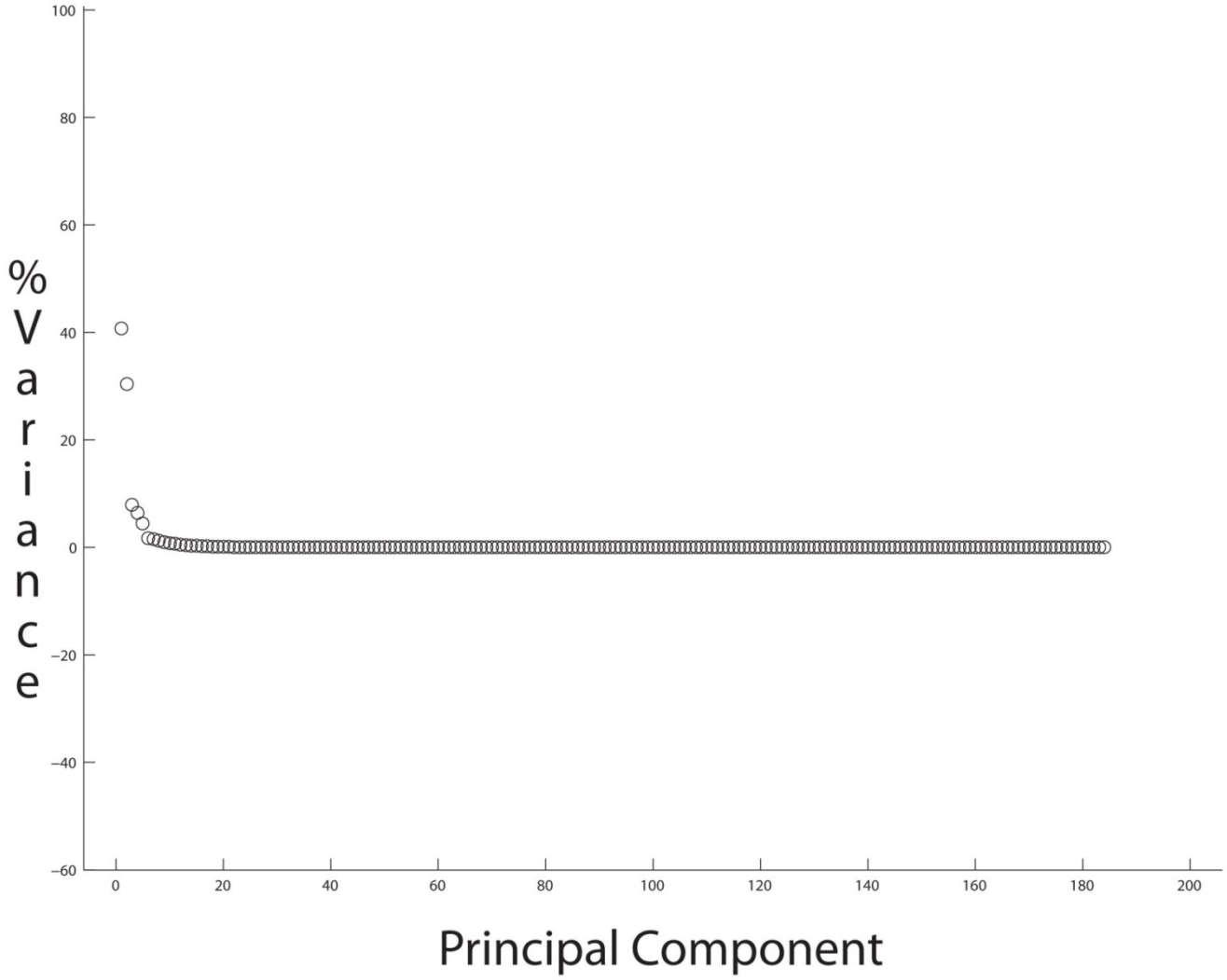


Figure 23: Canonival Variates Analysis plot of the first 30 principal components of left paramere shape for 15 *Pseudoloxops* species. Species are labeled, color-coded and enclosed by convex hulls.

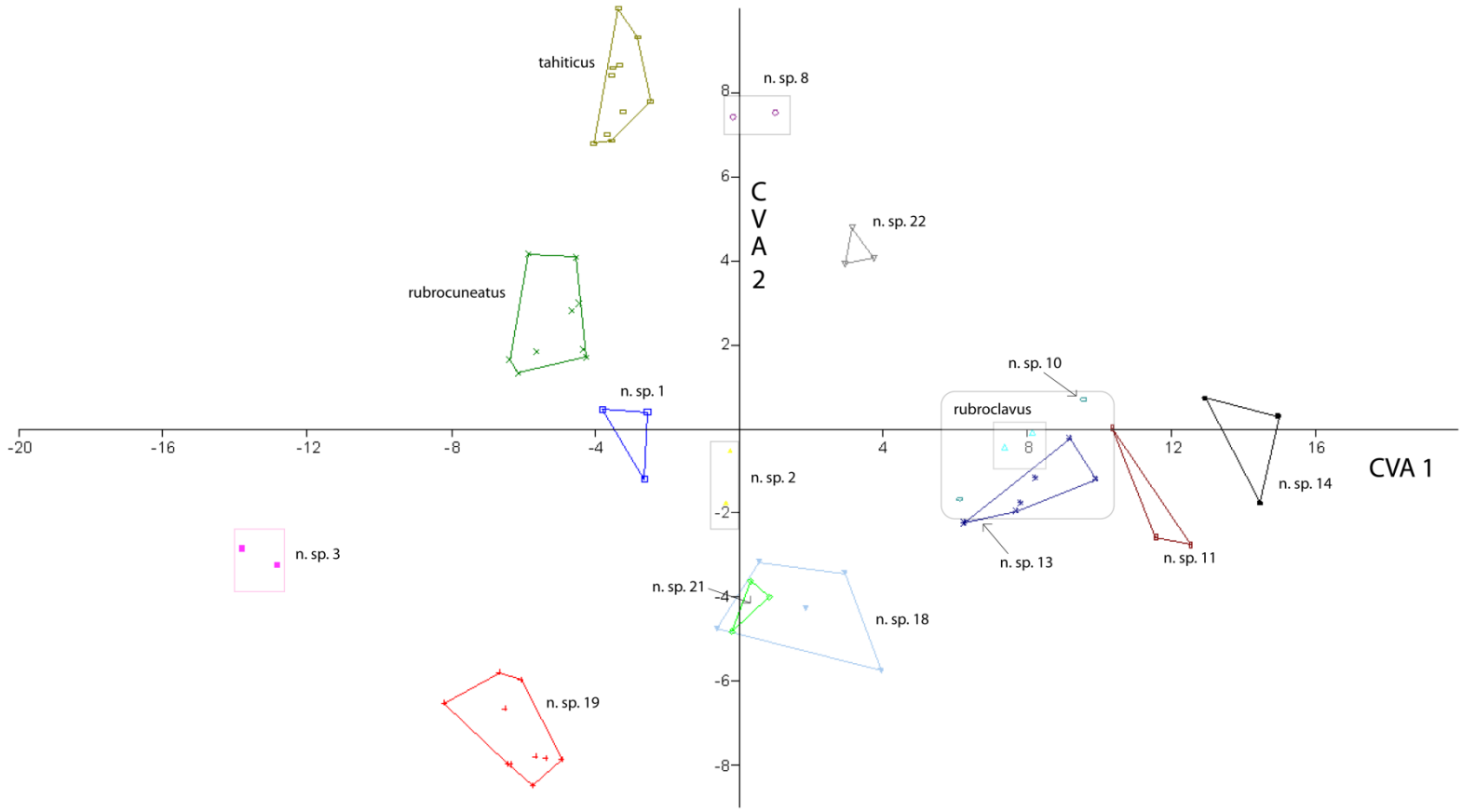


Figure 24: 50% majority-rules molecular consensus Bayesian tree with final *Pseudoloxops* species indicated at terminals.

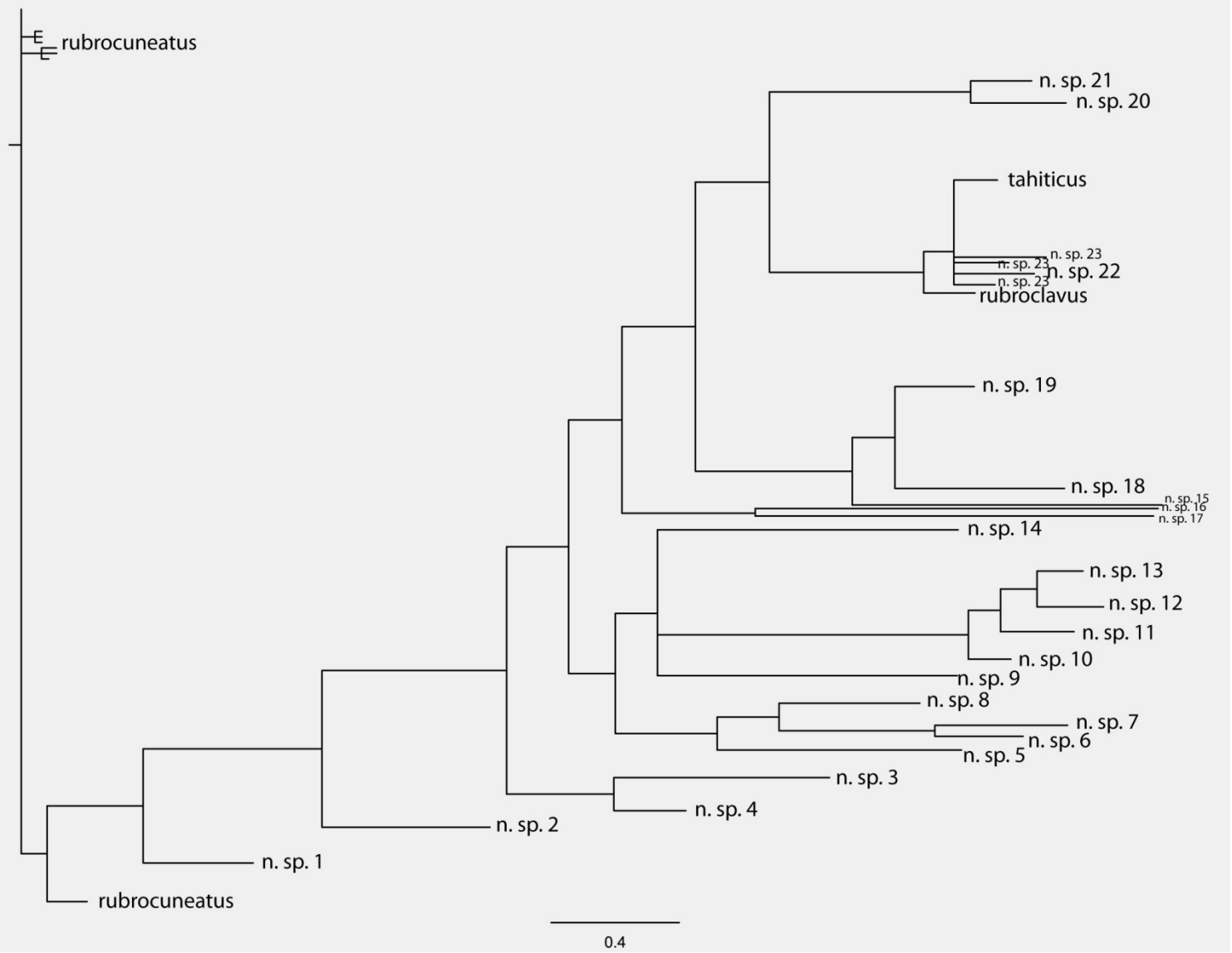


Figure 25 (a-b): Paratypes of *Pseudoloxops rubrocuneatus*; (a) specimen Z27, ♀; (b) specimen Z47, ♂.

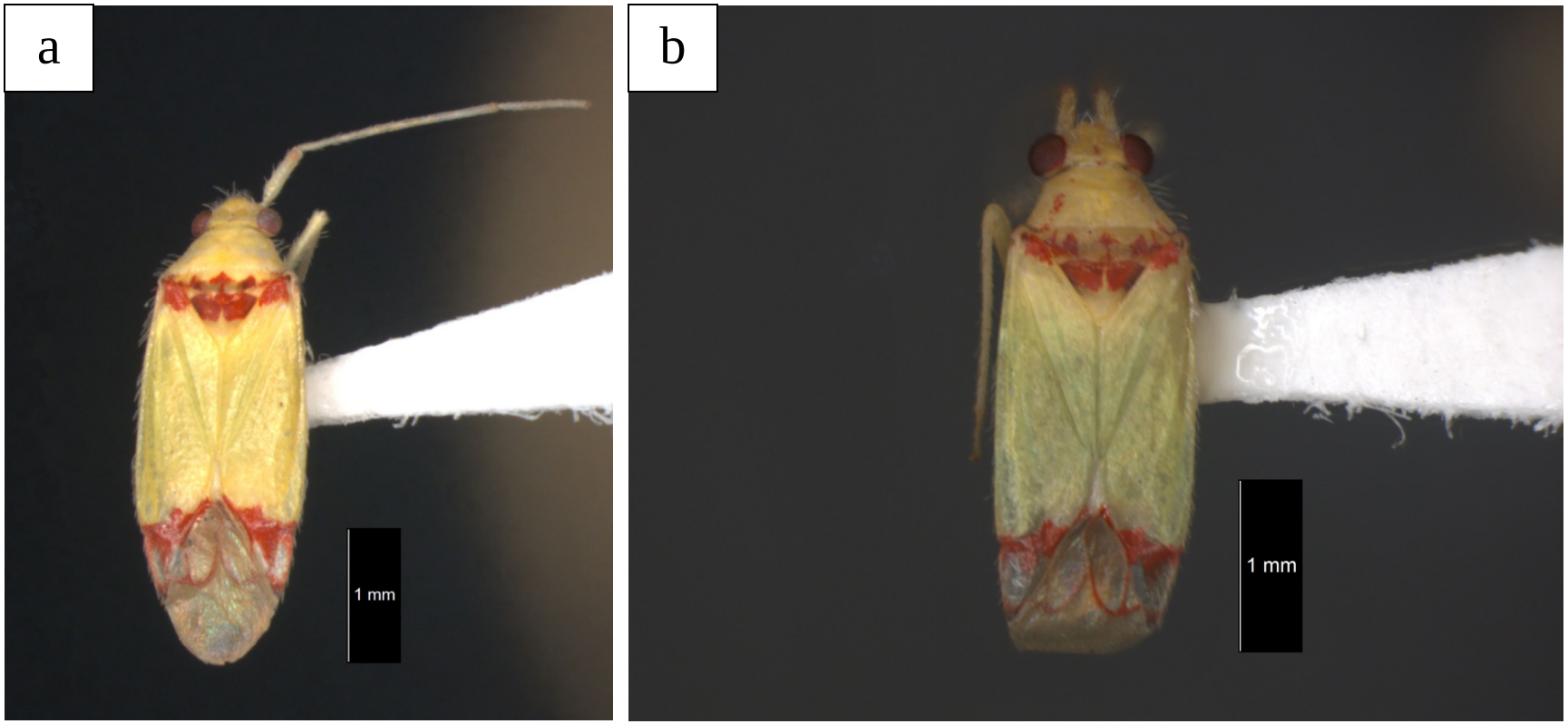


Figure 26 (a-b): Paratypes of alternate color morph for *Pseudoloxops rubrocuneatus*; (a) specimen Z6, ♂; (b) specimen Z65, ♀.

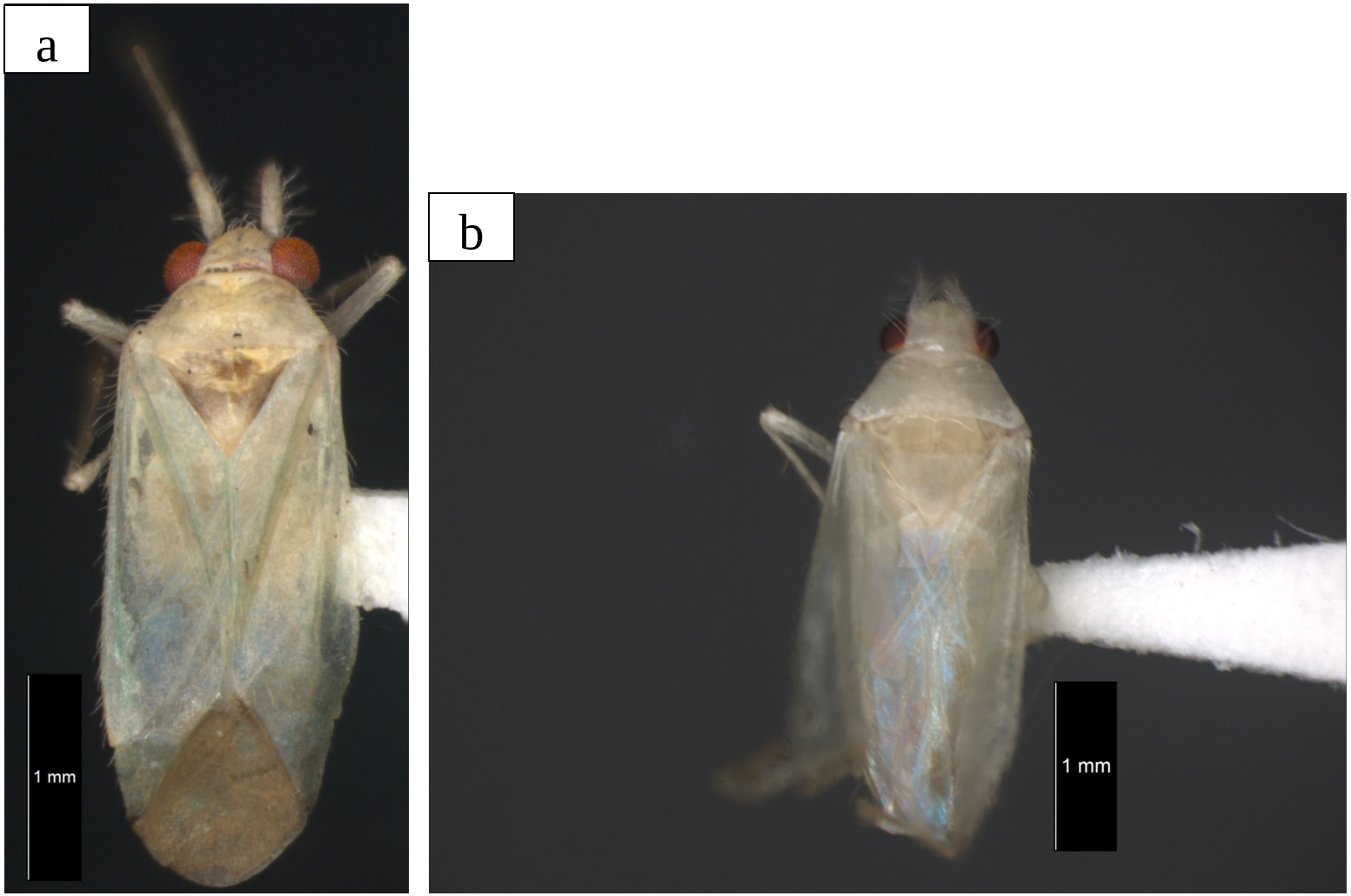


Figure 27 (a-c): Male genitalia of *Pseudoloxops rubrocuneatus*, specimen 42; (a) aedeagus; (b) left paramere; (c) right paramere.

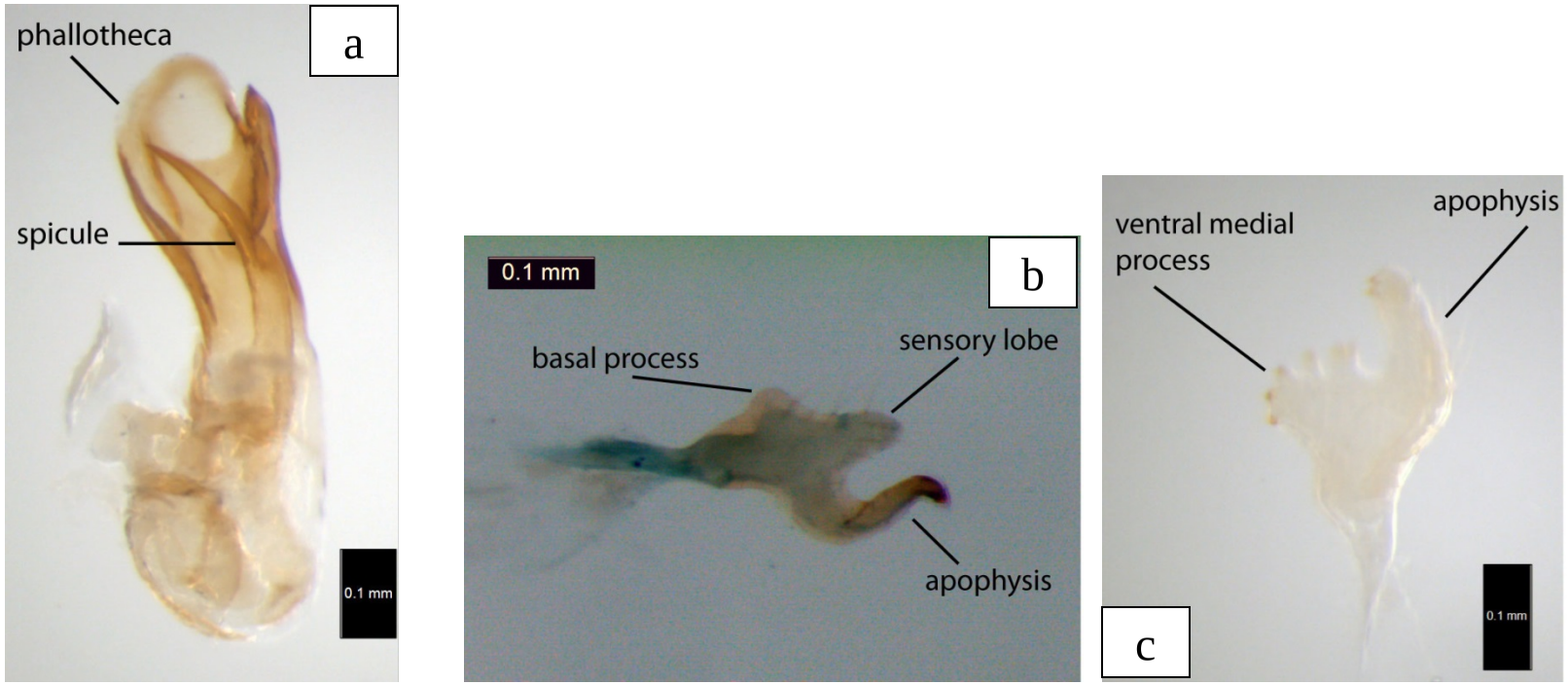


Figure 28: Distribution map for *Pseudoloxops rubrocuneatus*.

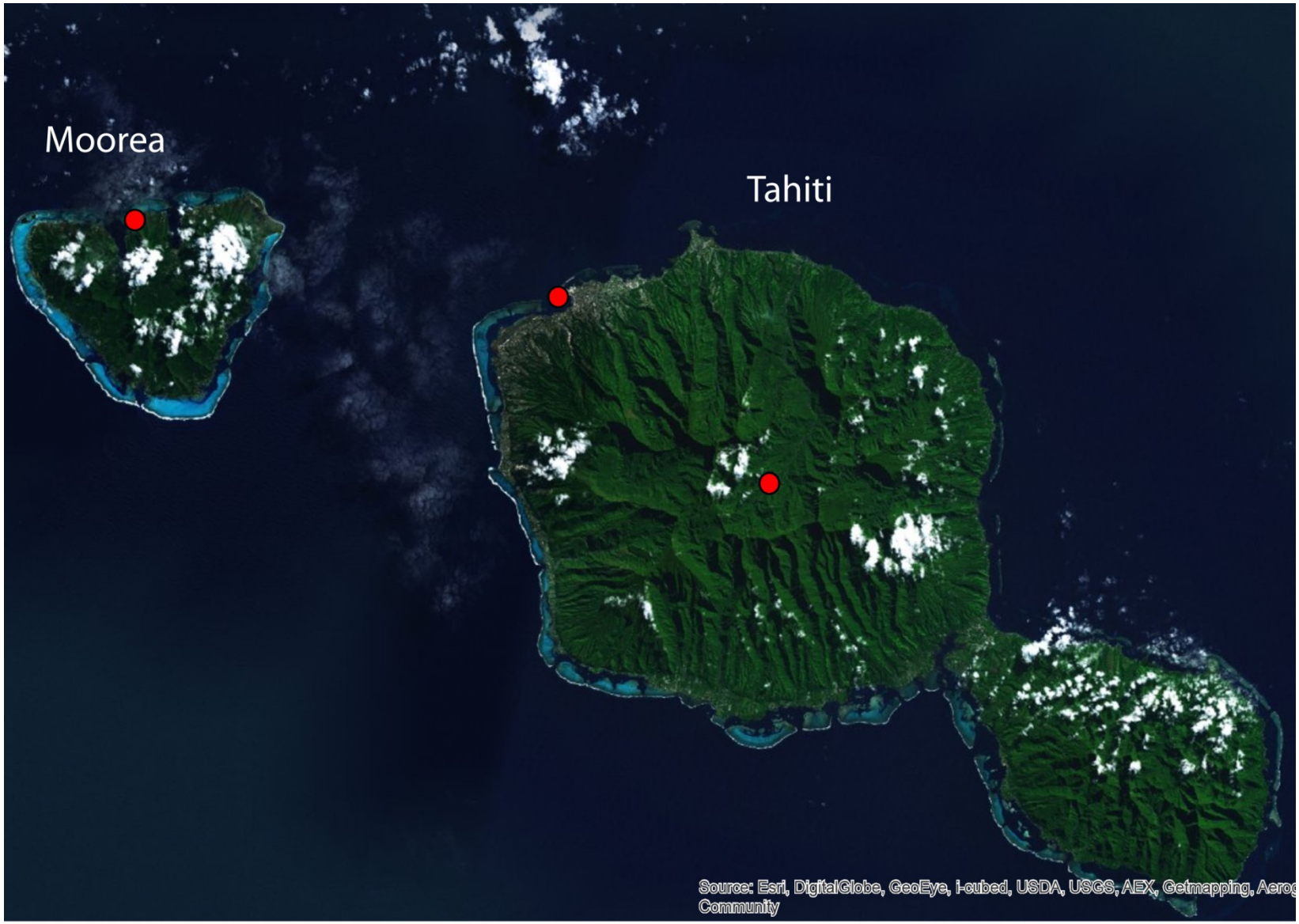


Figure 29 (a-b): Holotype and paratype of P. n. sp. 1; (a) holotype (♂), specimen Z17; (b) paratype (♀), specimen Z12.

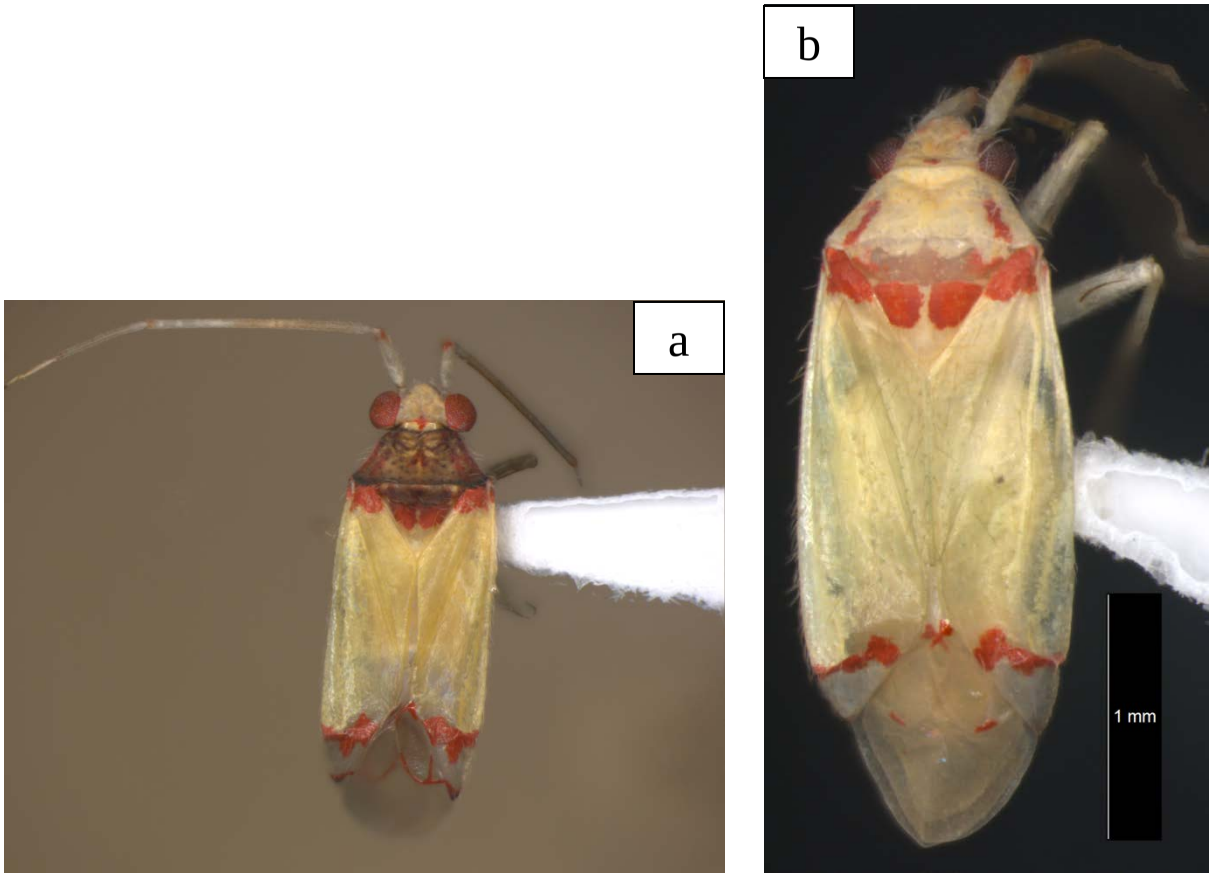


Figure 30 (a-c): Male genitalia of P. n. sp. 1, specimen Z17; (a) aedeagus; (b) left paramere; (c) right paramere.

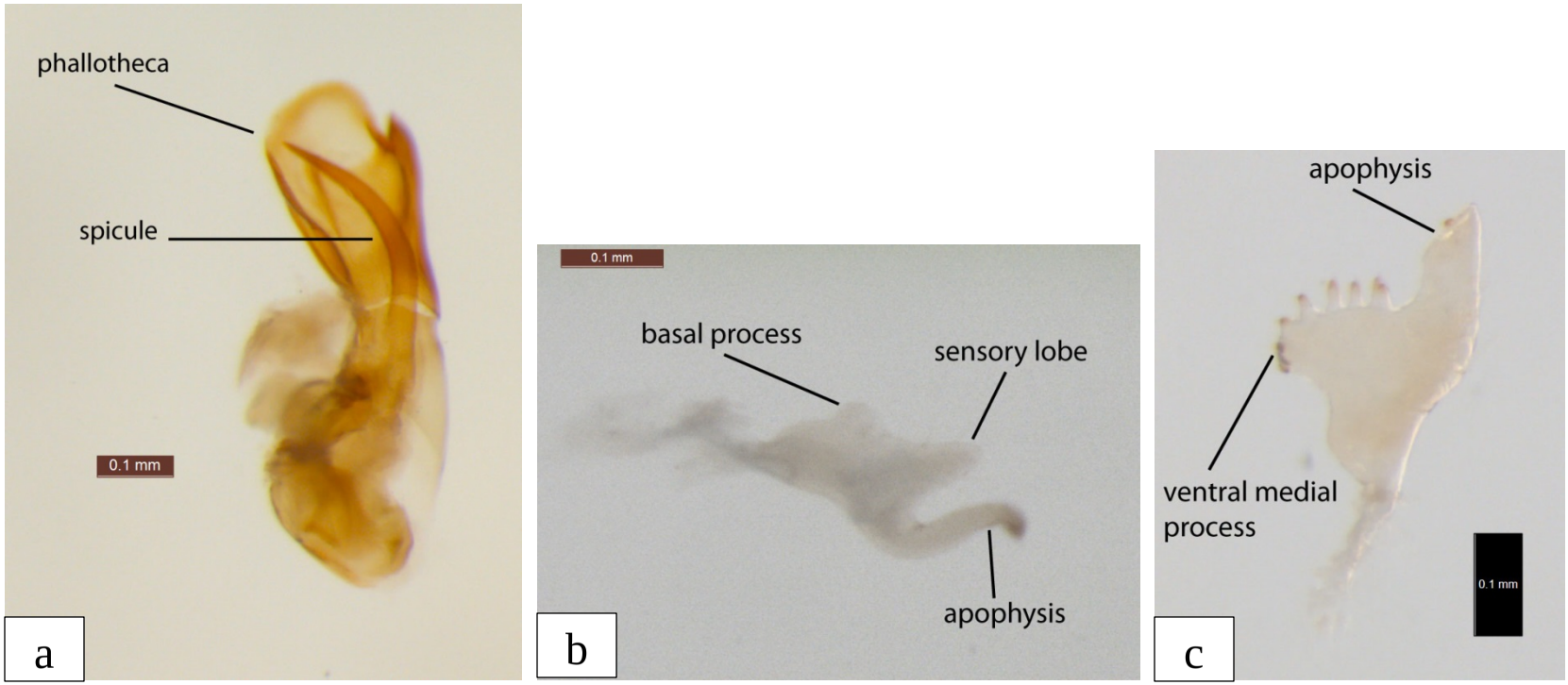


Figure 31: Distribution maps for P. n. sp. 1

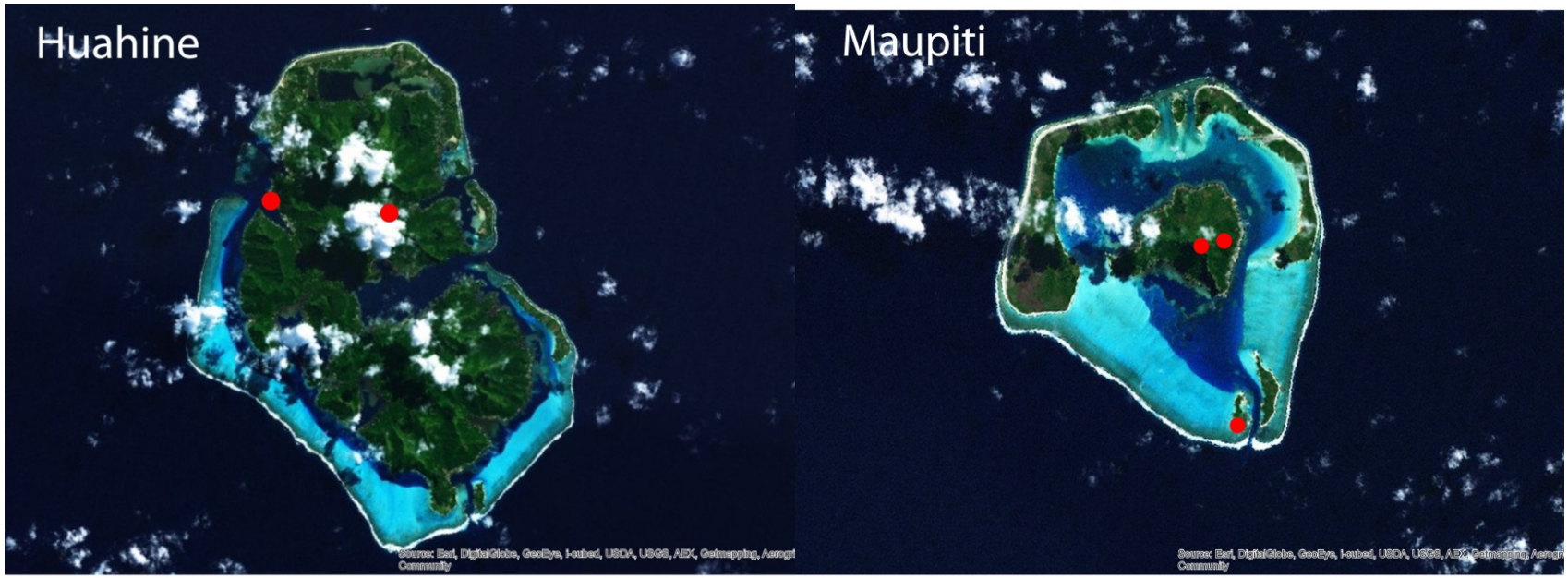


Figure 32: Holotype (♂) of P. n. sp. 2, specimen Z11.

Figure 33 (a-c): Male genitalia of P. n. sp. 2; (a) aedeagus; (b) left paramere; (c) right paramere.

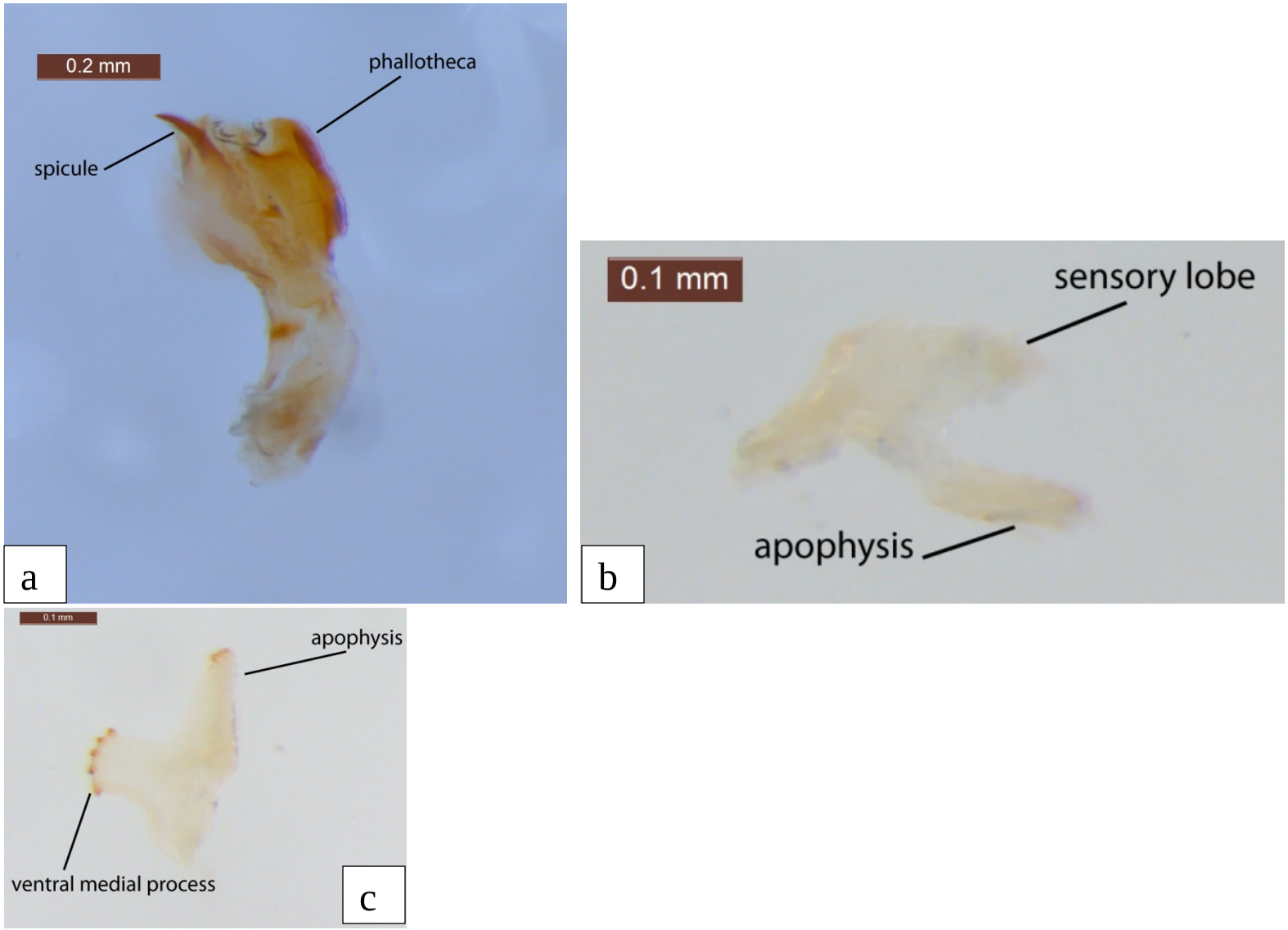


Figure 34: Distribution map for P. n. sp. 2 (Rurutu distribution not shown due to lack of precise GPS coordinates).

Figure 35 (a-b): (a) Holotype (♂) of P. n. sp. 3, specimen Z14; (b) paratype (♀), specimen Z30

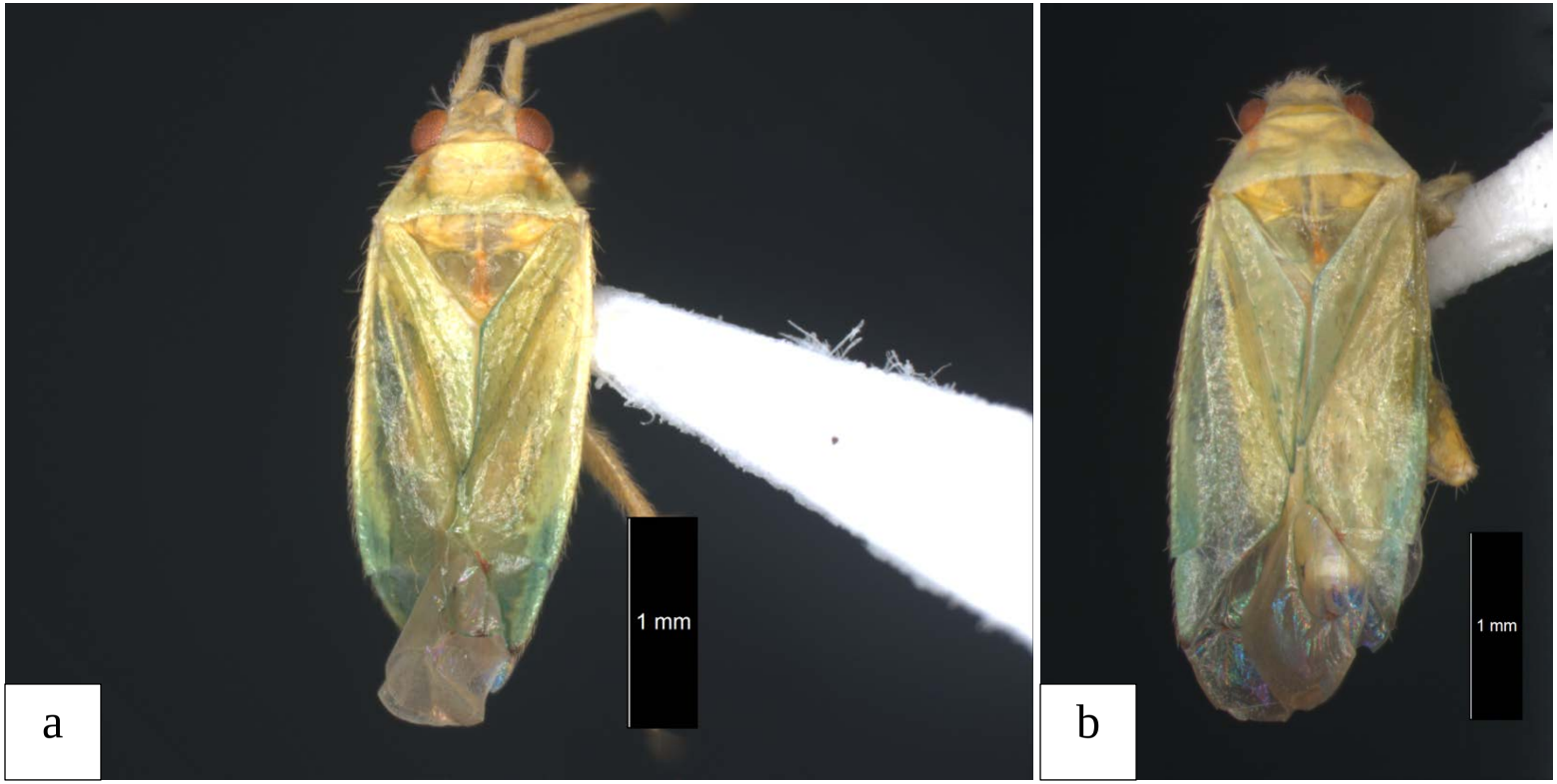


Figure 36 (a-c): Male genitalia of P. n. sp. 3, specimen Z14; (a) aedeagus; (b) left paramere; (c) right paramere.

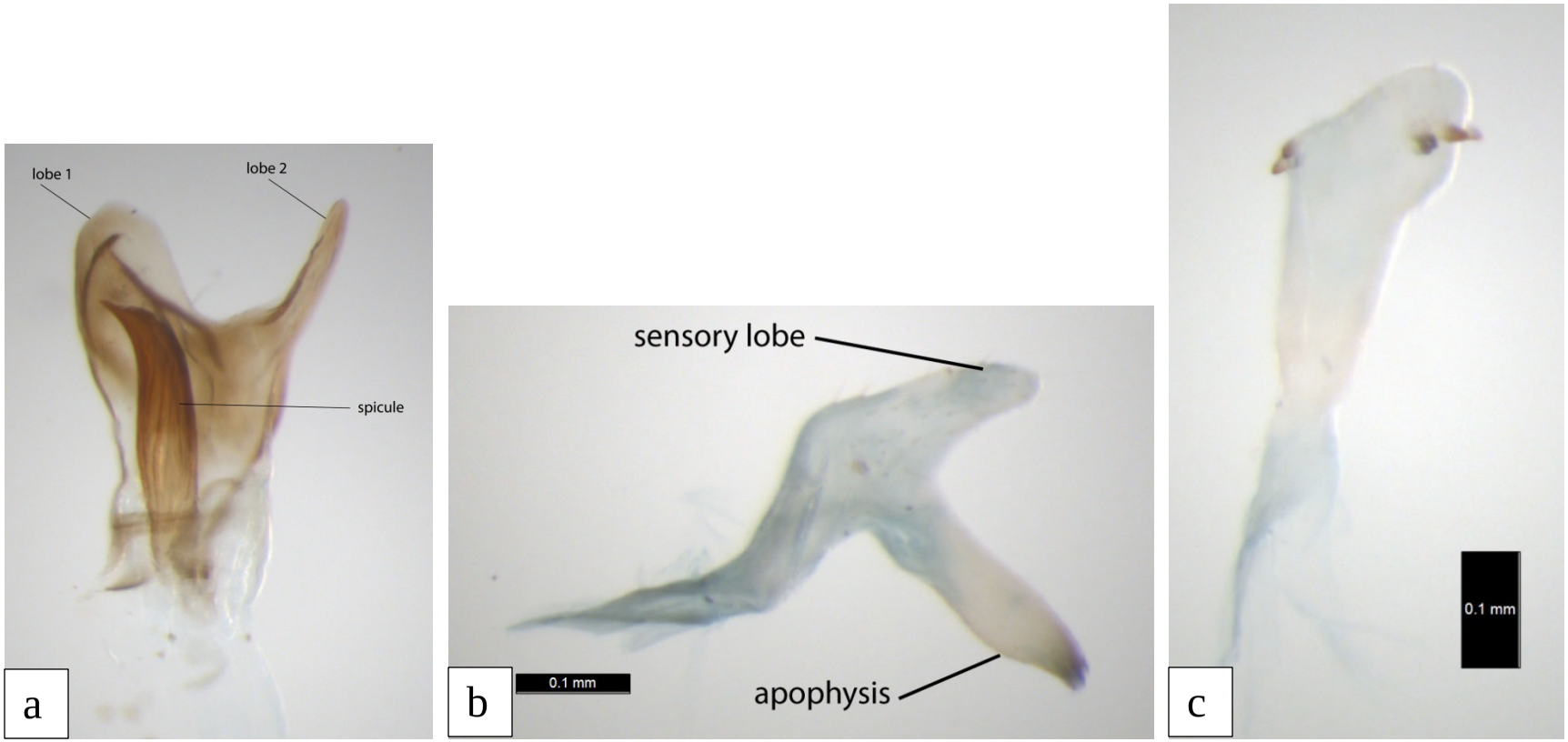


Figure 37: Distribution map for P. n. sp. 3.

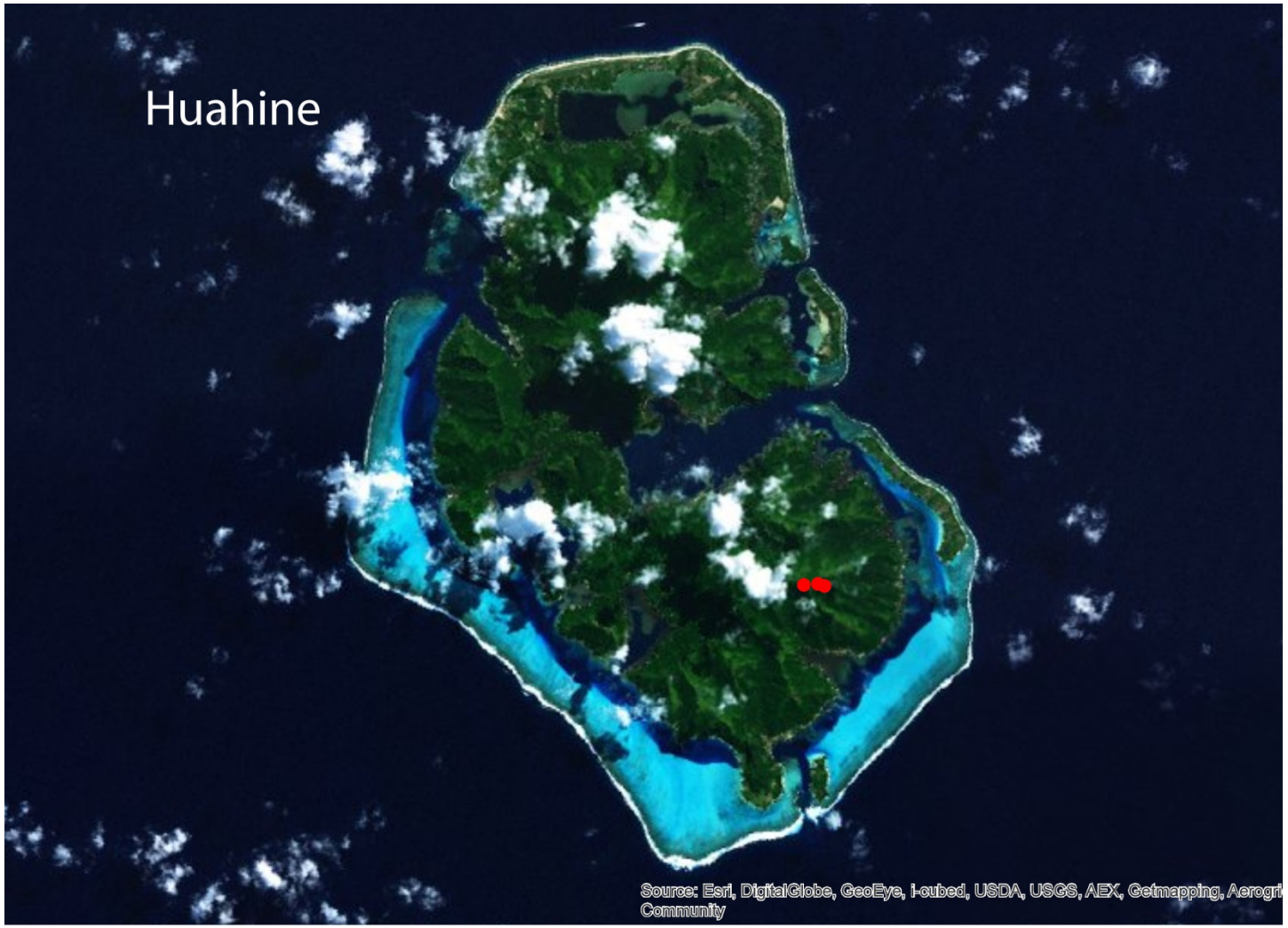


Figure 38 (a-b): (a) Holotype (♂) of P. n. sp. 4, specimen Z41; (b) paratype (♀), specimen Z58

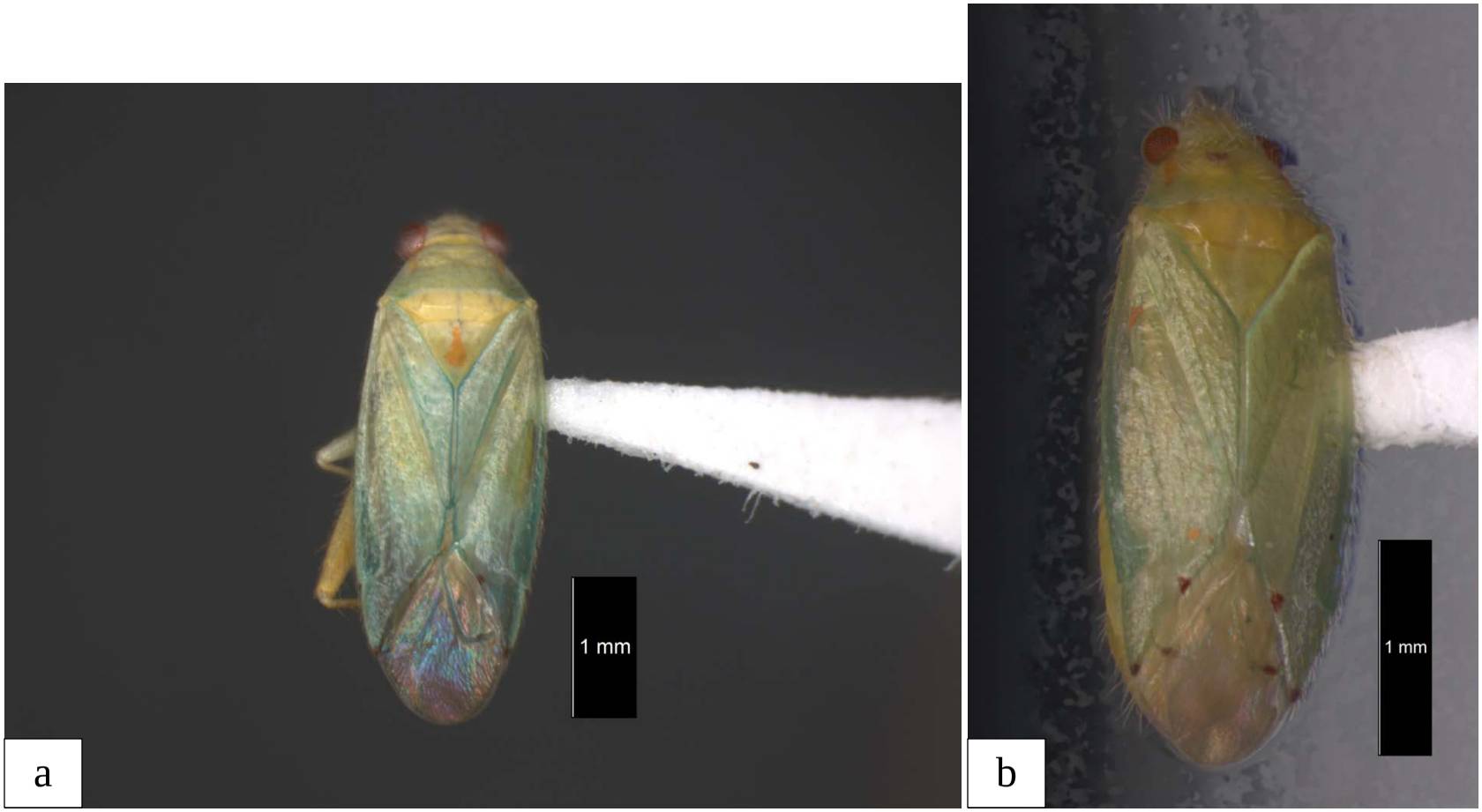


Figure 39 (a-c): Male genitalia of P. n. sp. 4; (a) aedeagus of specimen Z40; (b) left paramere of specimen Z41; (c) right paramere of specimen Z41.

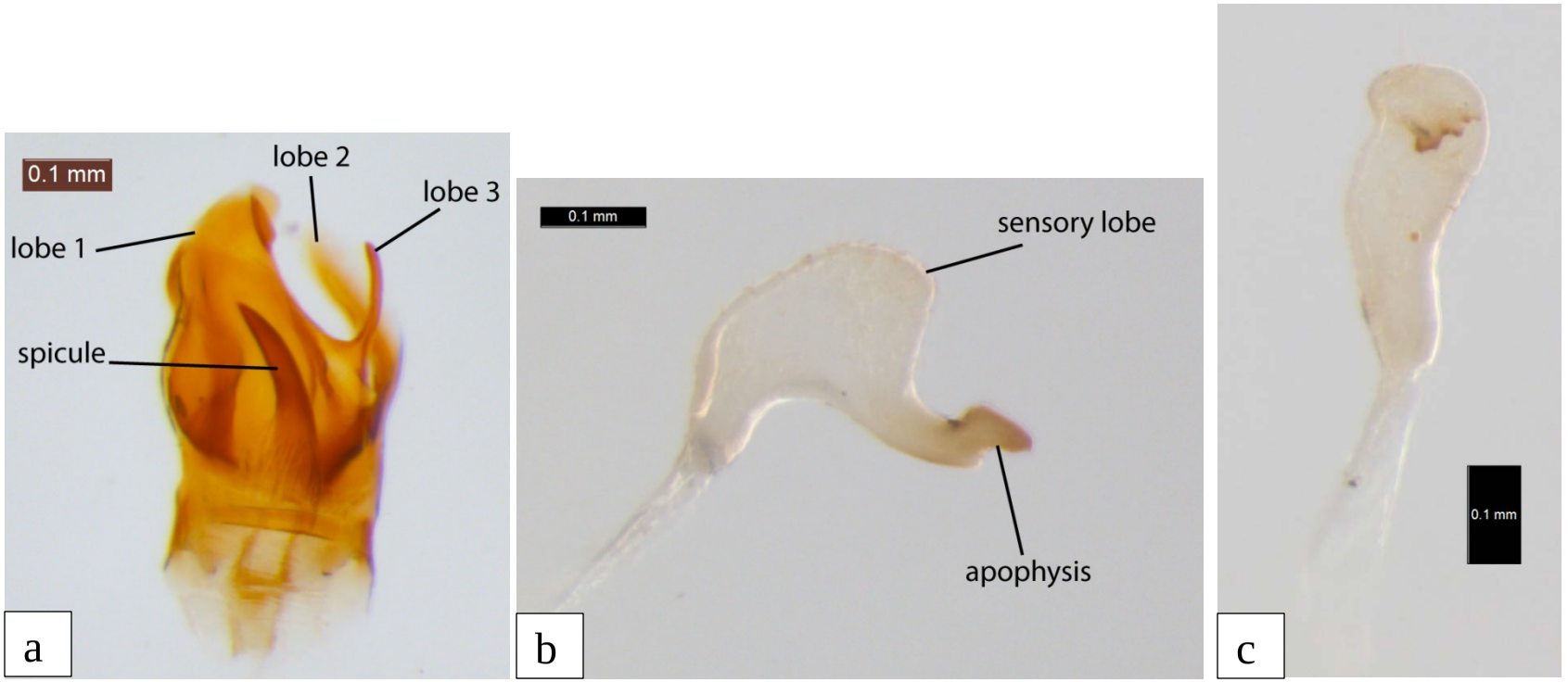


Figure 40: Distribution map of P. n. sp. 4.

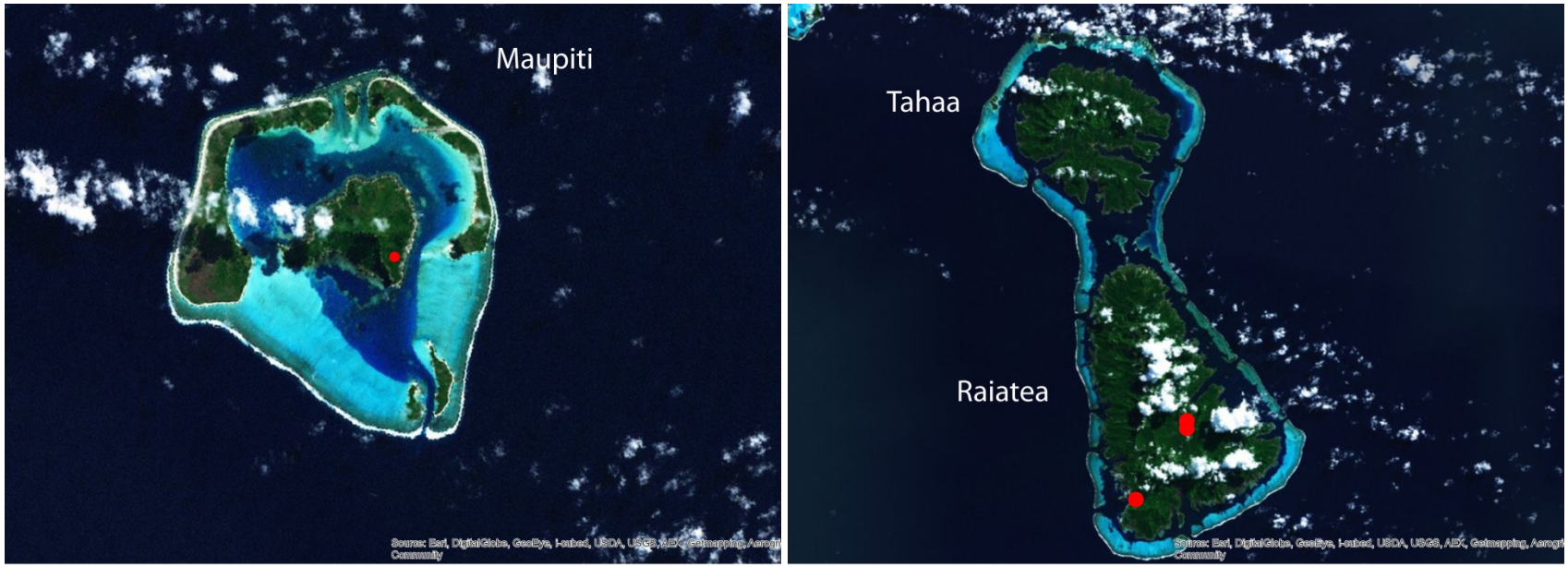


Figure 41: Holotype (♀) of P. n. sp. 5, specimen Z124.

Figure 42: Distribution map for P. n. sp. 5.

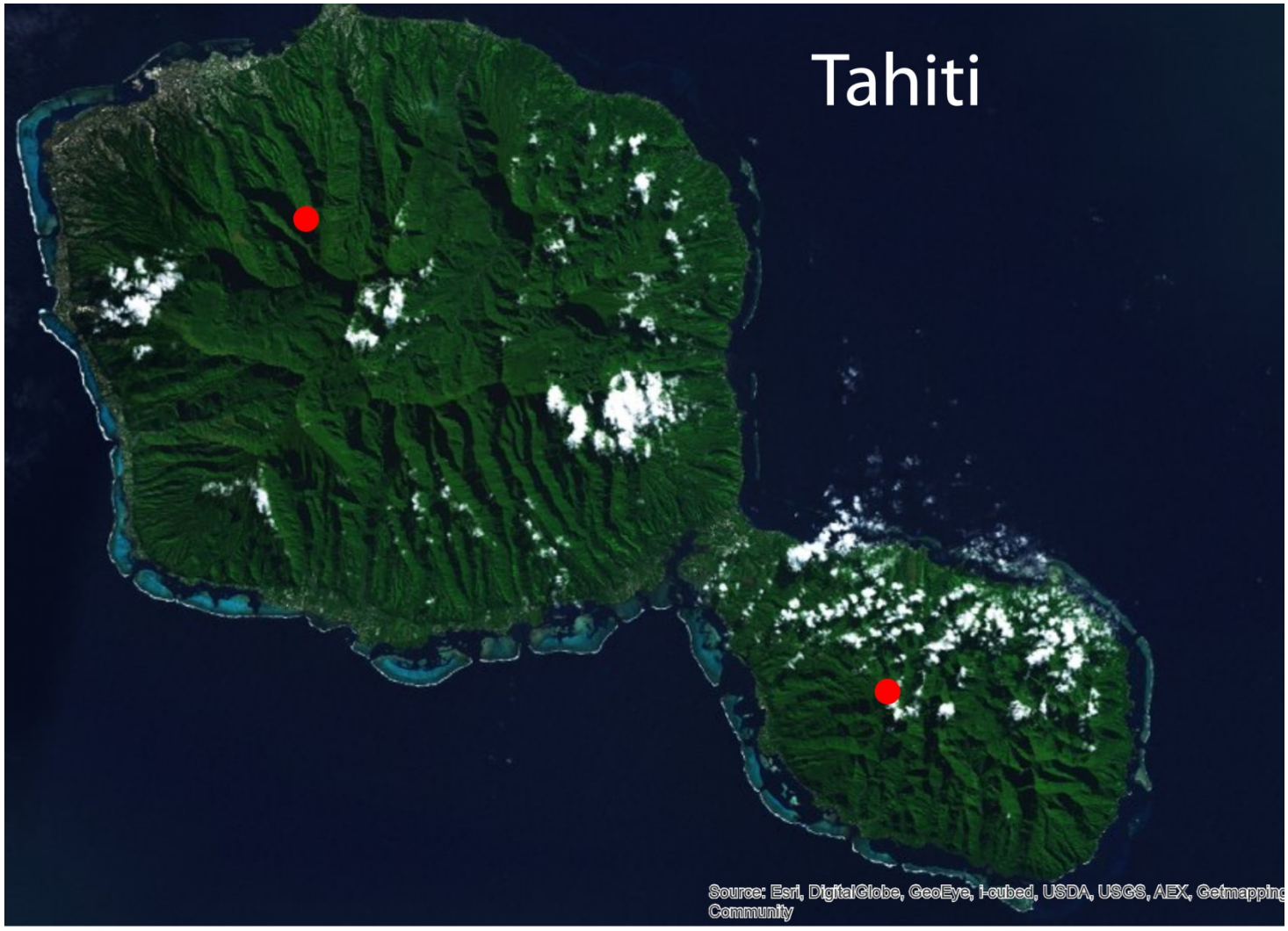


Figure 43: Holotype (♀) of P. n. sp. 6, specimen Z131.

Figure 44: Distribution map for P. n. sp. 6.

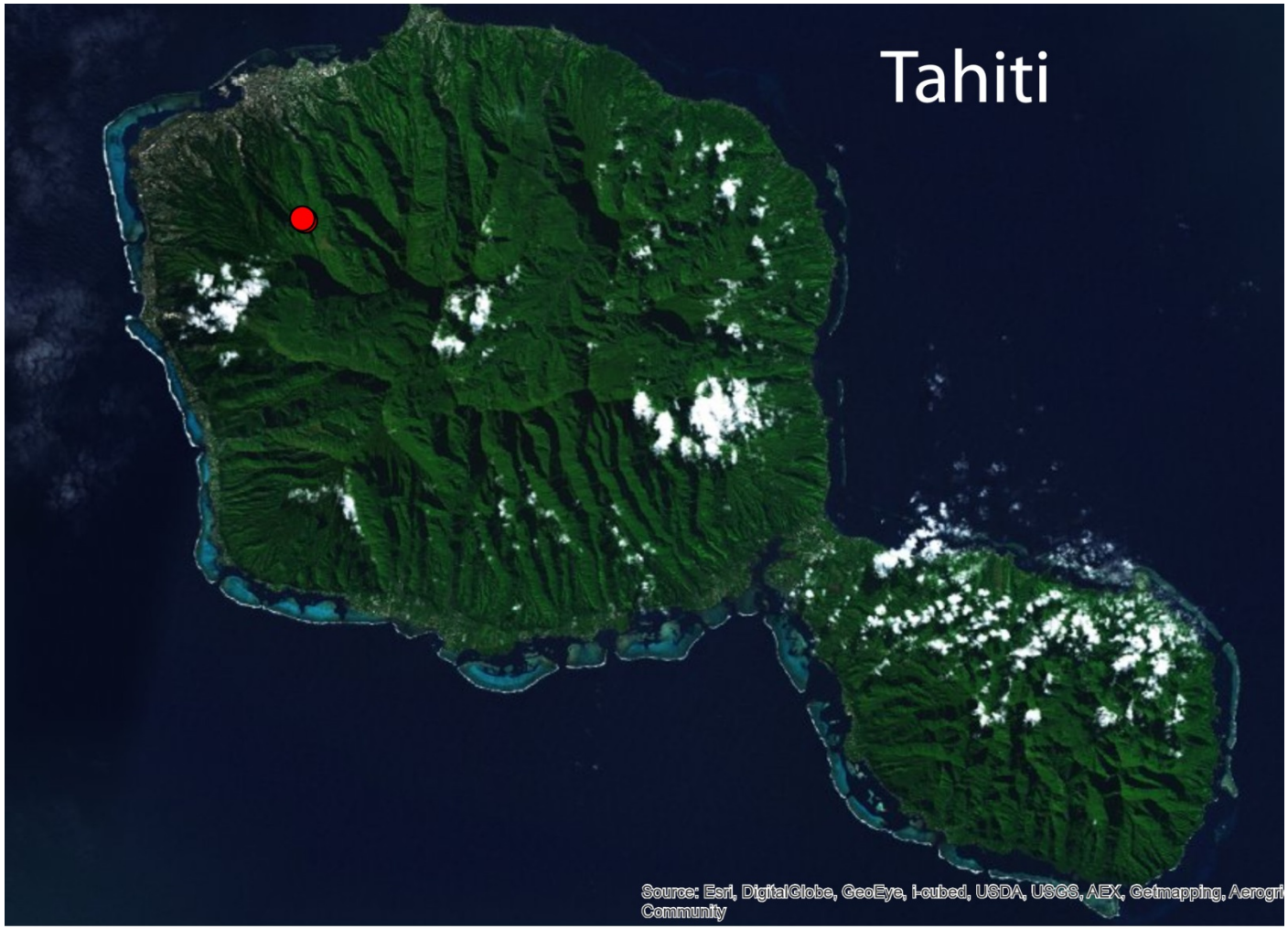


Figure 45: Holotype (♀) of P. n. sp. 7, specimen Z51.

Figure 46: Distribution map of P. n. sp. 7.

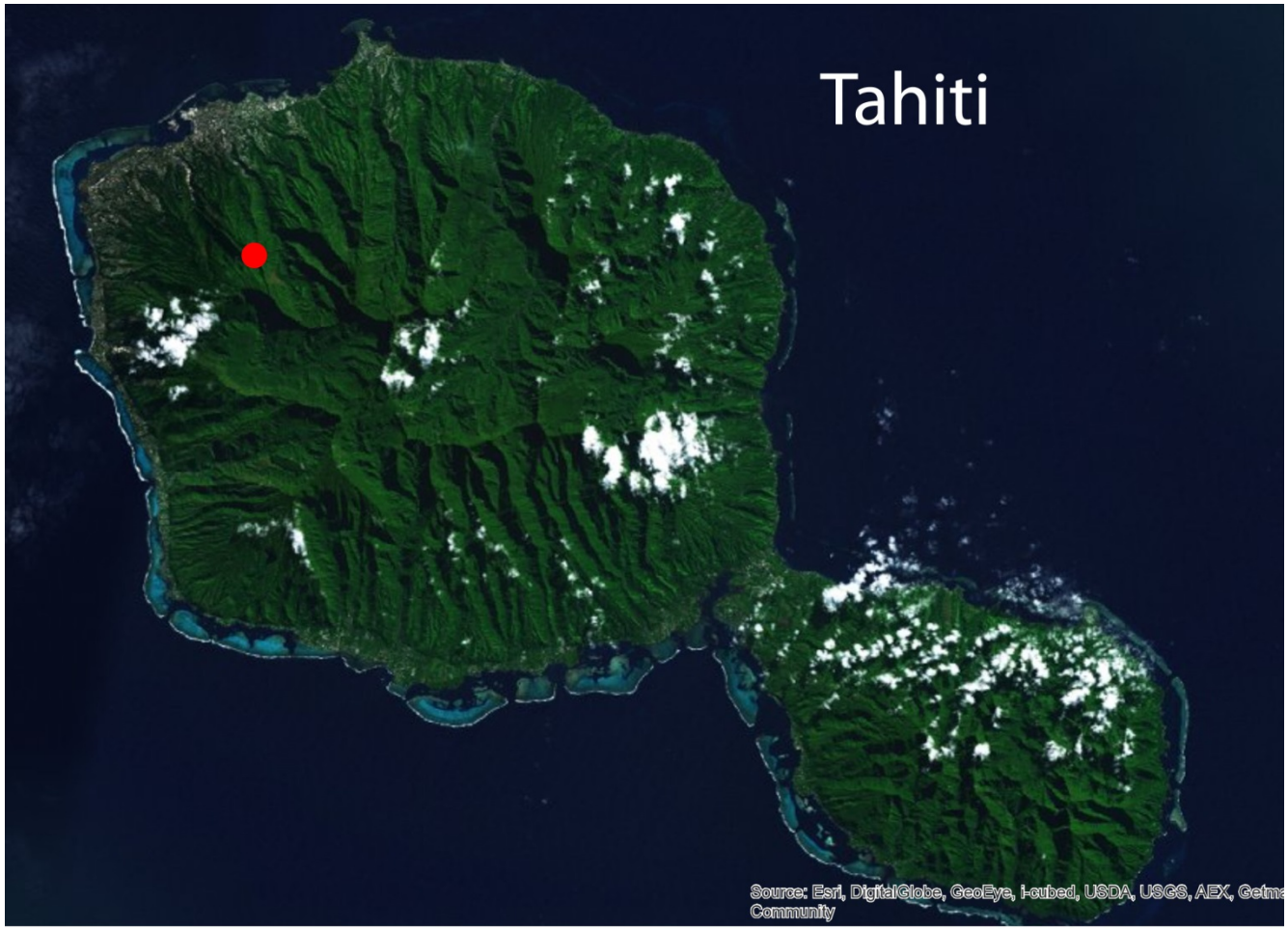


Figure 47 (a-b): Holotype (♂) of P. n. sp. 8, specimen Z45; (b) paratype (♀), specimen Z60.

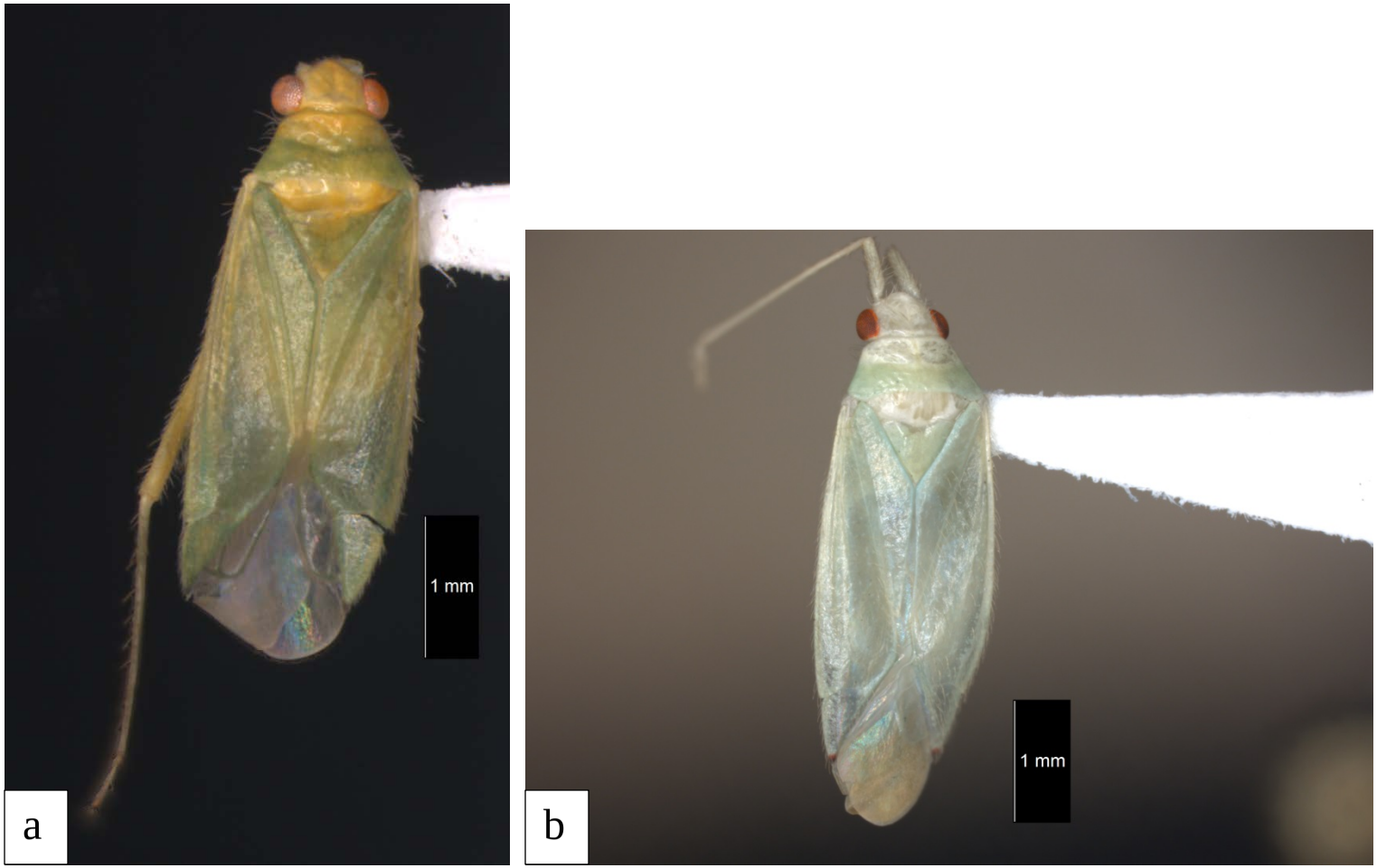


Figure 48 (a-c): Male genitalia of P. n. sp. 8, specimen Z45; (a) aedeagus; (b) left paramere; (c) right paramere.

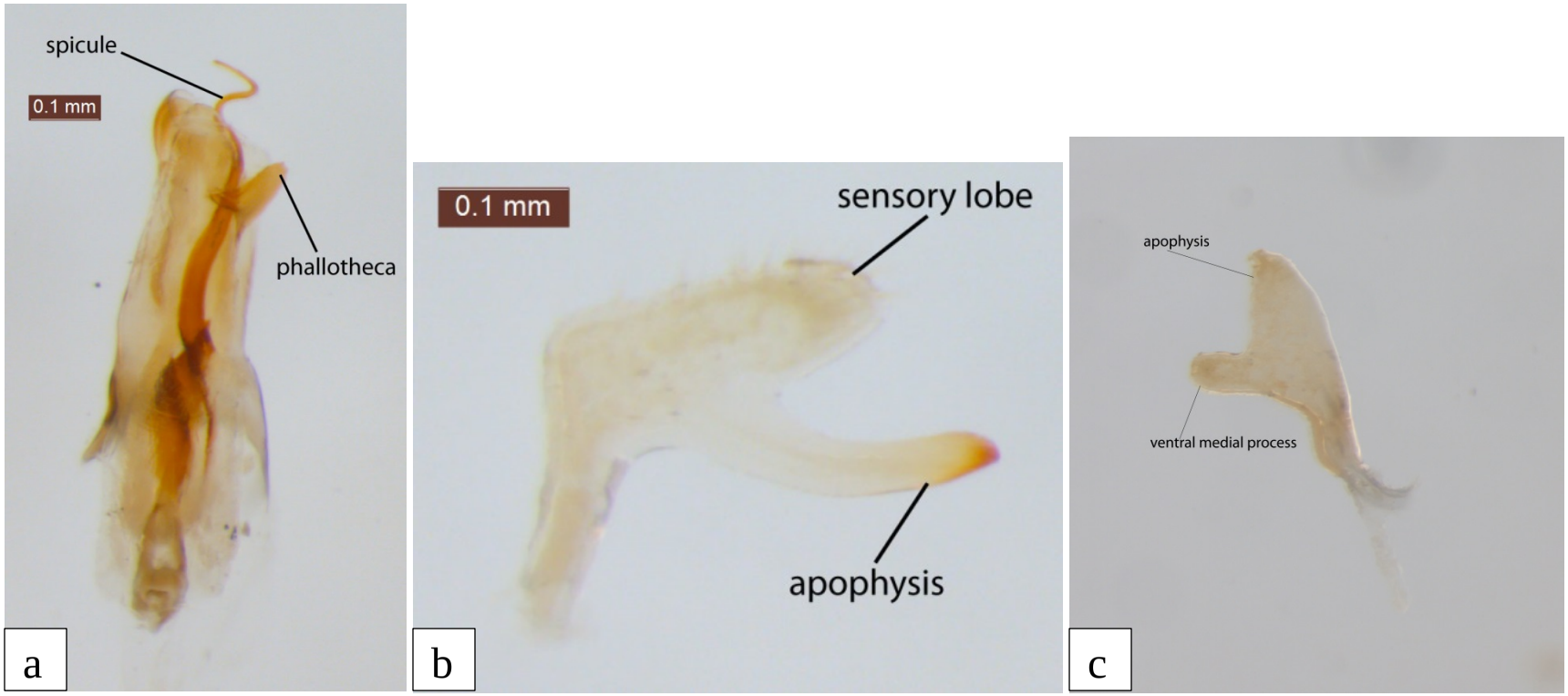


Figure 49: Distribution map of P. n. sp. 8.

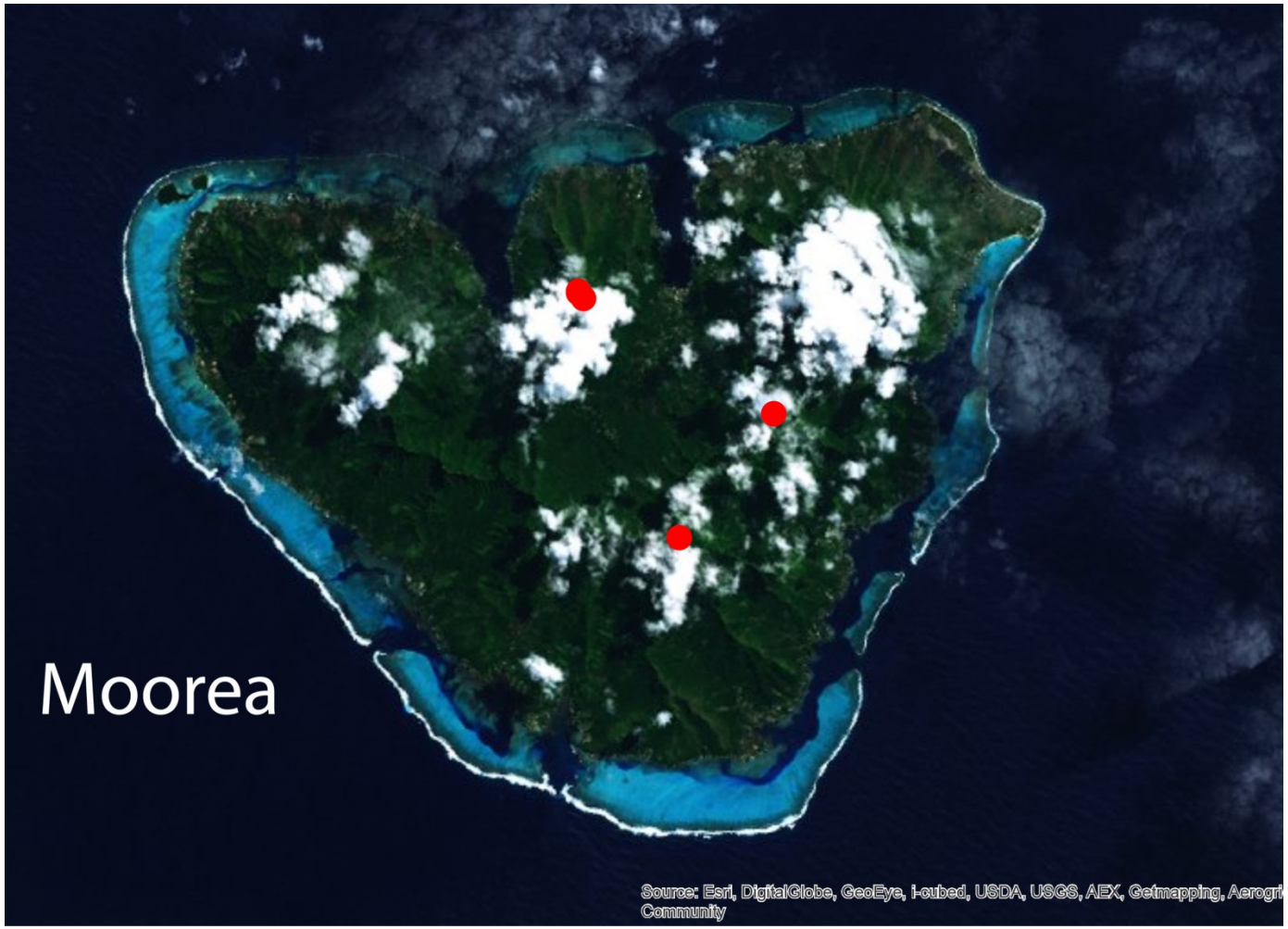


Figure 50 (a-b): (a) Holotype (♂) of P. n. sp. 9, specimen Z205 (head missing); (b) paratype (♀), specimen Z206.

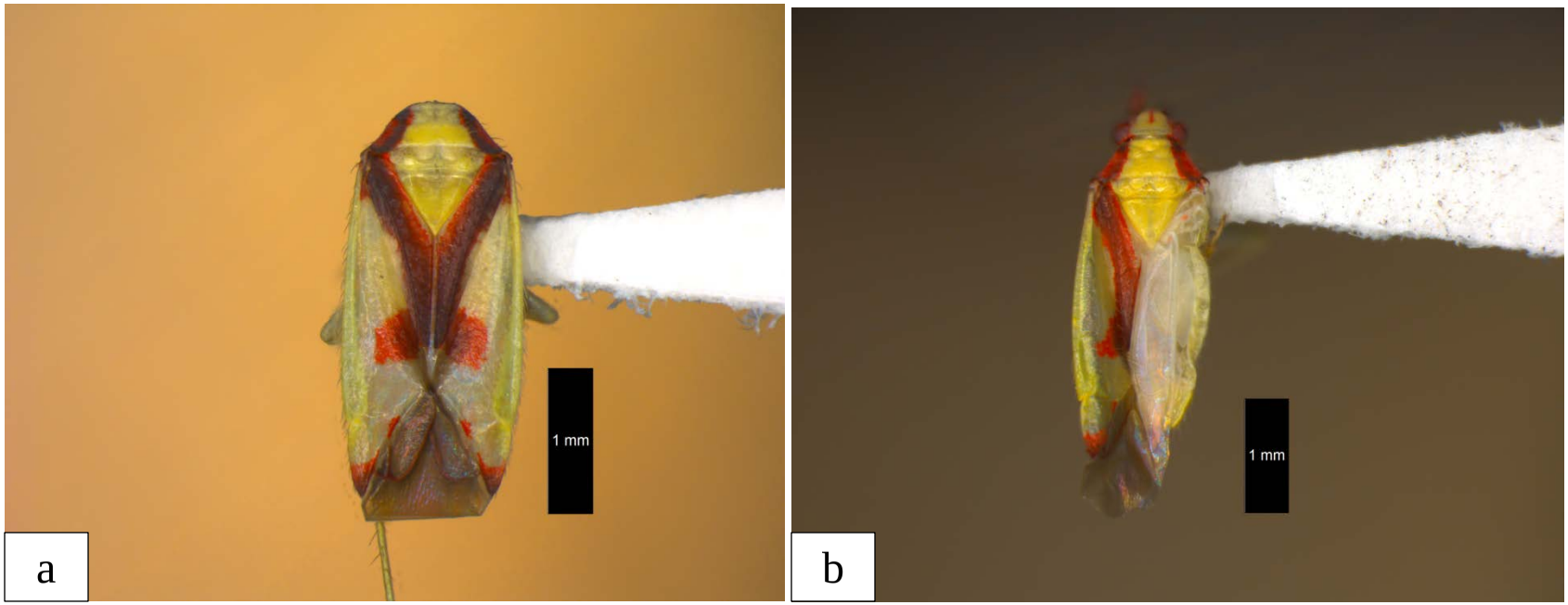
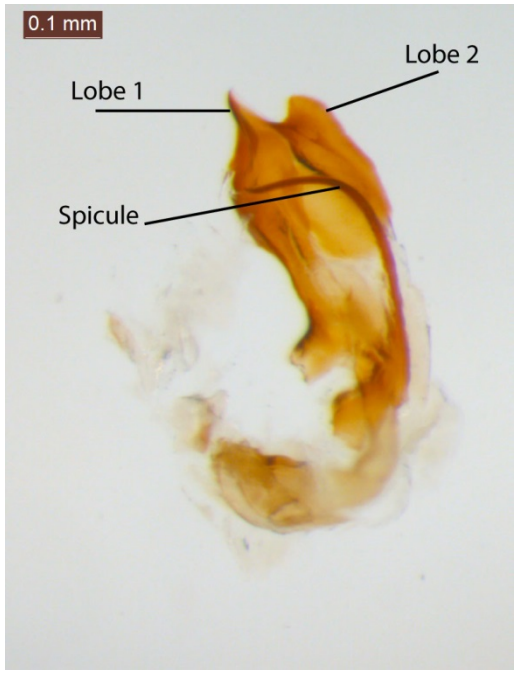
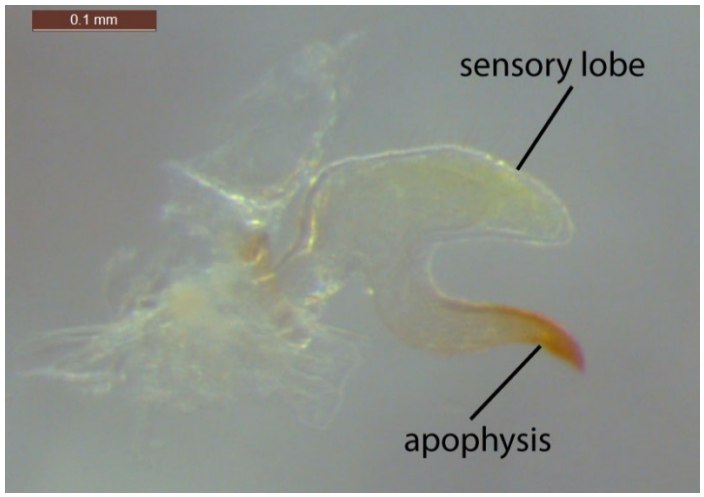


Figure 51 (a-c): Male genitalia P. n. sp. 9, specimen Z205; (a) aedeagus; (b) left paramere; (c) right paramere.





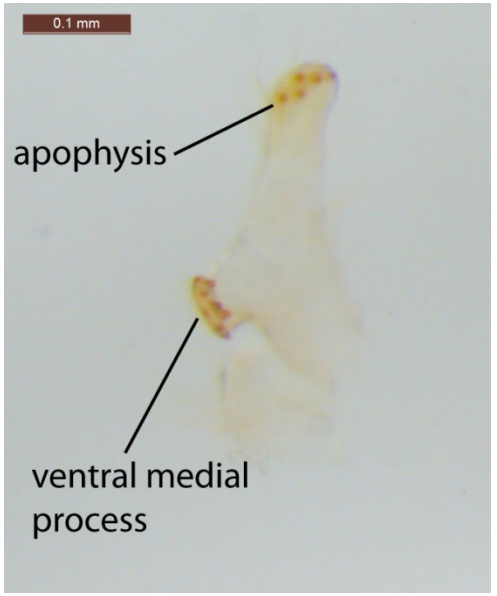


Figure 52: Distribution map of P. n. sp. 9.

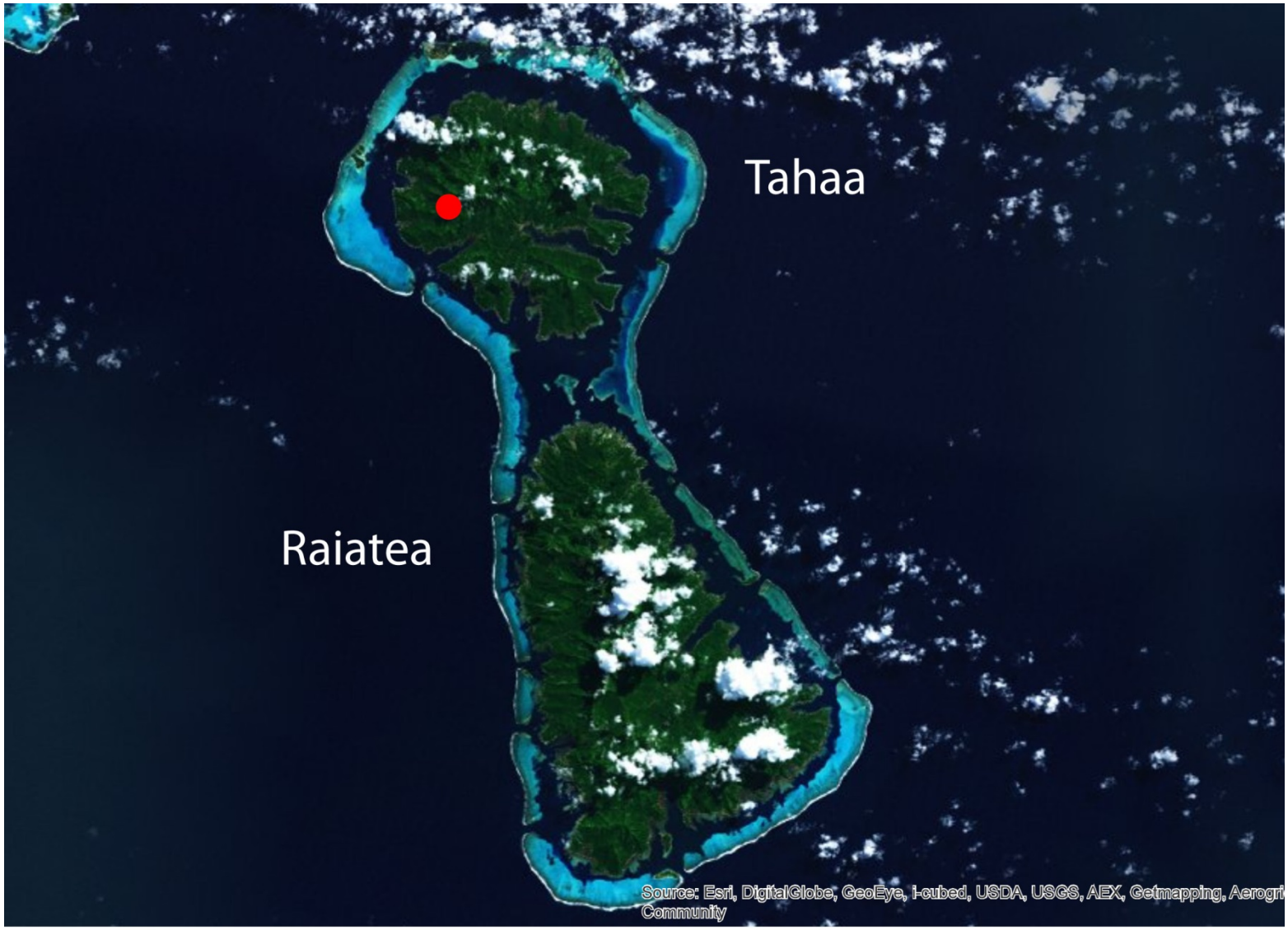


Figure 53 (a-b): (a) Holotype (♂) of P. n. sp. 10, specimen Z210; (b) paratype (♀), specimen Z140.

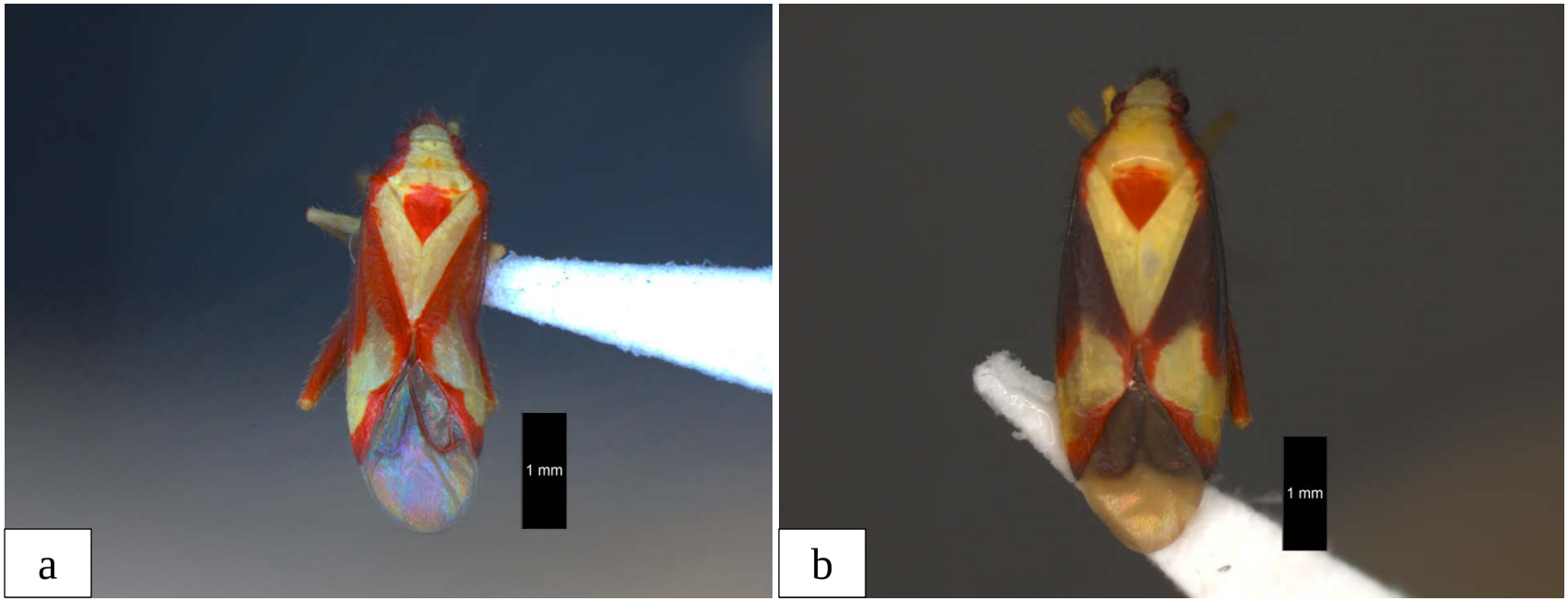


Figure 54 (a-c): Male genitalia of P. n. sp. 10, specimen Z210; (a) aedeagus; (b) left paramere; (c) right paramere.

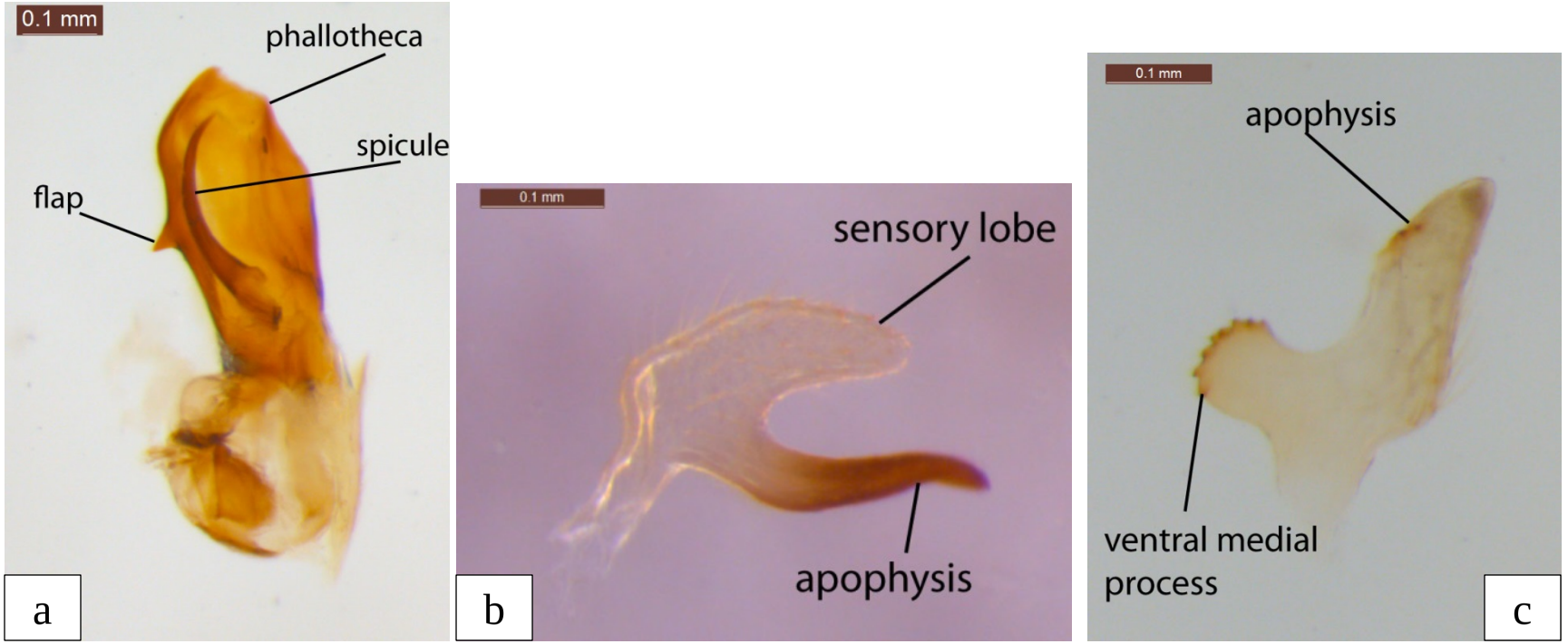


Figure 55: Distribution map of P. n. sp. 10.

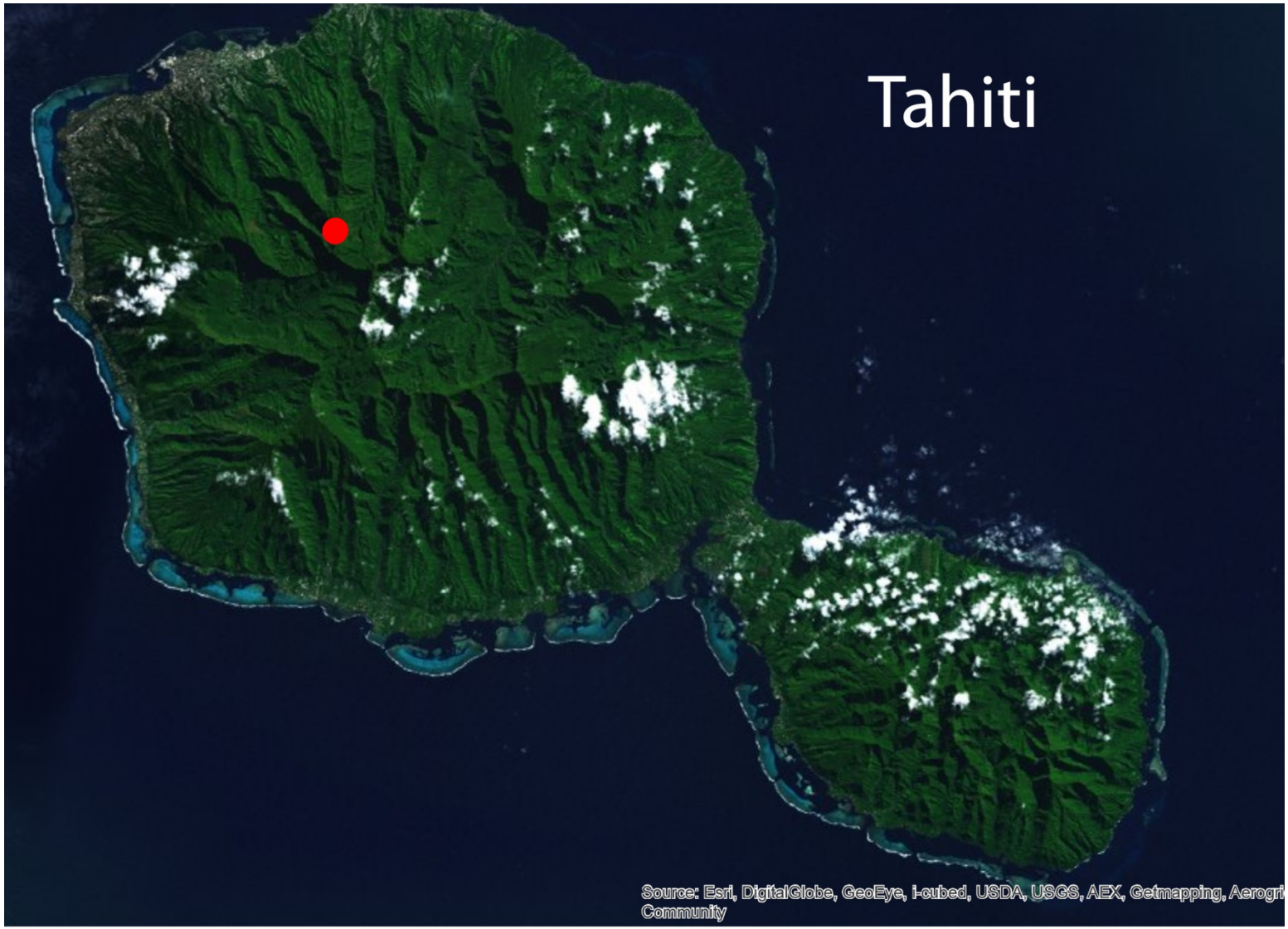


Figure 56 (a-b): (a) Holotype (♂) of P. n. sp. 11, specimen Z123; (b) paratype (♀), specimen Z148.

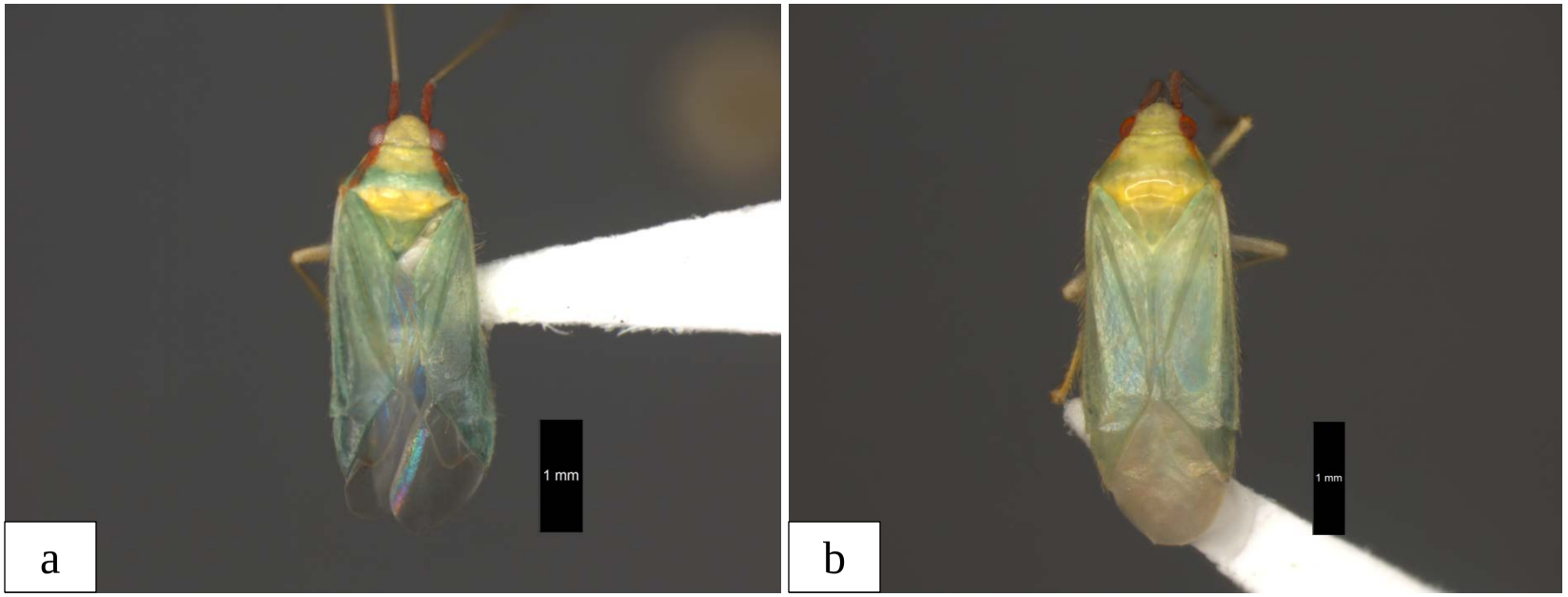


Figure 57 (a-c): Male genitalia of P. n. sp. 11, specimen Z123; (a) aedeagus; (b) left paramere; (c) right paramere.

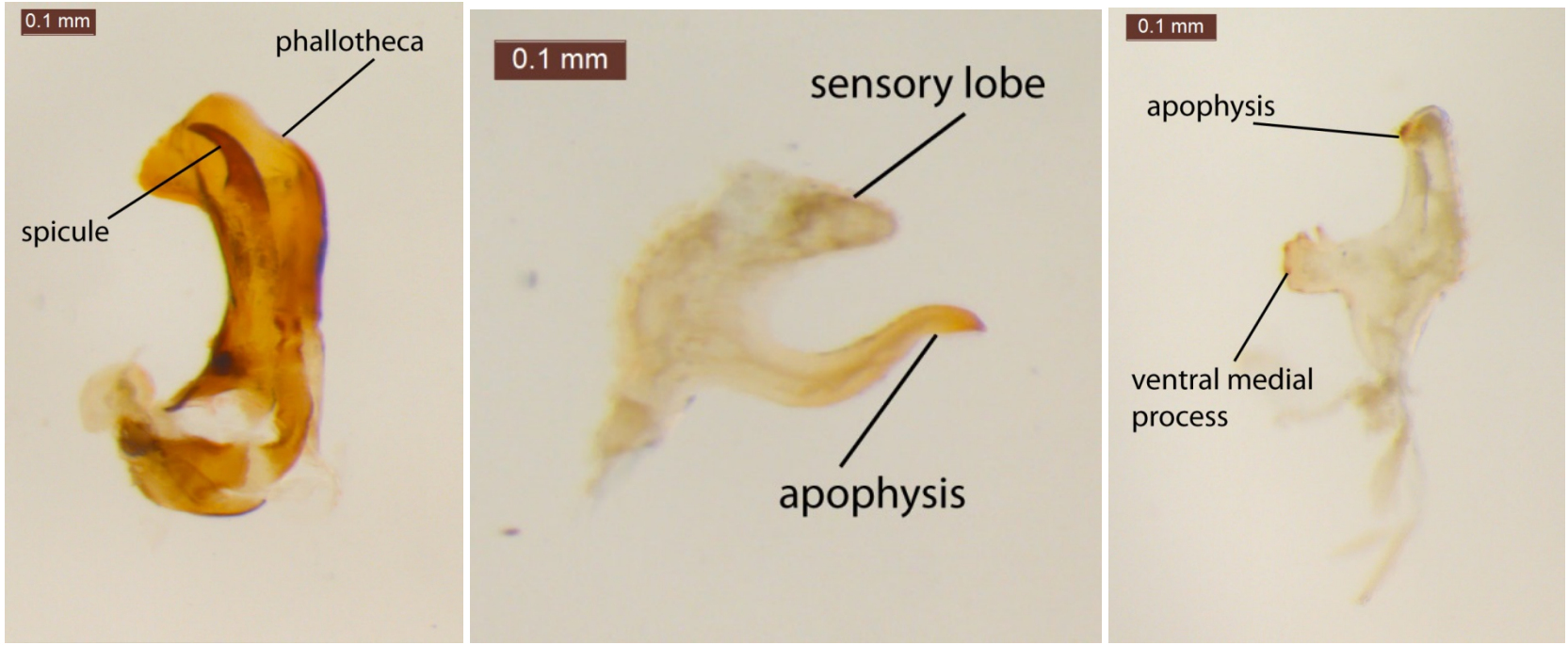


Figure 58: Distribution map for P. n. sp. 11.

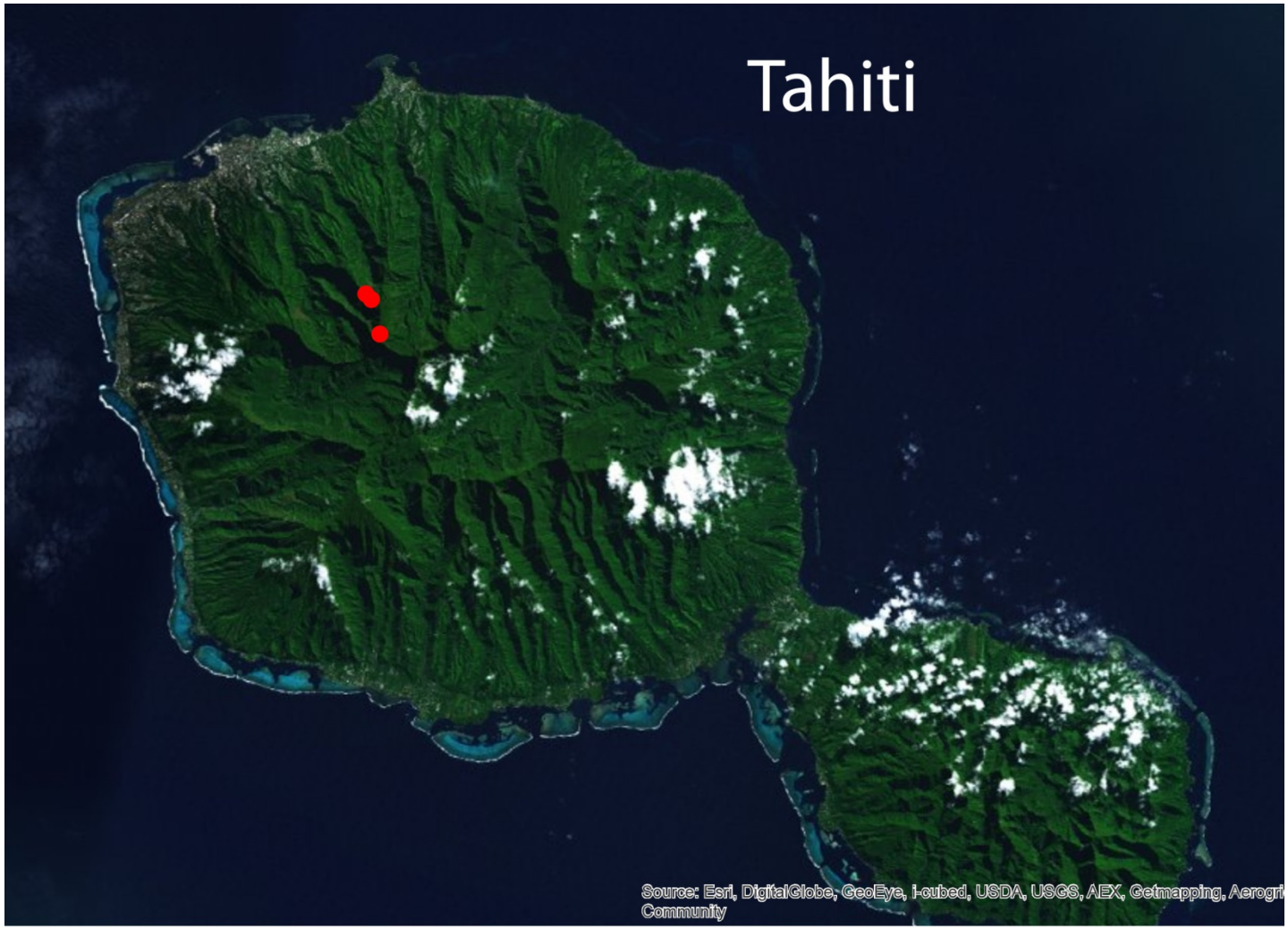


Figure 59: Holotype (♀) for P. n. sp. 12, specimen Z208.

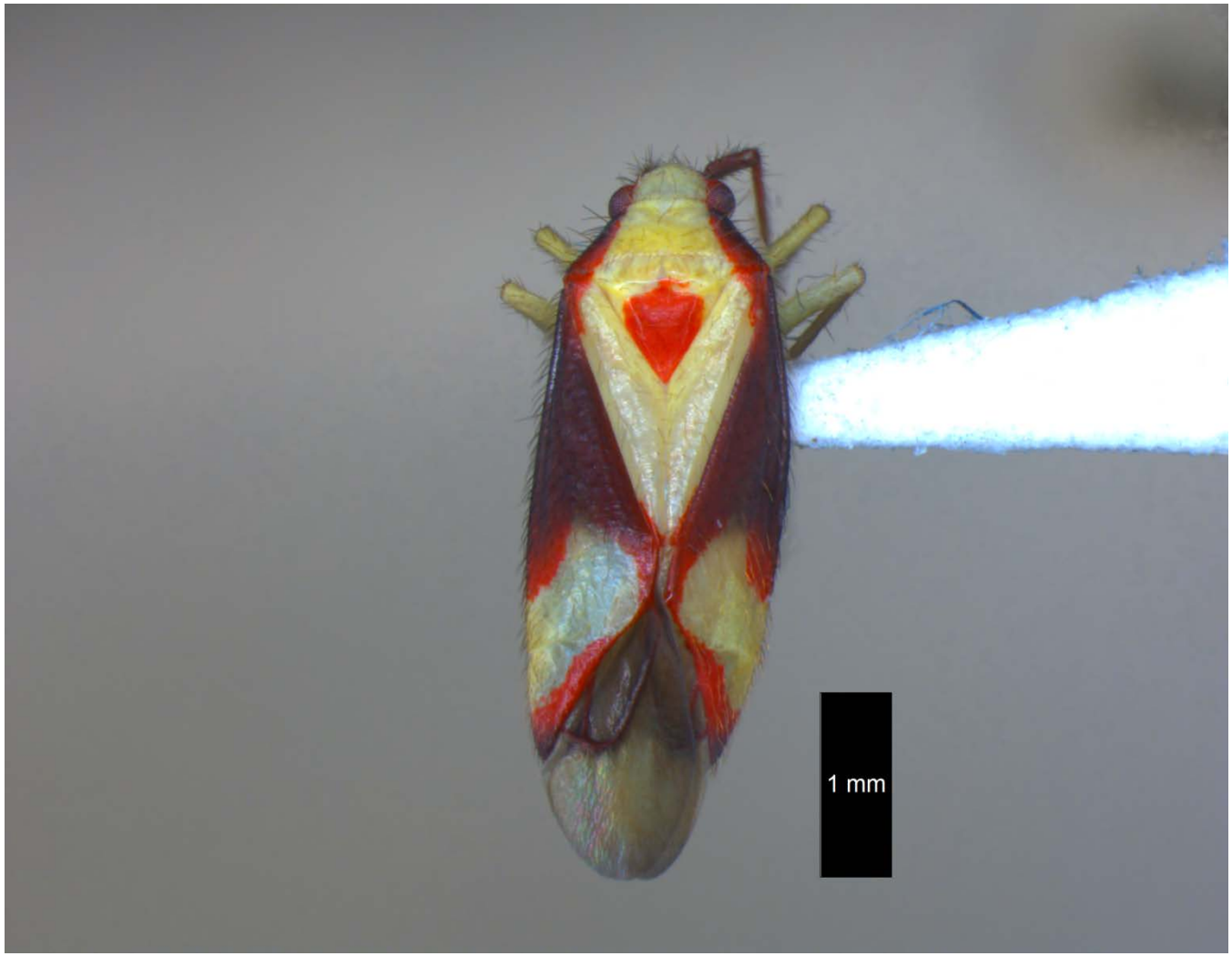


Figure 60: Distribution map for P. n. sp. 12.

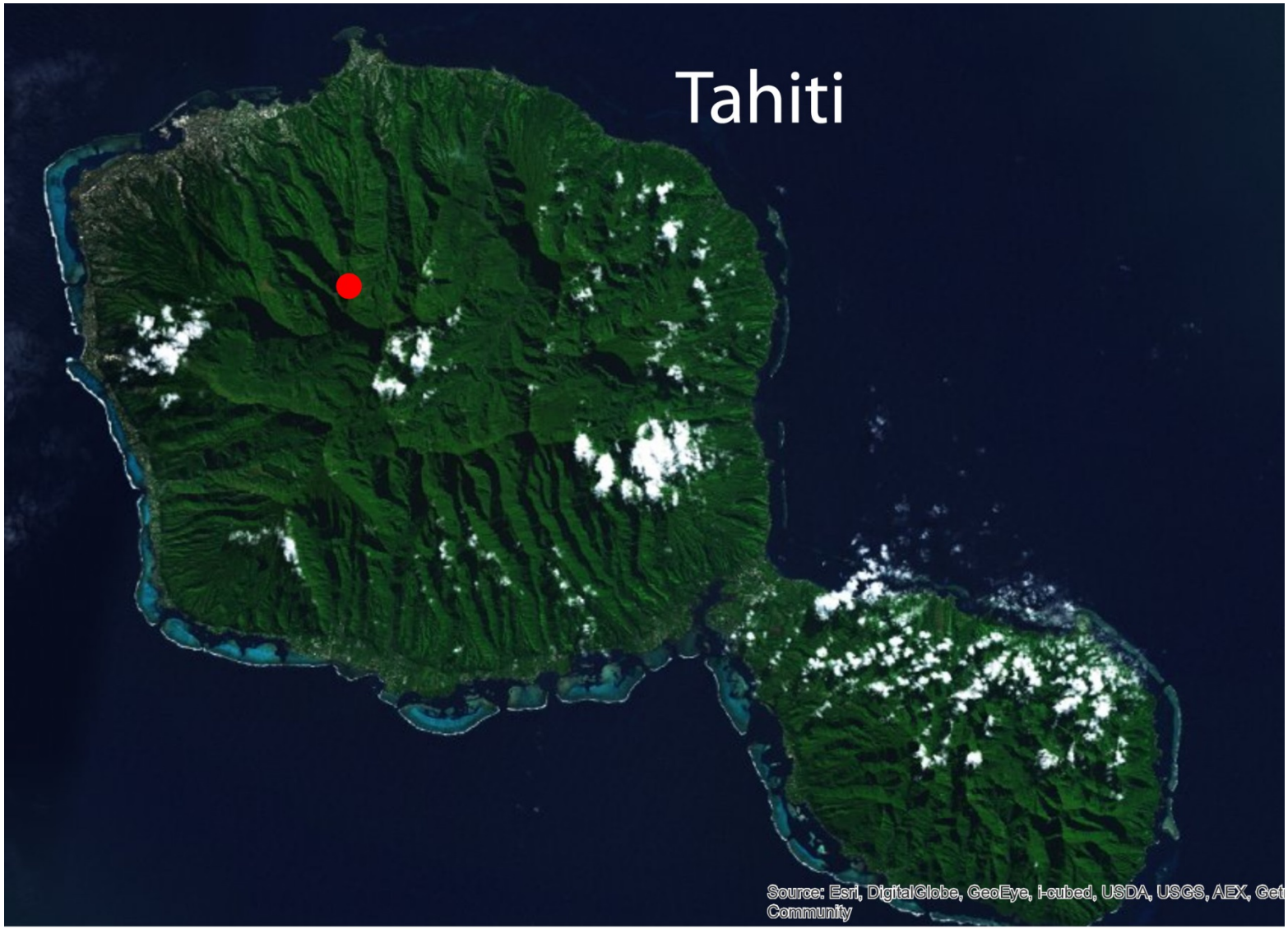


Figure 61 (a-b): (a) Holotype (♂) of P. n. sp. 13, specimen Z201; (b) paratype (♀), specimen Z118.

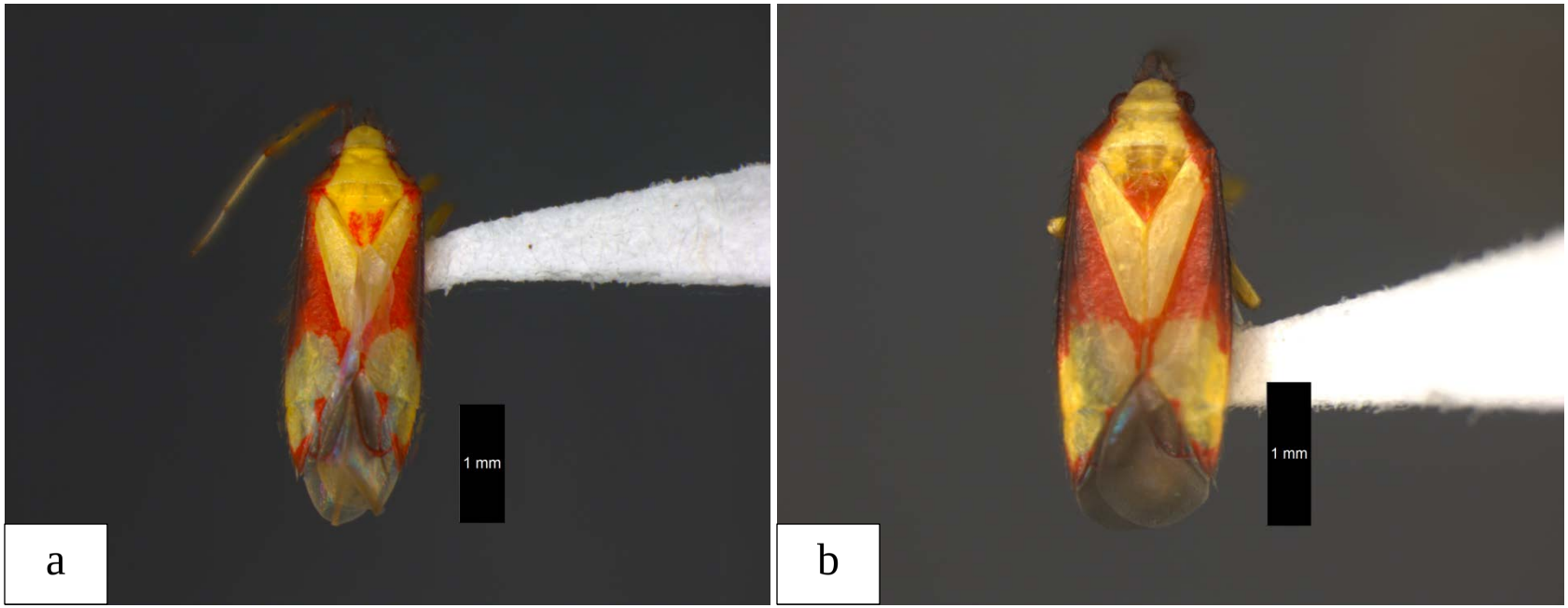


Figure 62 (a-c): Male genitalia of P. n. sp. 13, specimen Z201; (a) aedeagus; (b) left paramere; (c) right paramere.

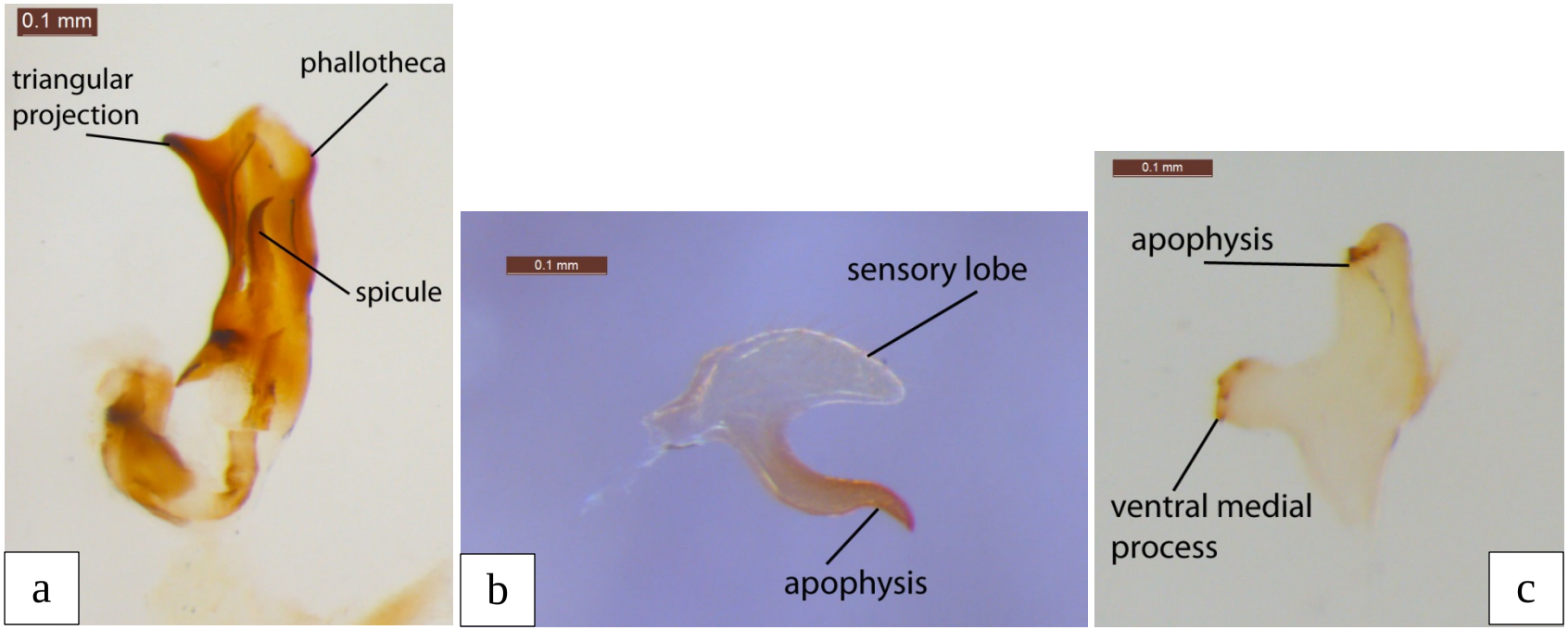


Figure 63: Distribution map for P. n. sp. 13.

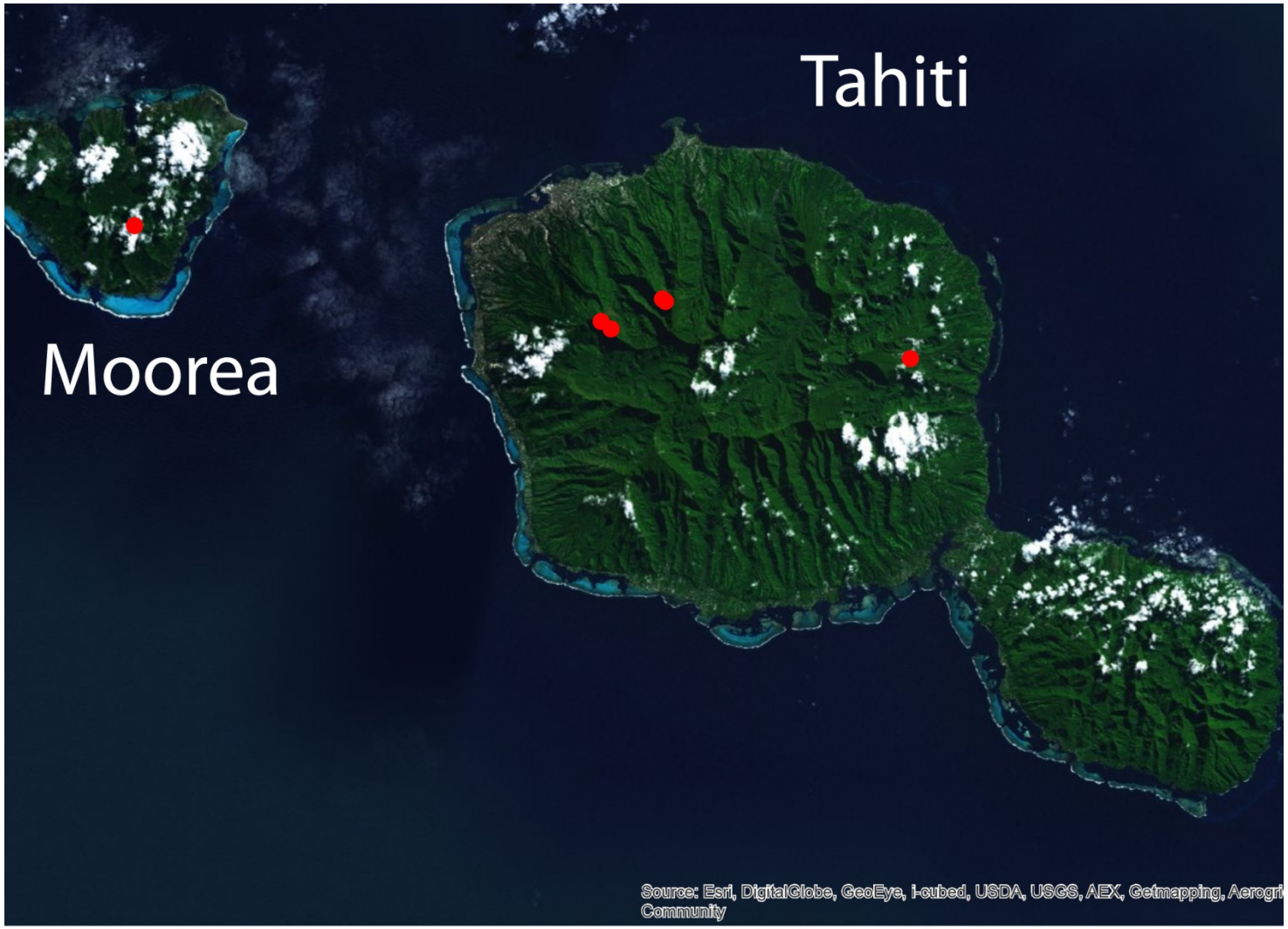


Figure 64 (a-b): (a) Holotype (♂) of P. n. sp. 14, specimen Z313; (b) paratype (♀), specimen Z9.

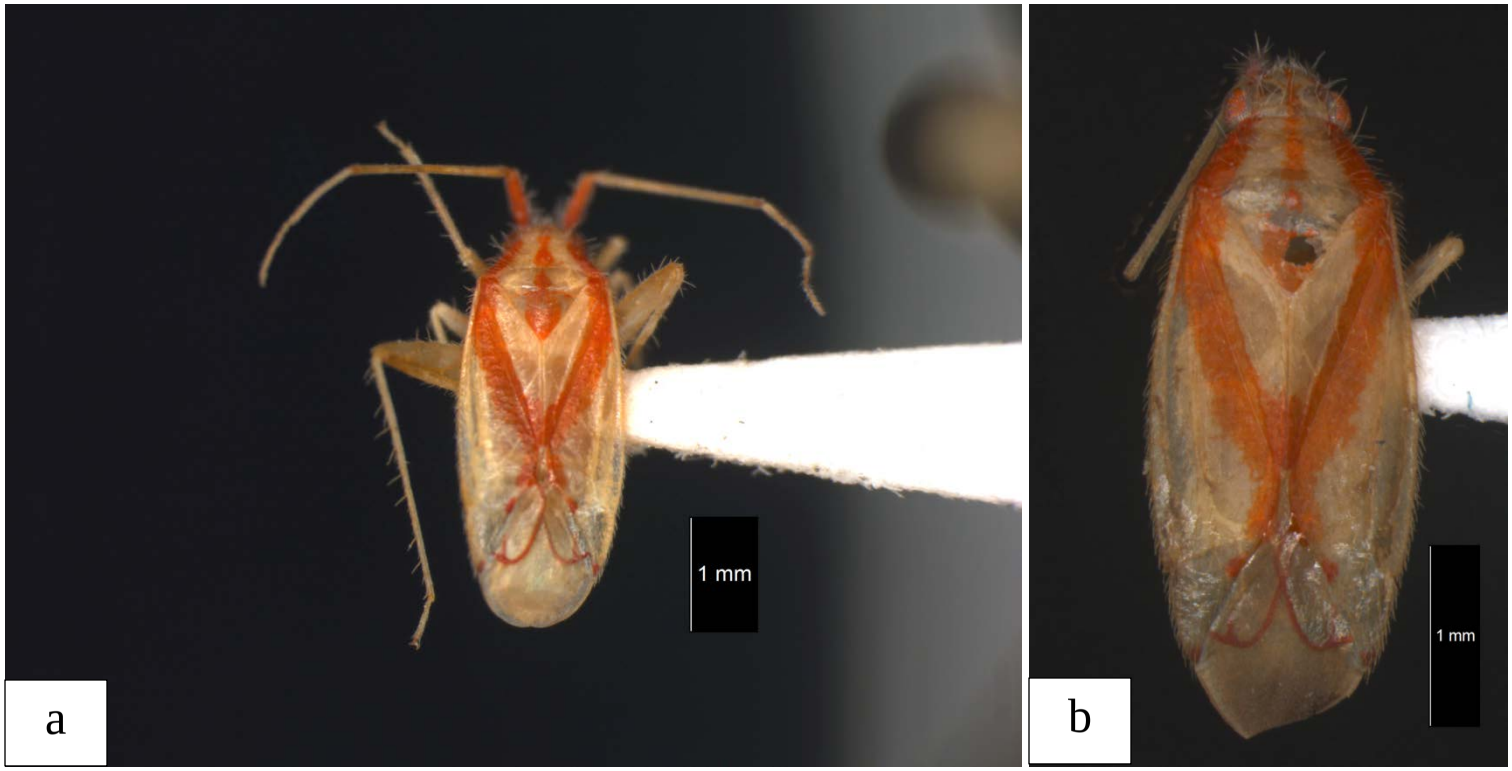


Figure 65 (a-c): Male genitalia of P. n. sp. 14, specimen Z313; (a) aedeagus; (b) left paramere; (c) right paramere.

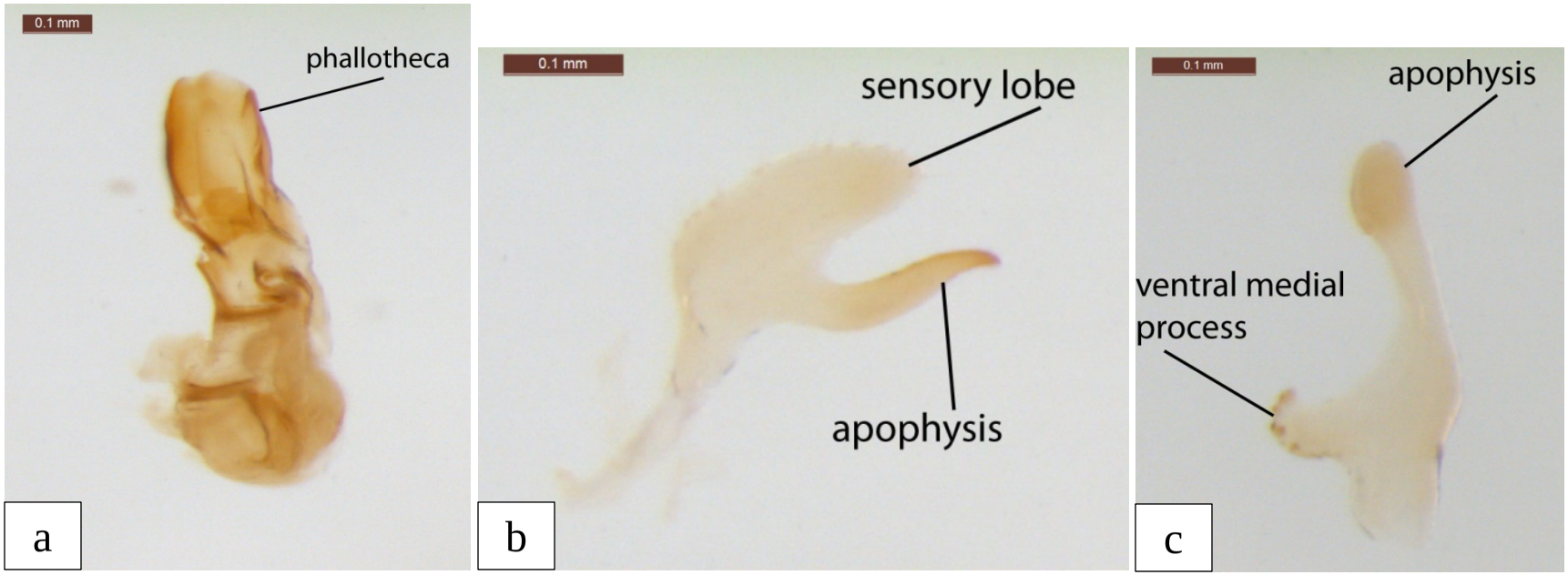


Figure 66: Distribution map for P. n. sp. 14.

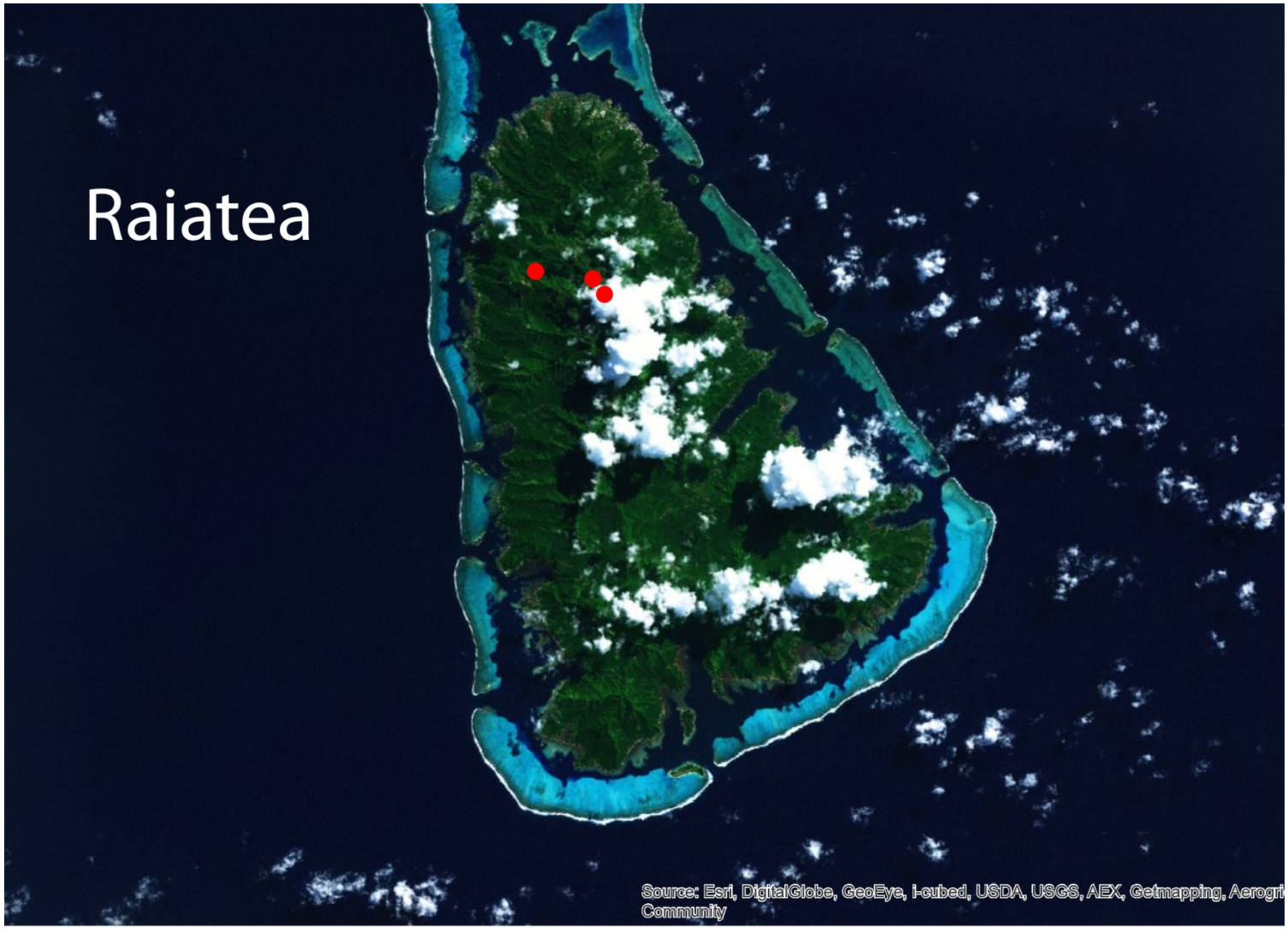


Figure 67: Holotype (♀) of P. n. sp. 15, specimen Z77.

Figure 68 (a-b): Male genitalia of P. n. sp. 15, specimen Z77; (a) left paramere; (b) right paramere.

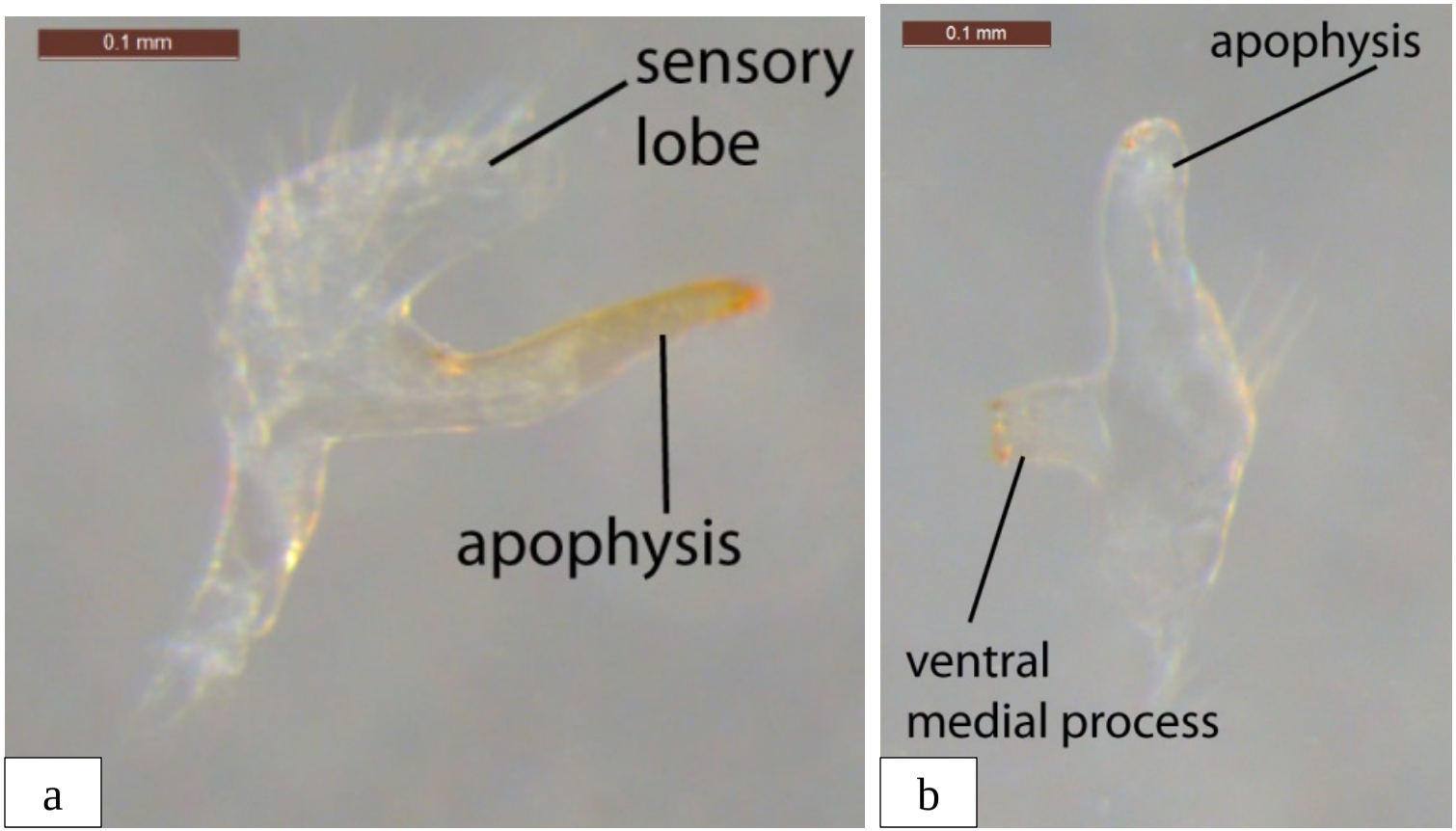


Figure 69: Distribution map for P. n. sp. 15.

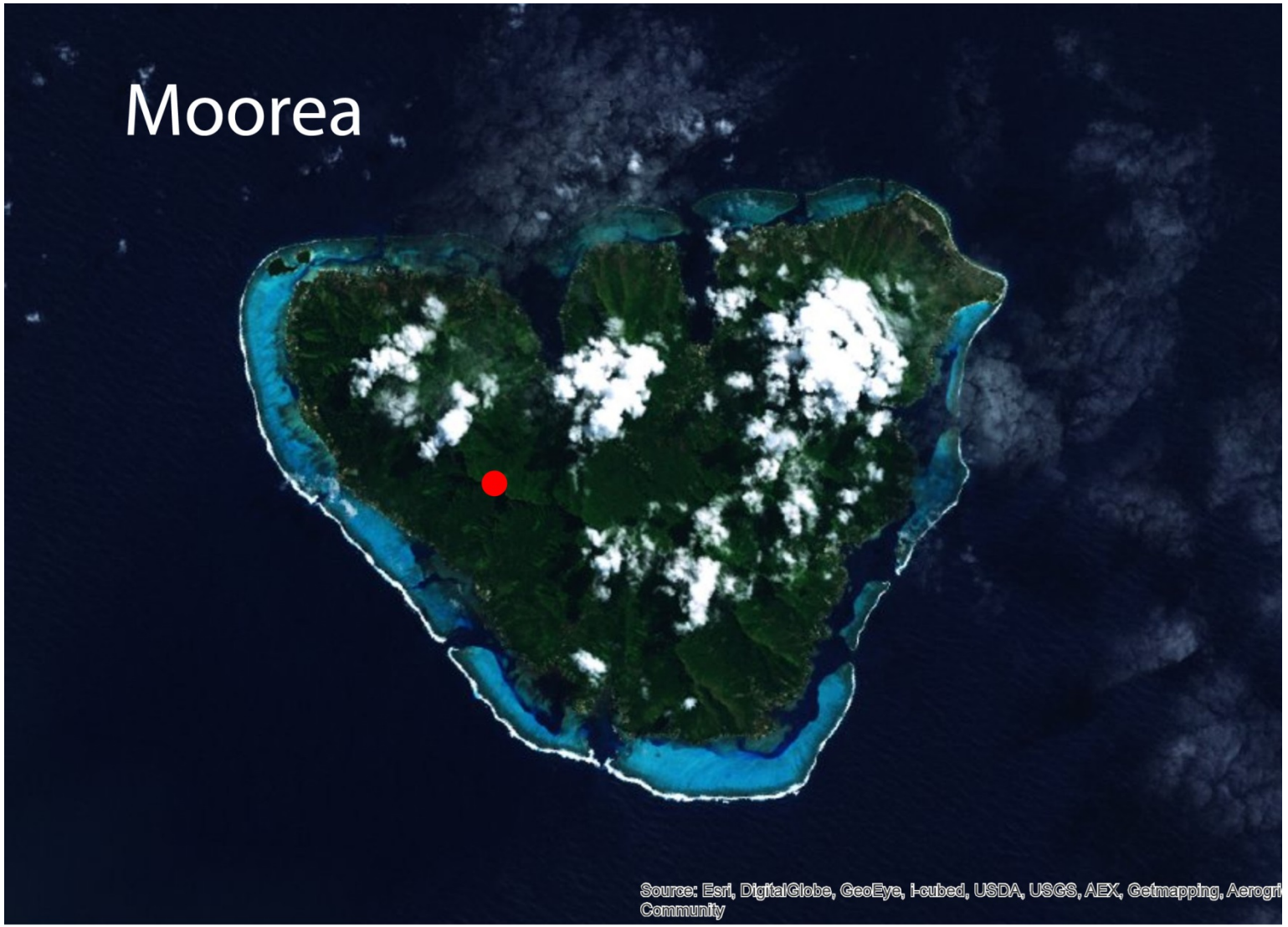


Figure 70: Holotype (♂) of P. n. sp. 16, specimen Z16.

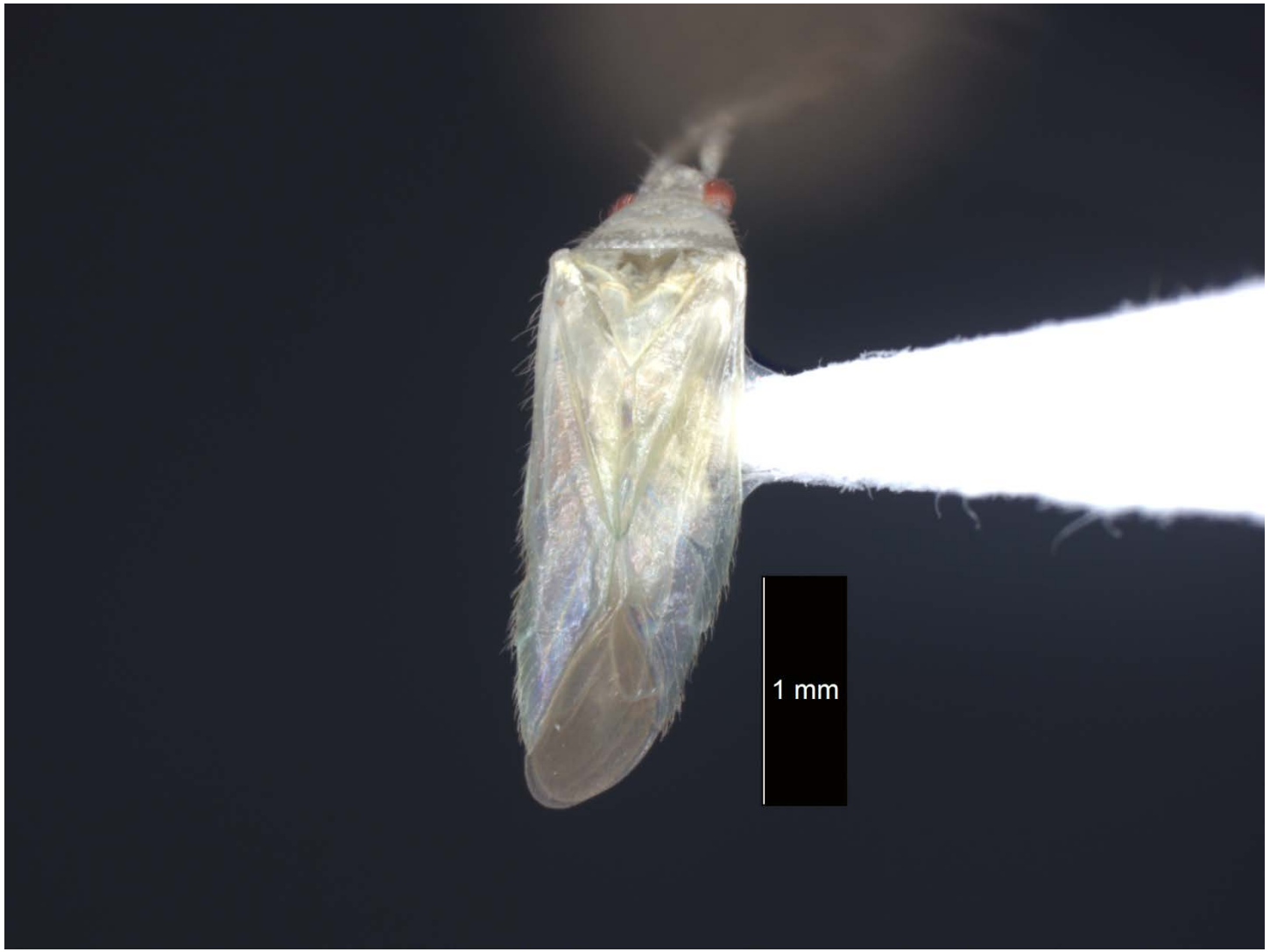


Figure 71 (a-b): Male genitalia of P. n. sp. 16, specimen Z16; (a) left paramere; (b) right paramere.

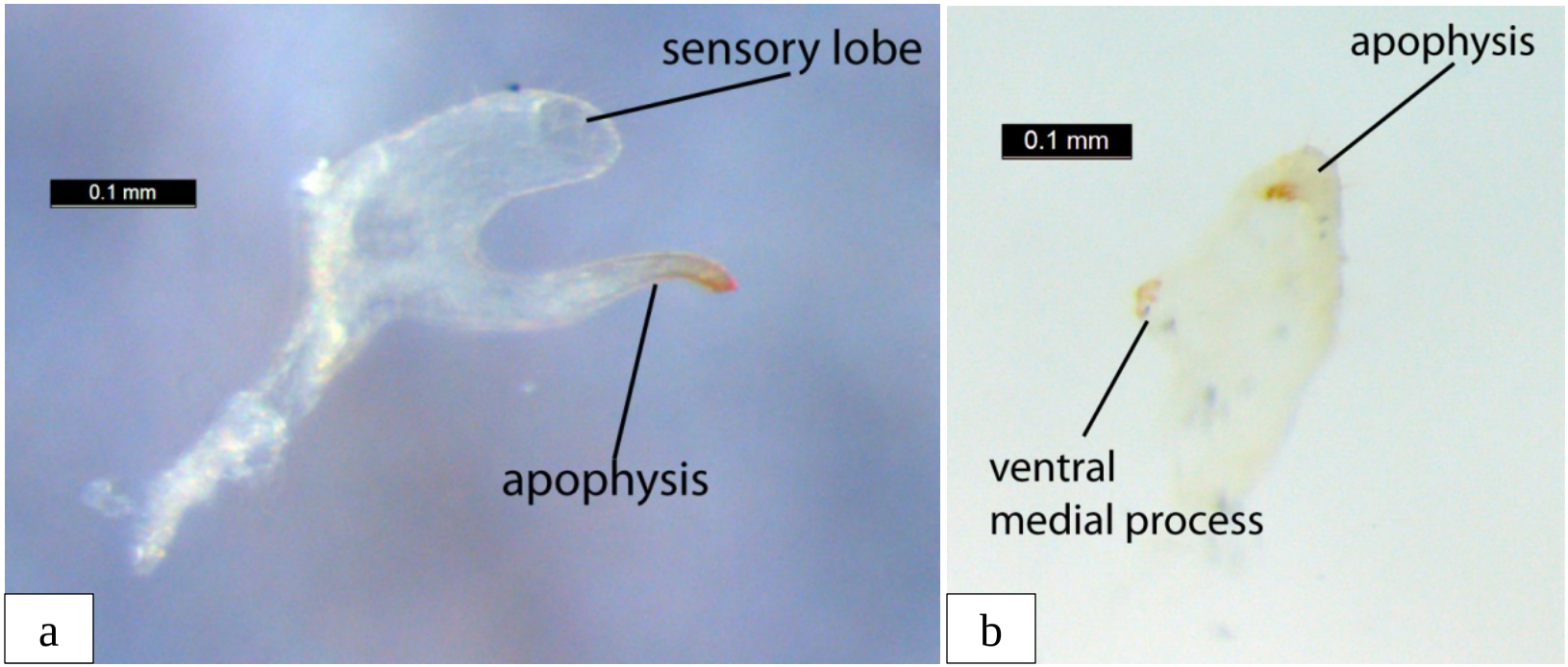


Figure 72: Distribution map of P. n. sp. 16.

Figure 73: Holotype (♀) of P. n. sp. 17, specimen Z212.

Figure 74: Distribution map for P. n. sp. 17.

Figure 75: Holotype (♂) of P. n. sp. 18, specimen Z128.

Figure 76 (a-c): Male Genitalia of P. n. sp. 18, specimen Z128; (a) aedeagus; (b) left paramere; (c) right paramere.

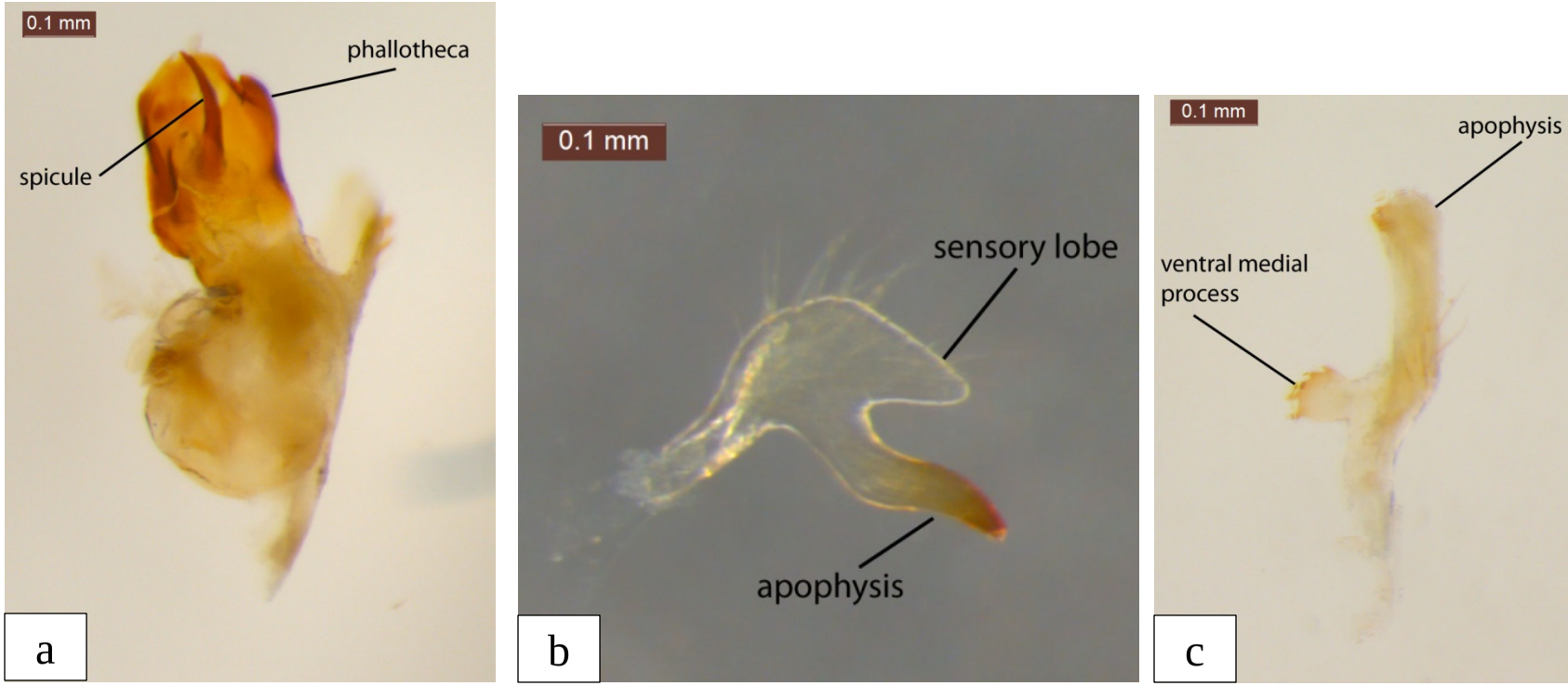


Figure 77: Distribution map of P. n. sp. 18.

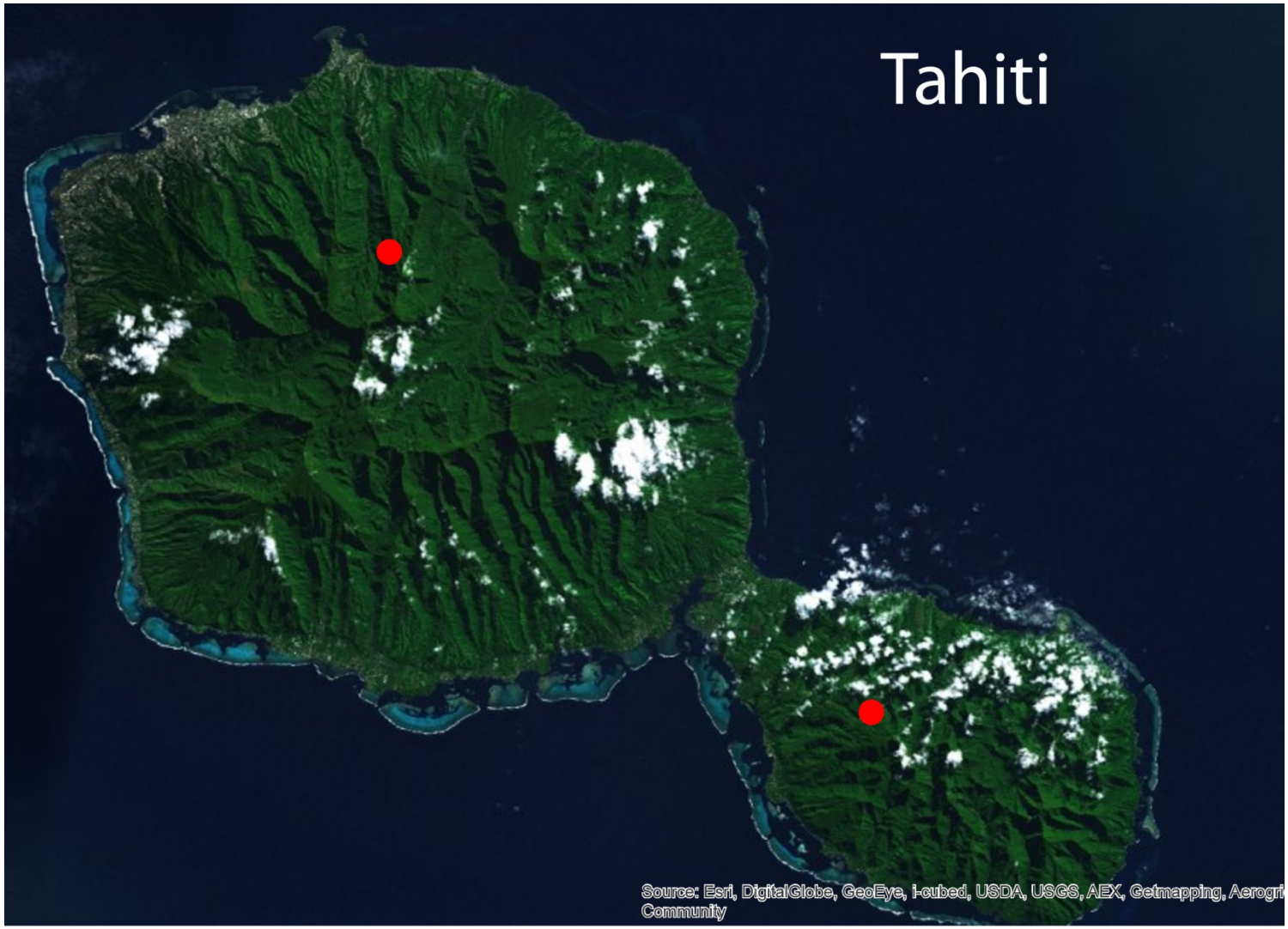


Figure 78 (a-b): (a) Holotype (♂) of P. n. sp. 19, specimen Z50; (b) paratype (♀) of n. sp. 19, specimen Z115.

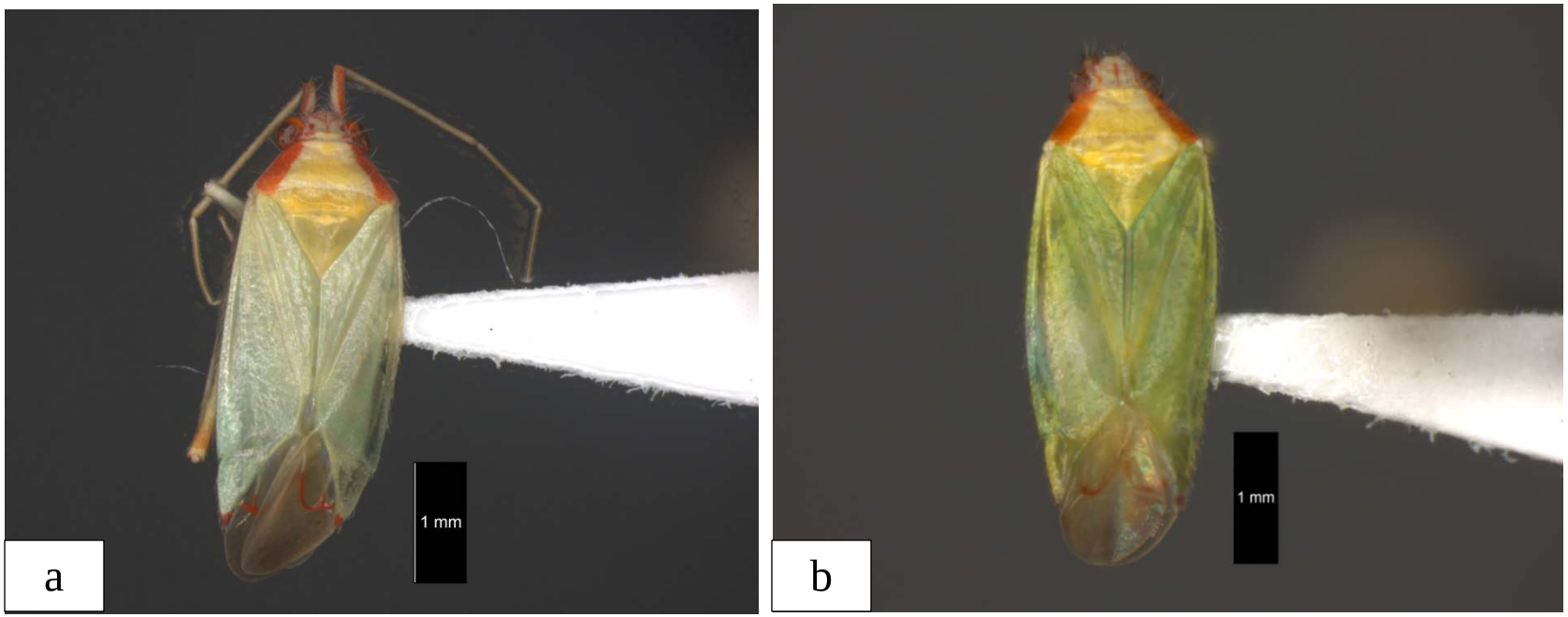


Figure 79 (a-c): Male genitalia of P. n. sp. 19, specimen Z50; (a) aedeagus; (b) left paramere; (c) right paramere.

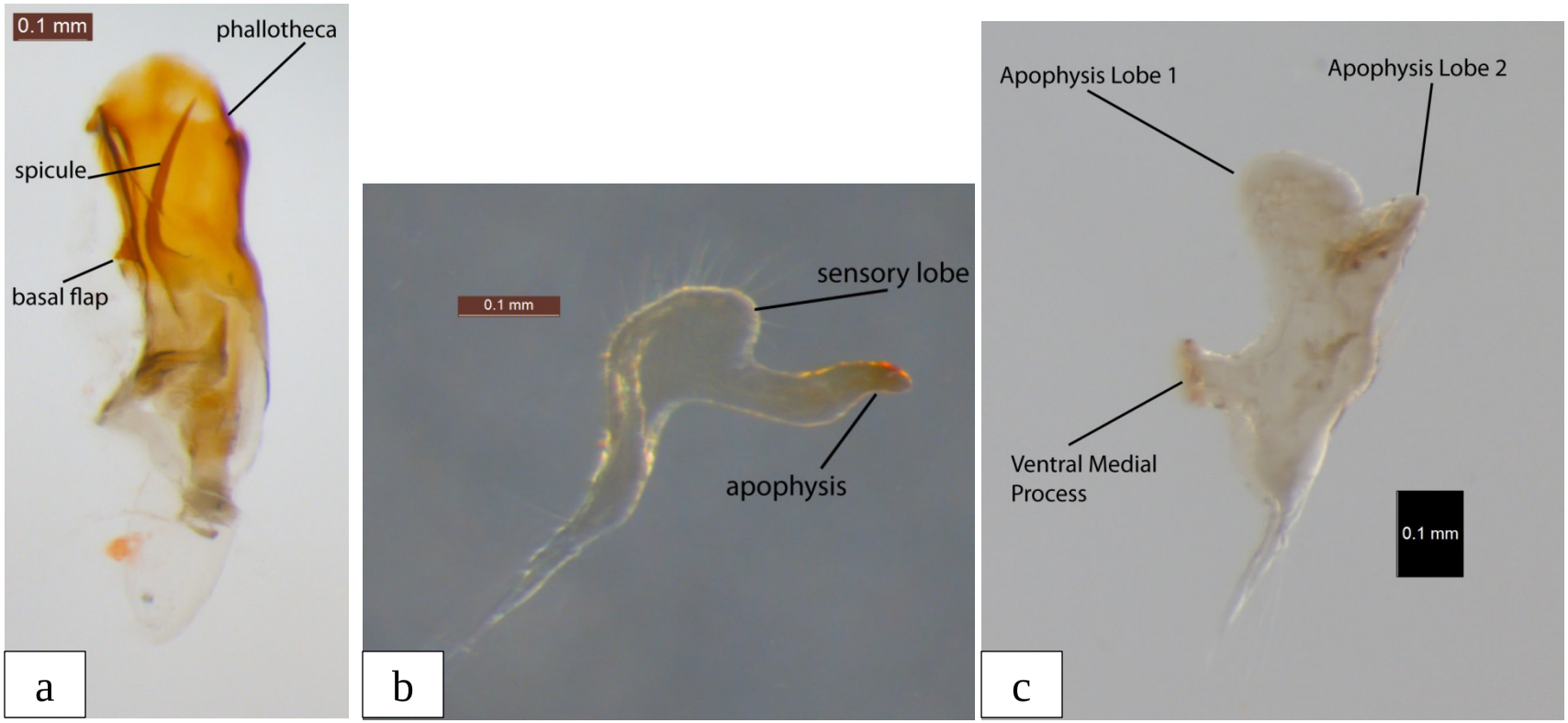


Figure 80: Distribution map of P. n. sp. 19.

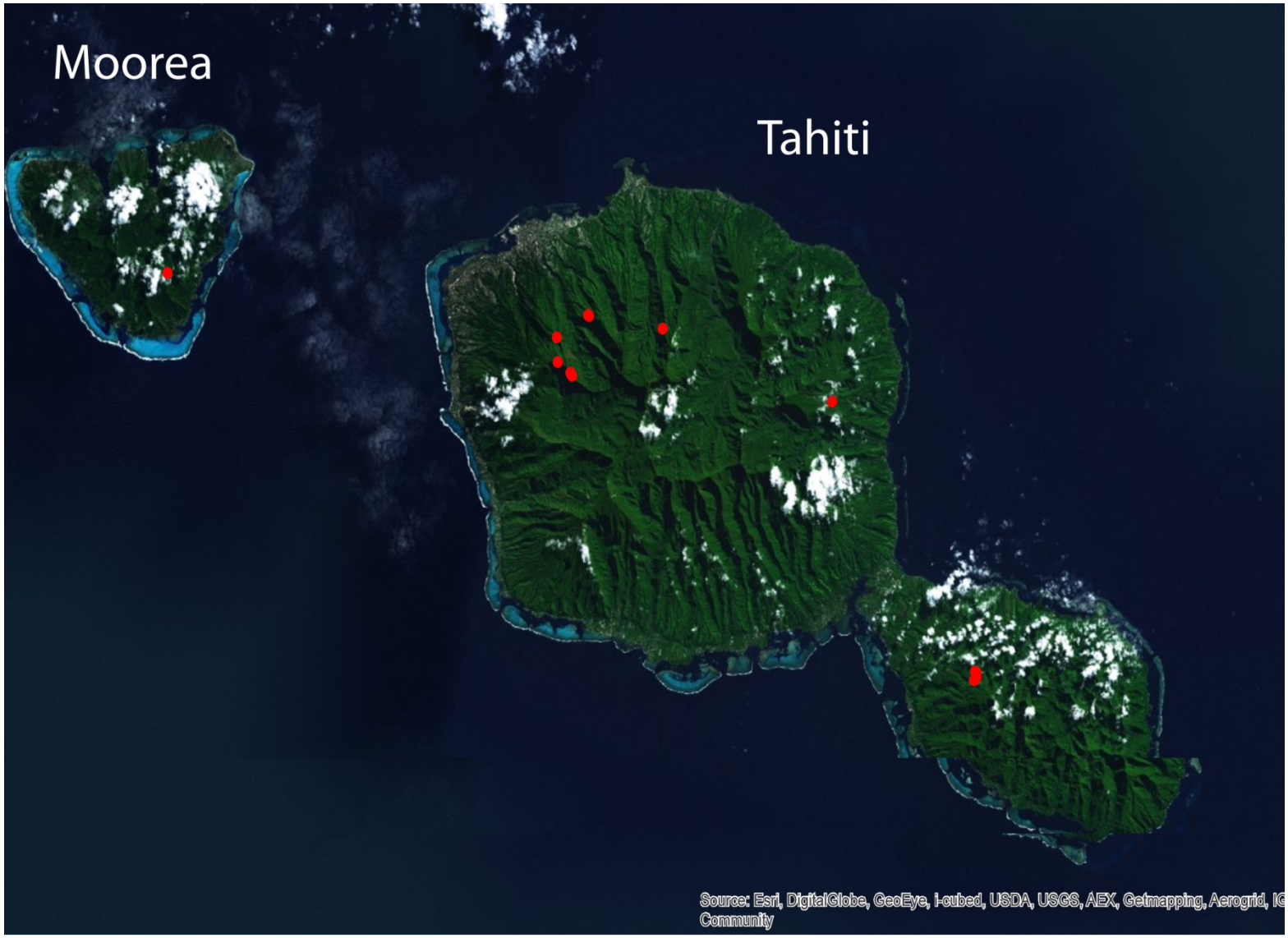


Figure 81: Holotype (♀) of P. n. sp. 20, specimen Z211.

Figure 82: Distribution map for P. n. sp. 82.

Figure 83 (a-b): (a) Holotype (♂) of P. n. sp. 21, specimen Z7; (b) paratype (♀), specimen Z70.

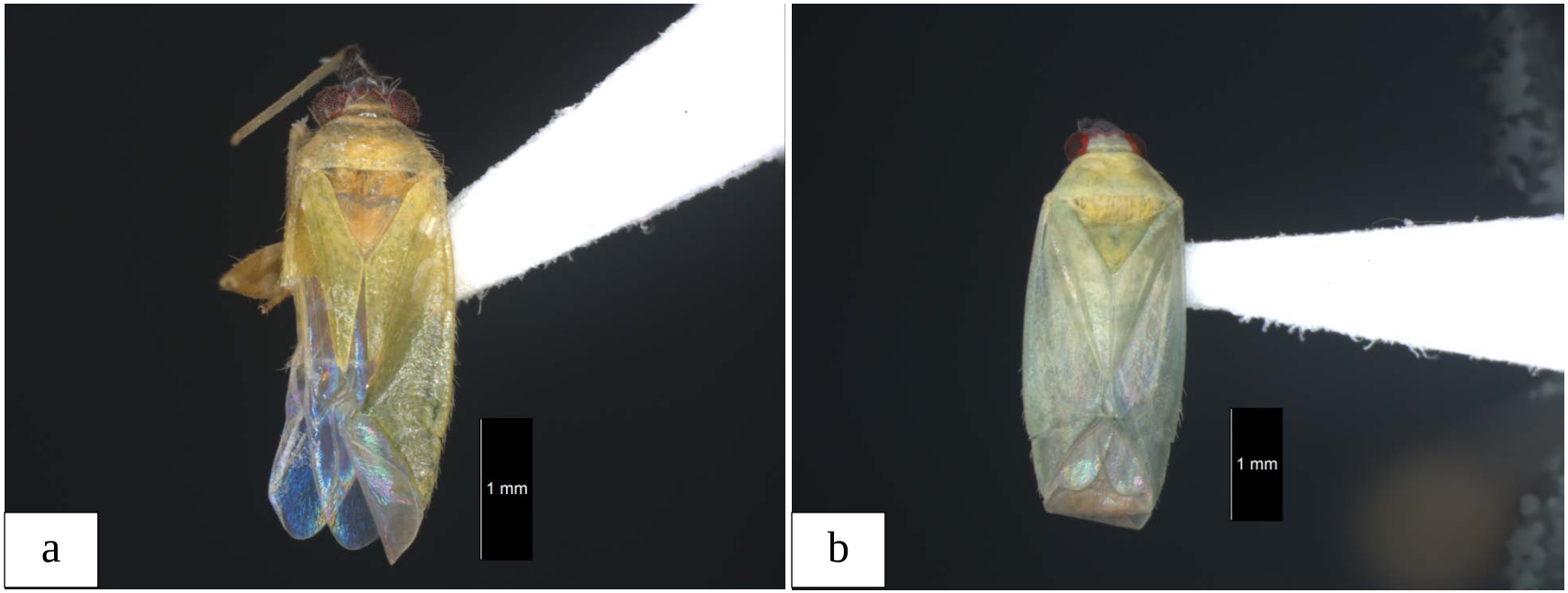


Figure 84 (a-b): Male genitalia of P. n. sp. 21, specimen Z7; (a) left paramere; (b) right paramere

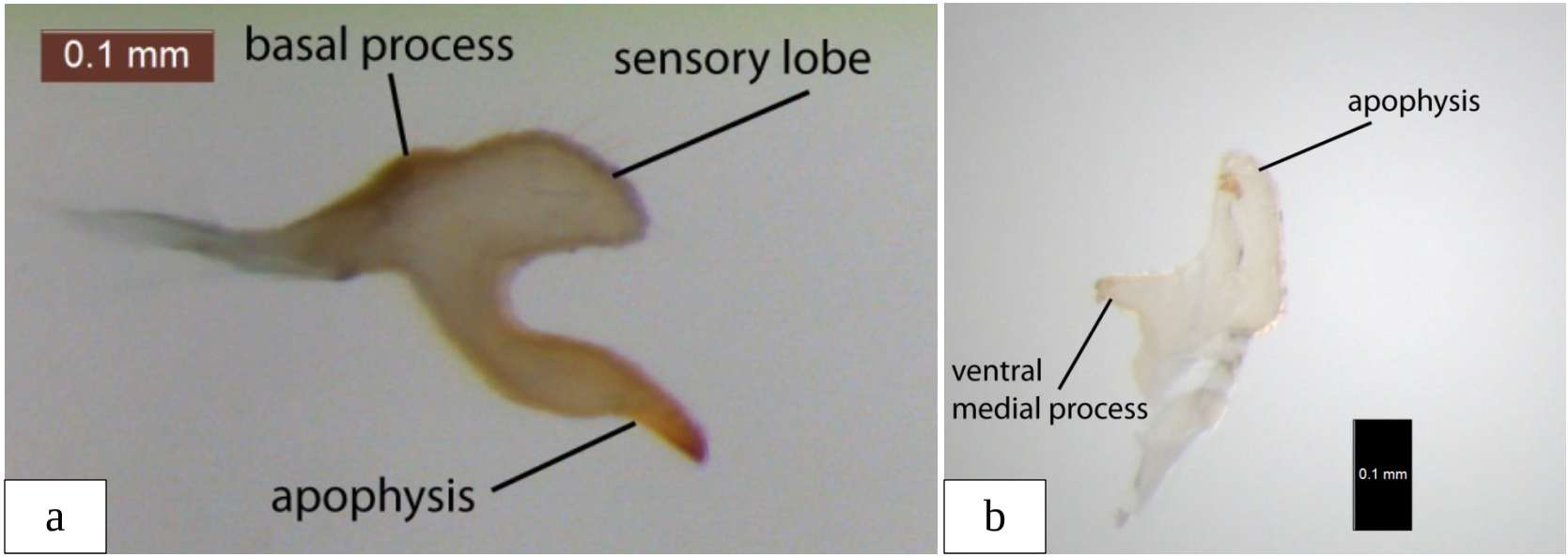


Figure 85: Distribution map for P. n. sp. 21.

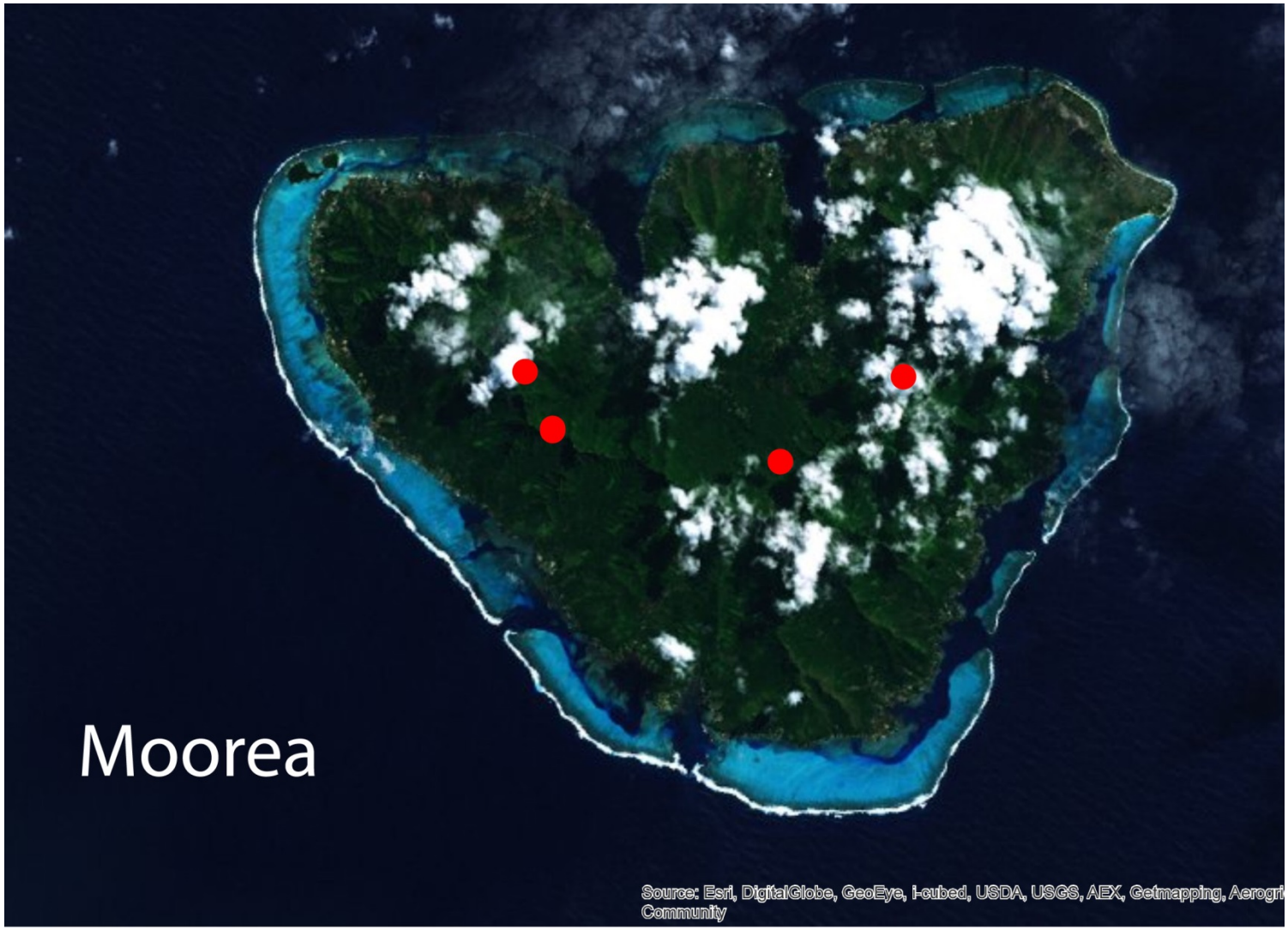


Figure 86 (a-b): (a) Paratype (♂) of *Pseudoloxops rubroclavus*, specimen Z78; (b) paratype (♀), specimen Z81.

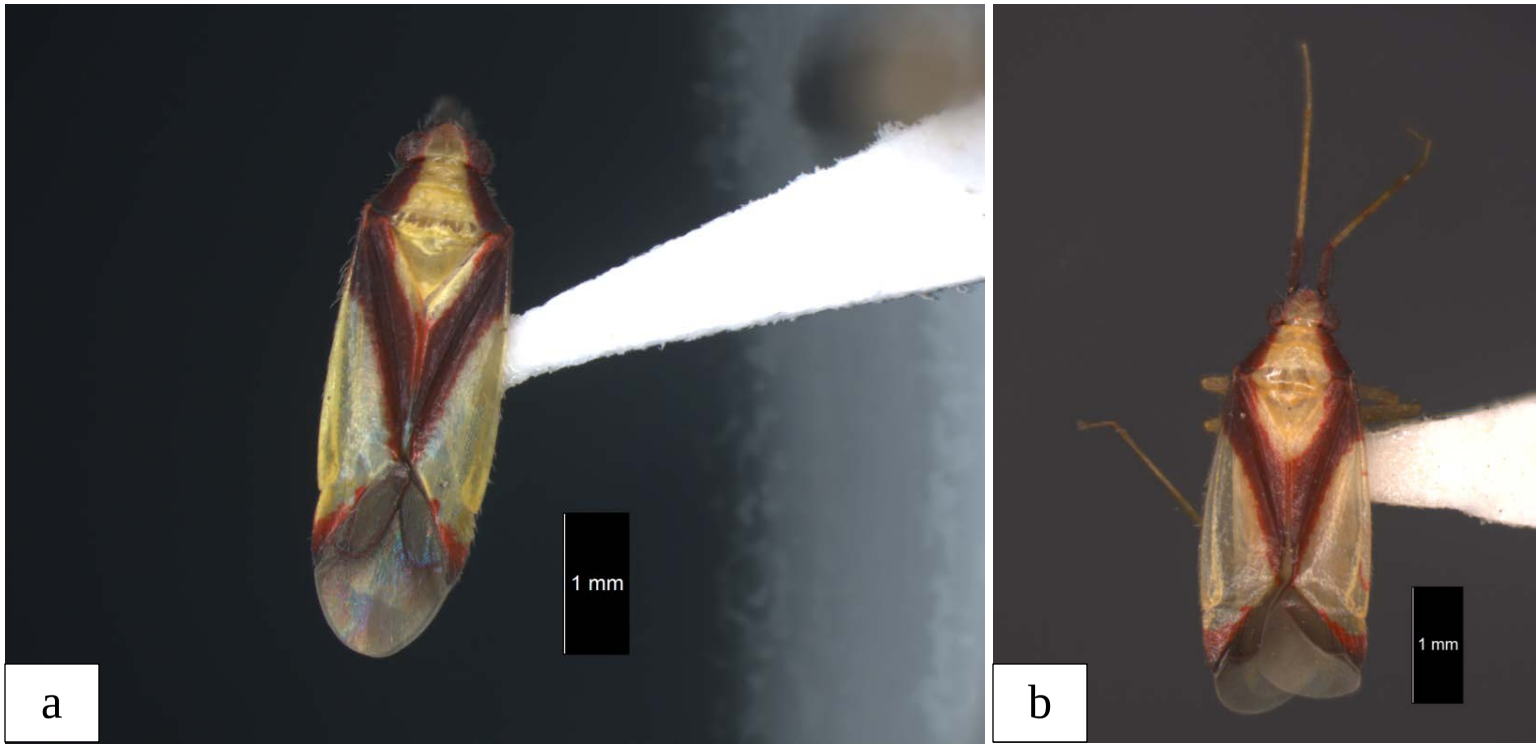


Figure 87 (a-c): Male genitalia of *P. rubroclavus*, specimen Z78; (a) aedeagus; (b) left paramere; (c) right paramere.

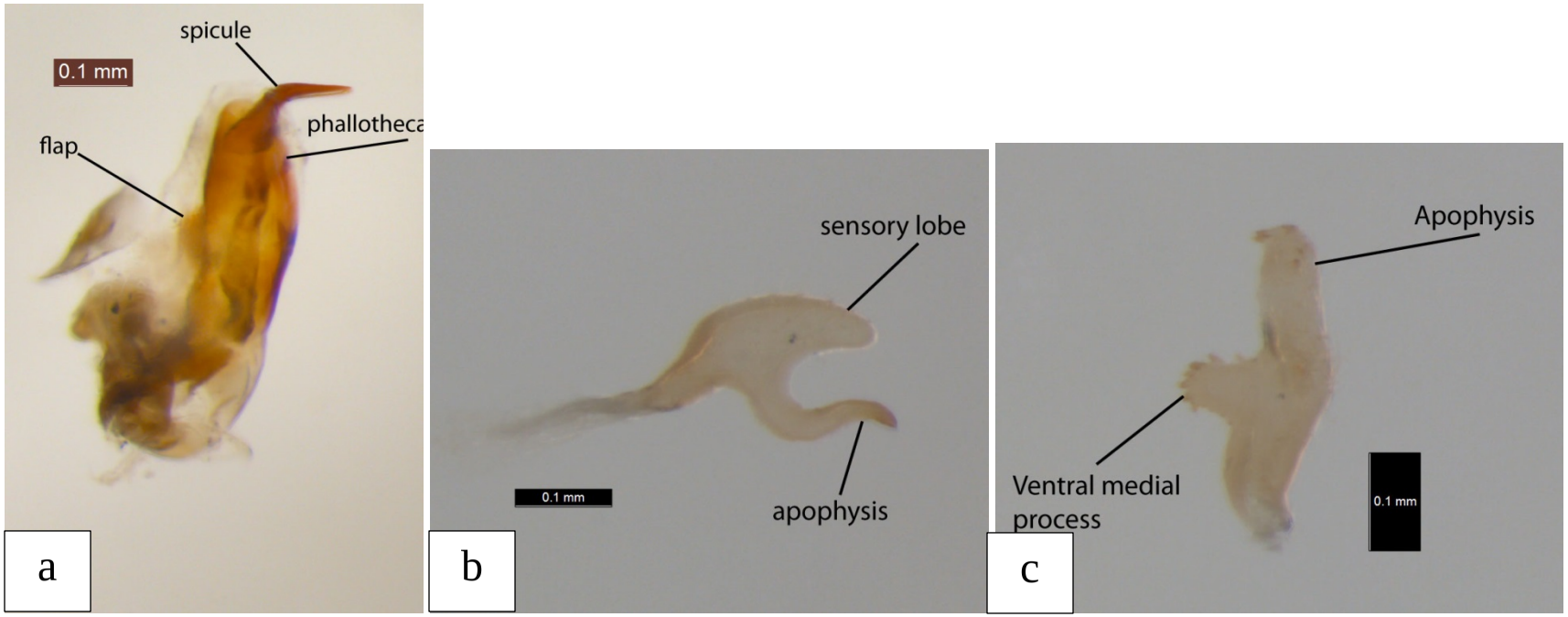


Figure 88: Distribution map for *P. rubroclavus.*

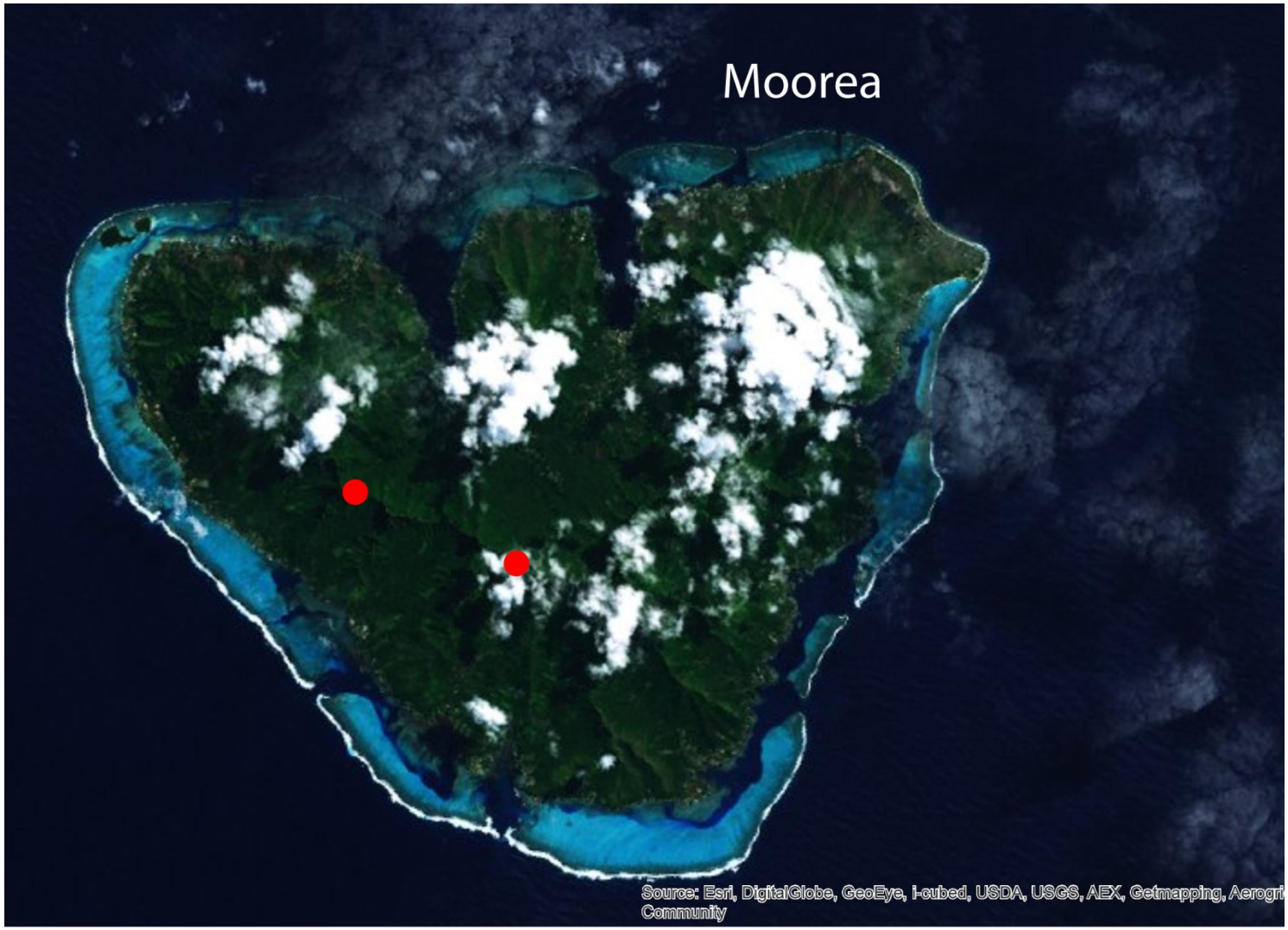
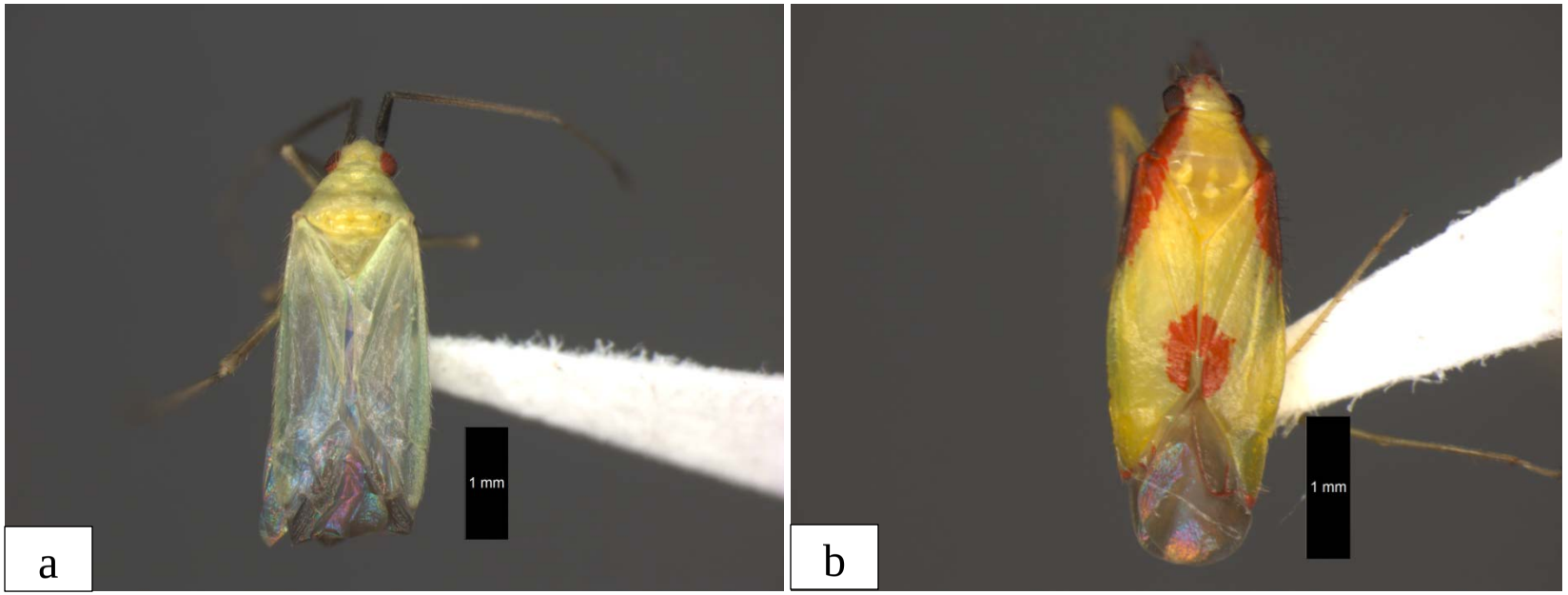


Figure 89 (a-c): Three different color morphs of *Pseudoloxops tahiticus;* (a) color morph 1, formerly *Pseudoloxops nigribasicornis*, specimen Z126; (b) color morph 2, specimen Z127; (c) color morph 3, *Pseudoloxops tahiticus rubromarginatus*, specimen Z152.



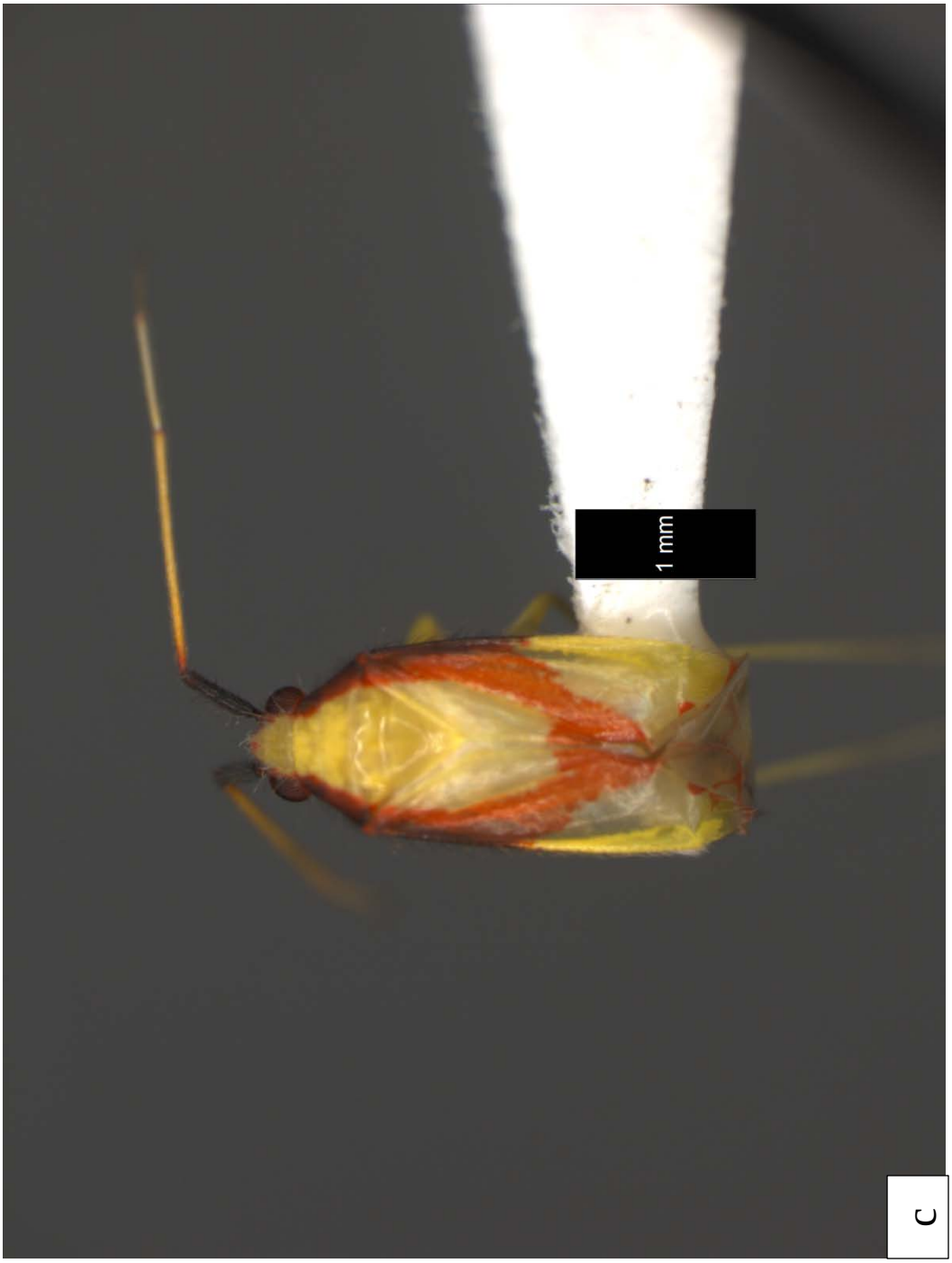

1 mm
C

Figure 90 (a-c): Male genitalia of *P. tahiticus*, specimen Z126; (a) aedeagus; (b) left paramere; (c) right paramere.

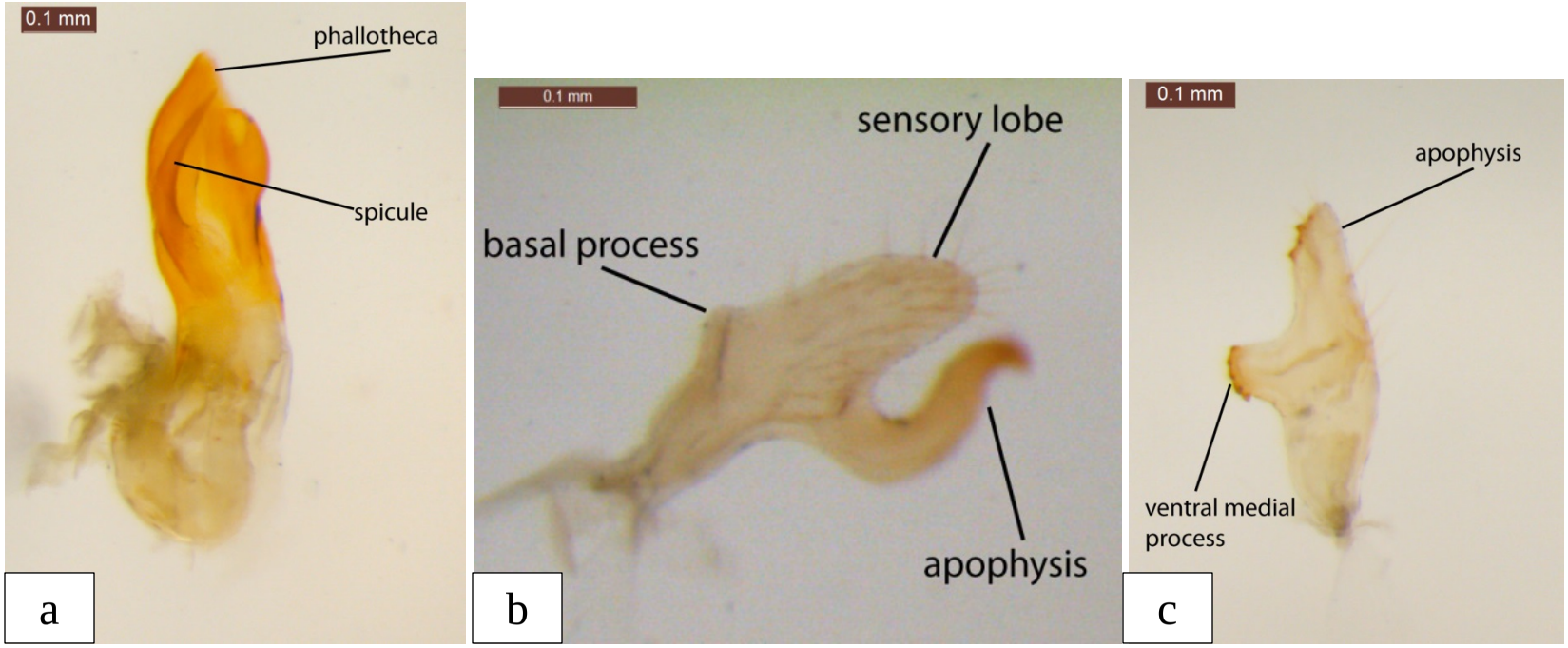


Figure 91: Distribution map for *P. tahiticus.*

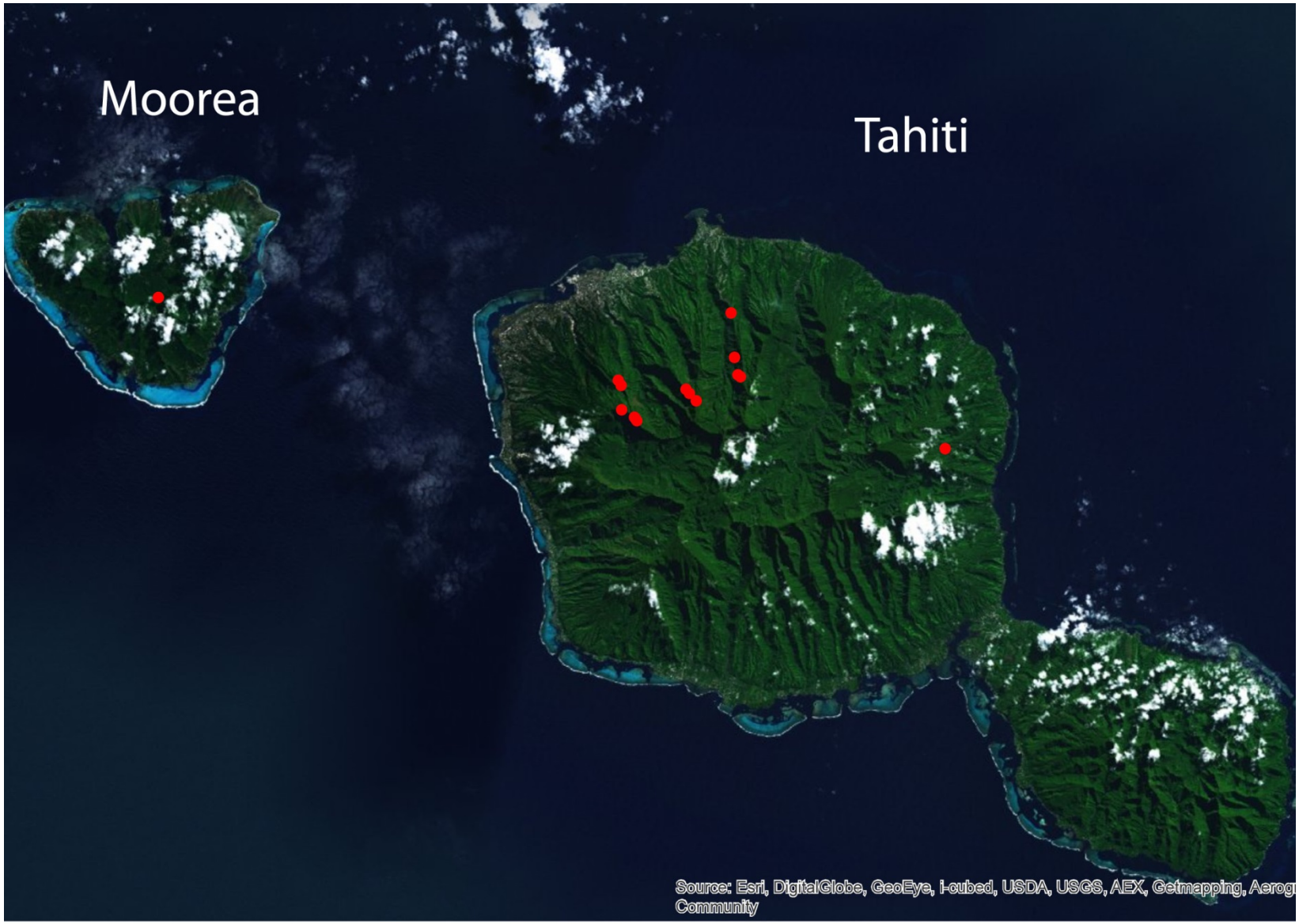
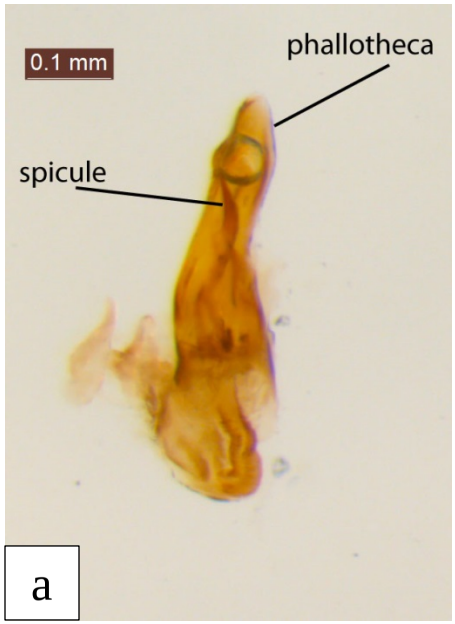
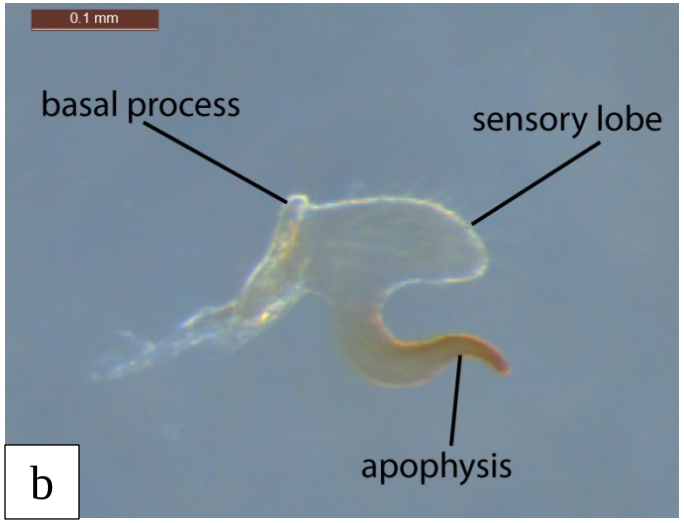


Figure 92: Holotype (♂) of P. n. sp. 22, specimen Z104.

Figure 93 (a-c): Male genitalia of P. n. sp, 22, specimen Z104; (a) aedeagus; (b) left paramere; (c) right paramere.





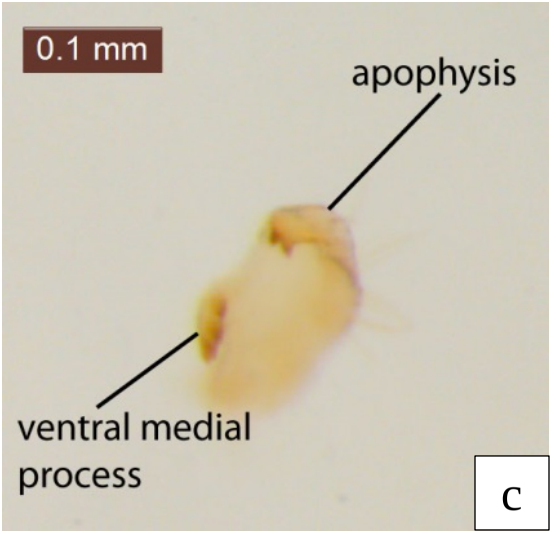


Figure 94: Distribution map of P. n. sp. 22.

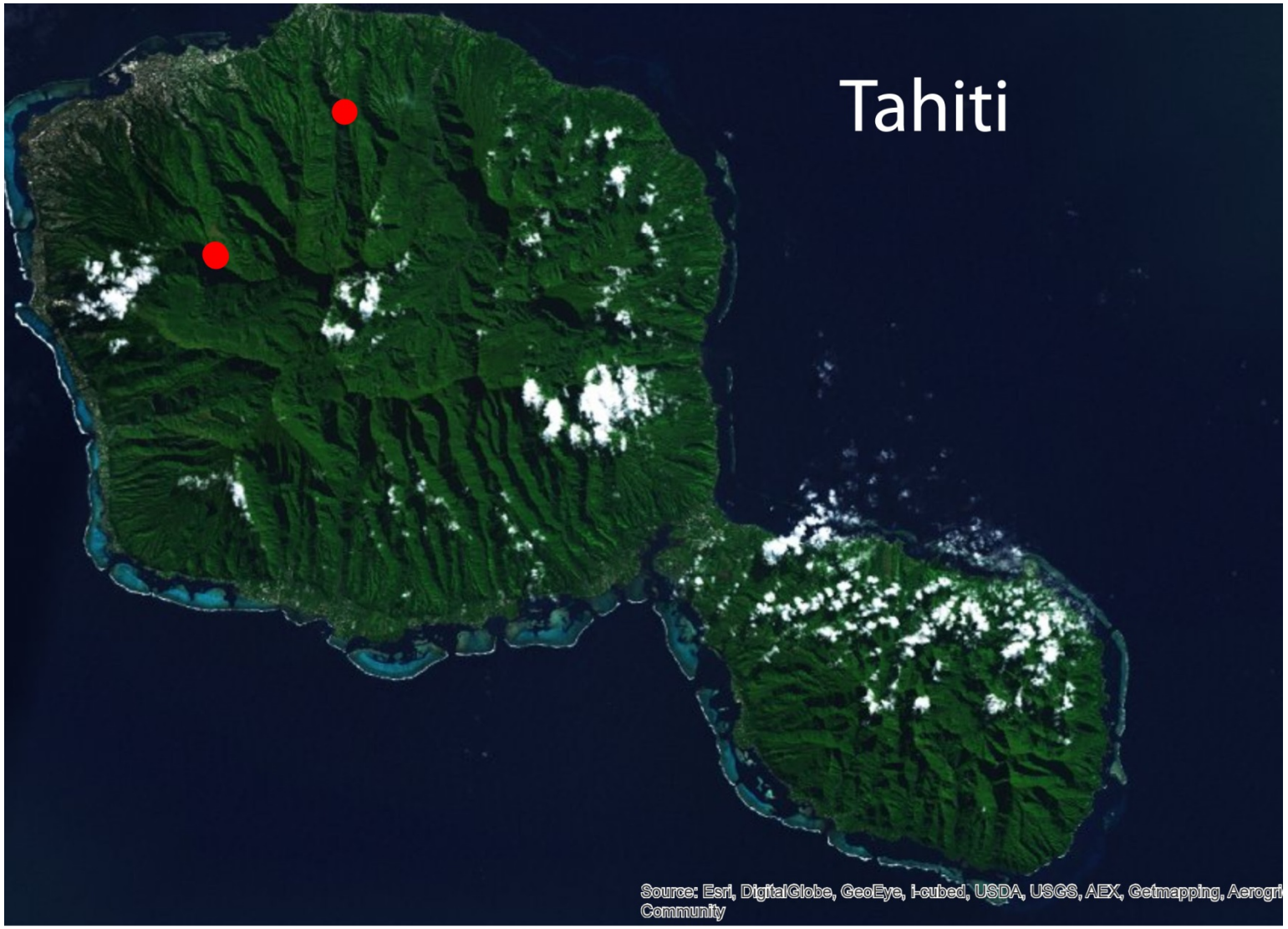


Figure 95 (a-b): (a) Holotype (♂) of P. n. sp. 23, specimen Z164; (b) paratype (♀), specimen Z101.

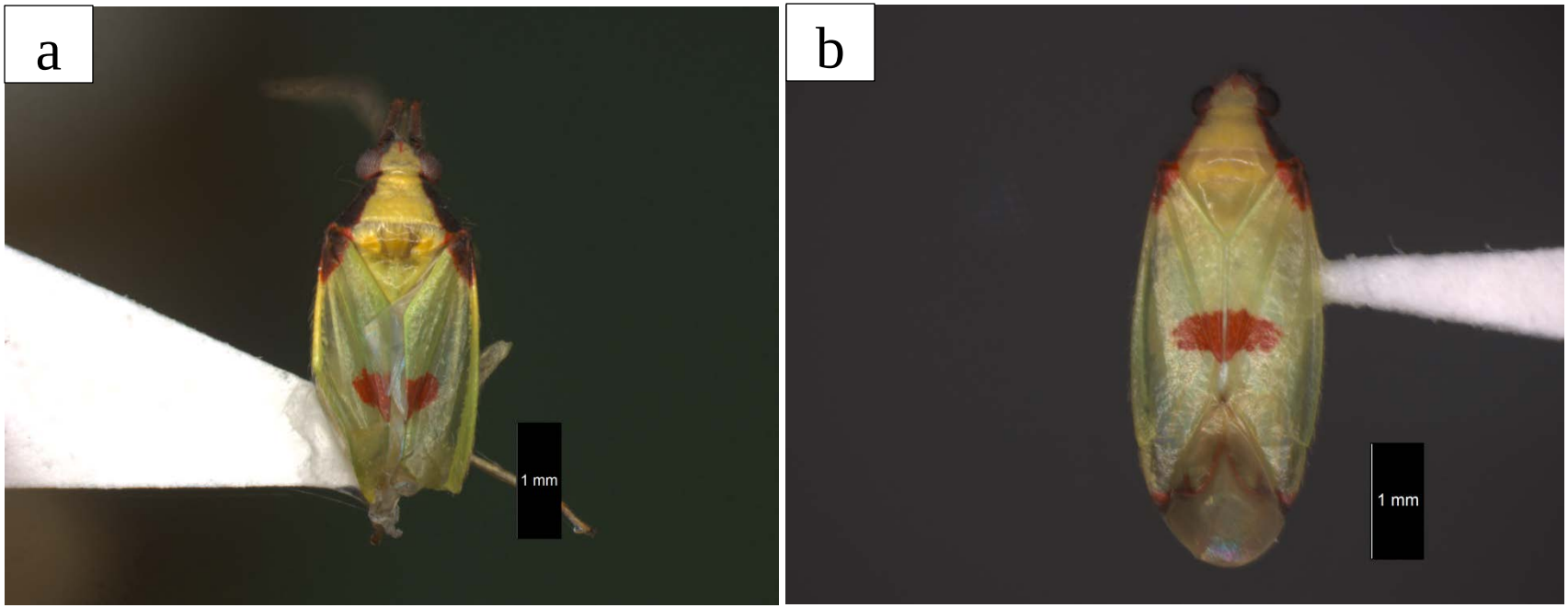


Figure 96 (a-c): Male genitalia of P. n. sp. 23, specimen Z164; (a) aedeagus; (b) left paramere; (c) right paramere.

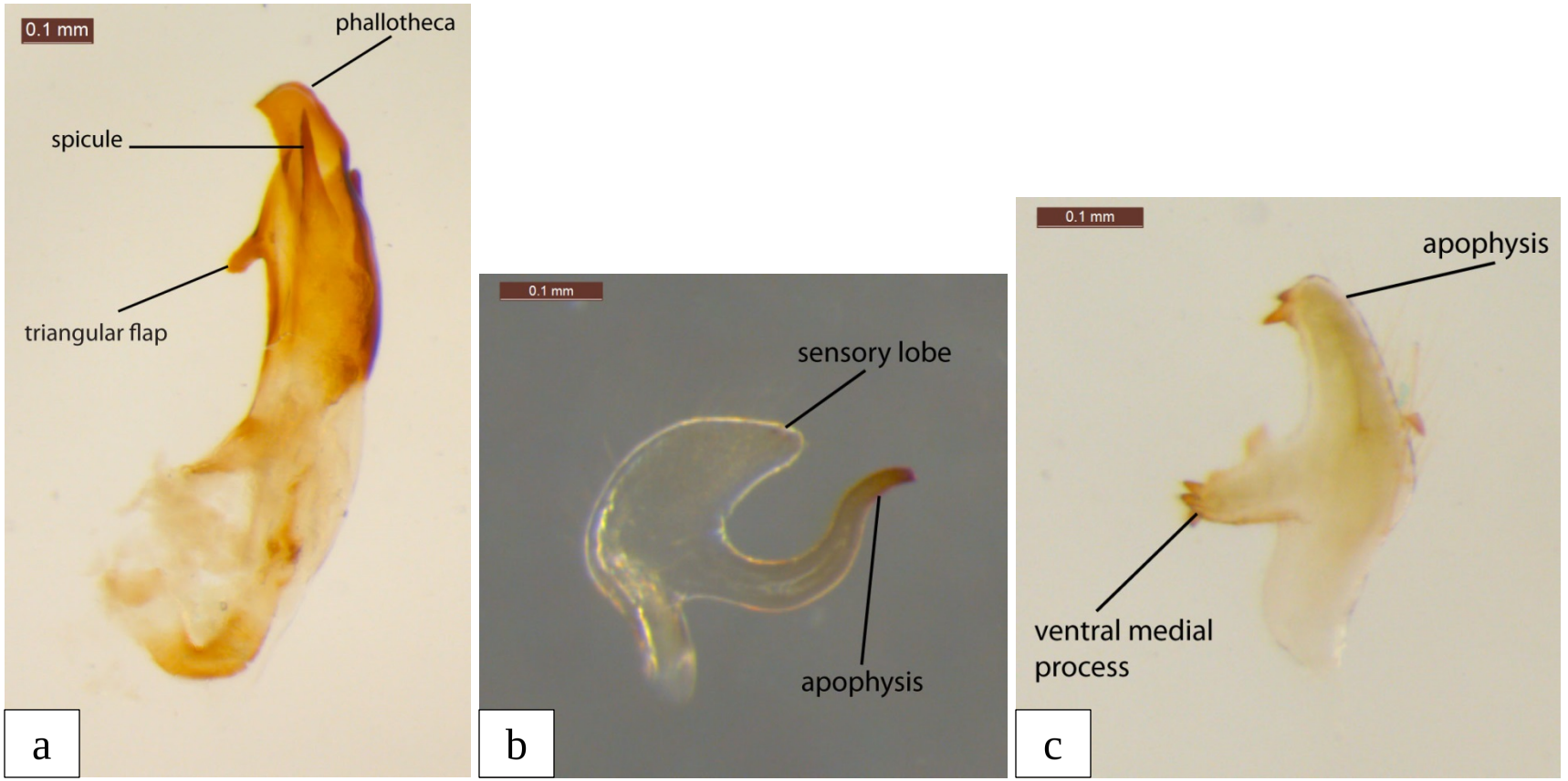


Figure 97: Distribution map for P. n. sp. 23.

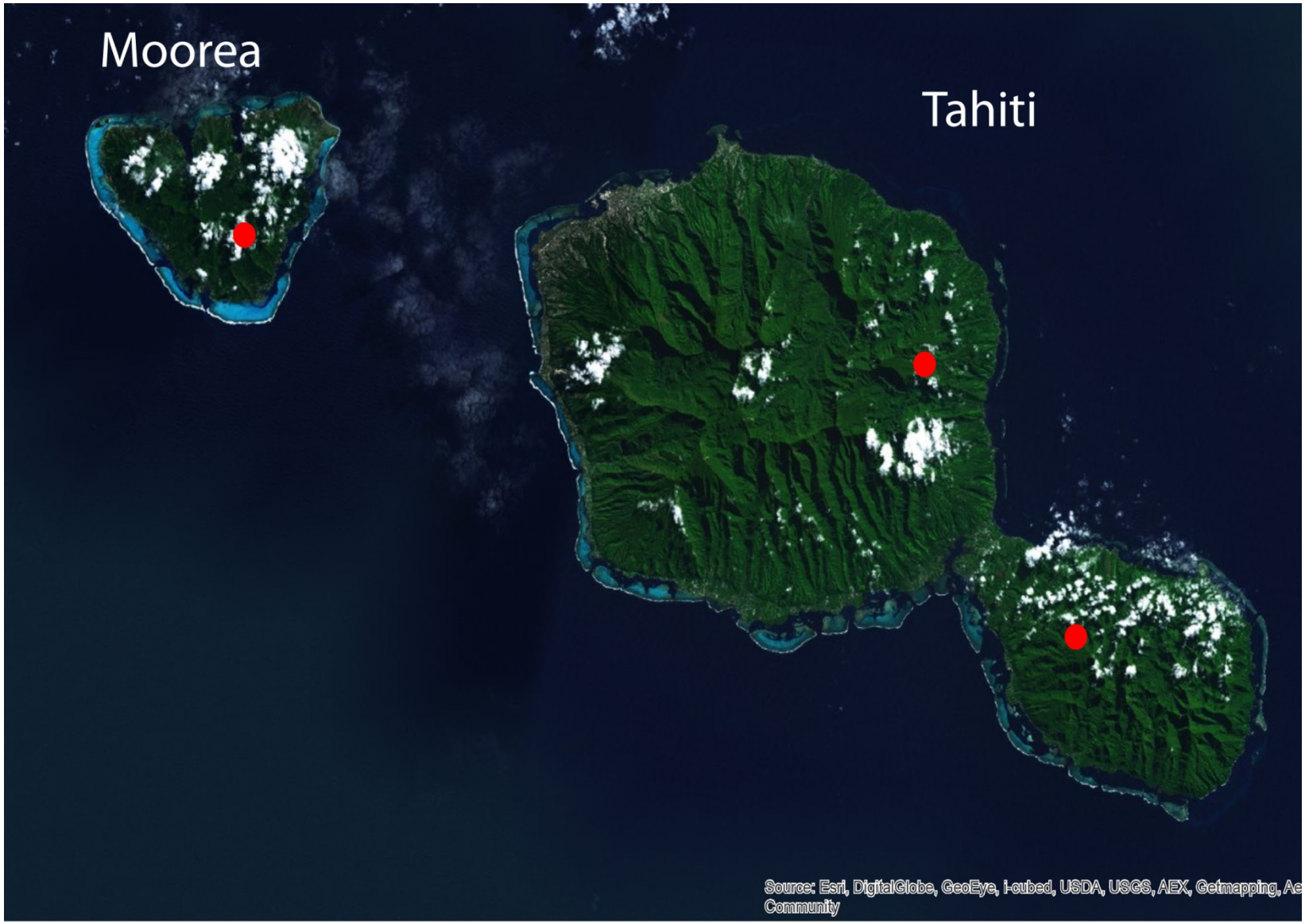
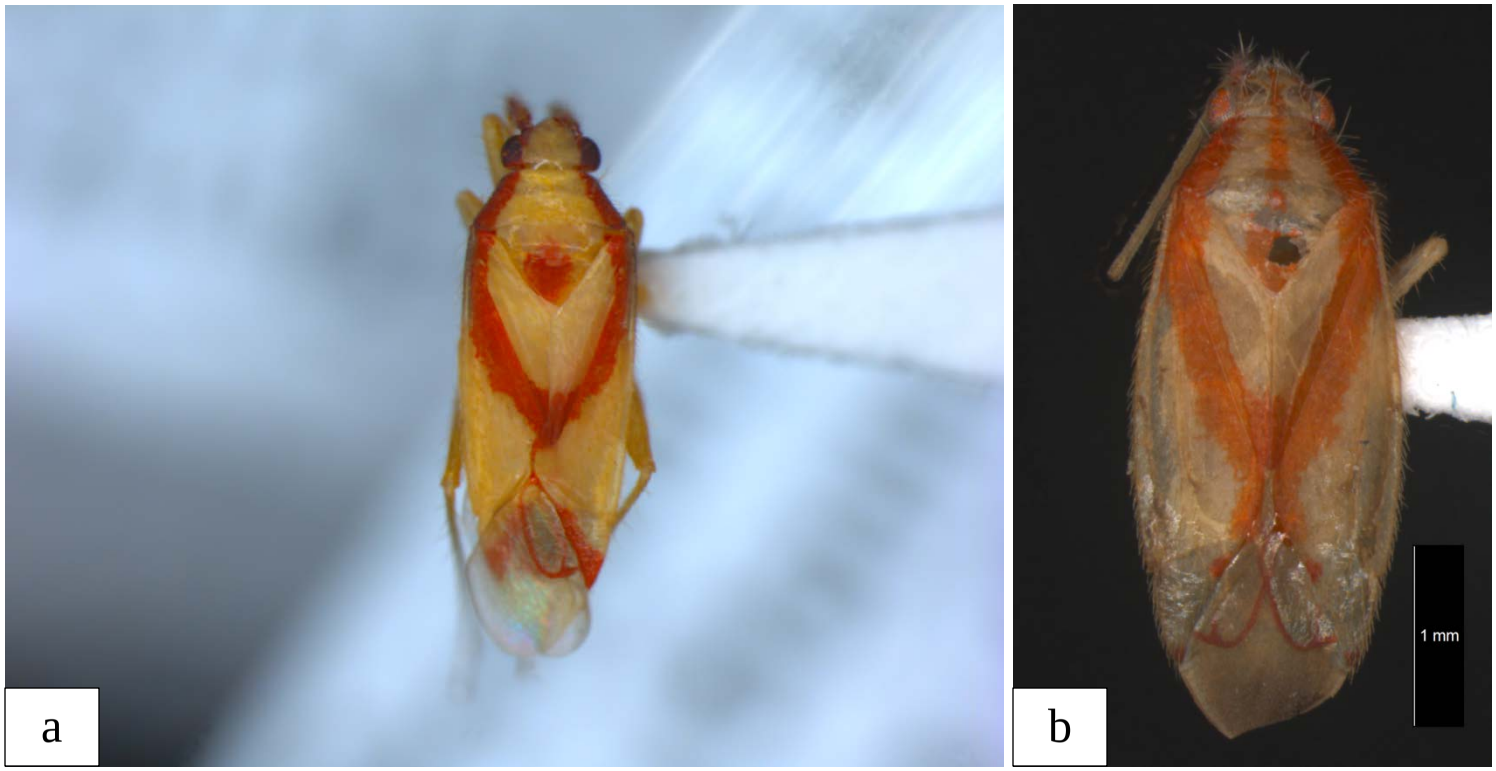


Figure 98 (a-b): Apparent convergence in general color pattern of *Pseudoloxops*; (a) *Pseudoloxops pancheriaphila*, from New Caledonia; (b) Pseudoloxops n. sp. 14 from French Polynesia.



CHAPTER 2

The relative role of geography and ecology in the radiation of *Pseudoloxops* (Hemiptera: Miridae) in French Polynesia

Introduction

Since Wallace and Darwin first proposed the mechanism of natural selection through adaptation to explain speciation (Darwin & Wallace, 1858), researchers have debated its relative importance when compared to other mechanisms, such as genetic drift, sexual selection, and polyploidy (reviewed in Coyne & Orr, 2004). Recent studies on organisms ranging from yeast (Dettman *et al.*, 2007) to marine sponges (Rutzler *et al.*, 2007) have demonstrated the potential role of adaptation through ecological specialization, often termed "ecological speciation," in the diversification process. Plant-feeding insects are considered a model system for such studies because their association with host plants for breeding and feeding provides a convenient way to quantify ecological specialization (Funk *et al.*, 2002; Matsubayashi *et al*., 2009; Fordyce, 2010). Among the better-known examples are ecotypes of *Timema* walking-sticks adapted to different host plants (Nosil *et al*., 2008), and the shift of the apple maggot, *Rhagoletis pomonella* Walsh (1867) from hawthorn to domesticated apple trees (Filchak *et al.*, 2000). When such ecological shifts result in the proliferation of multiple species within a lineage, an adaptive radiation occurs. The most oft-cited examples come from island systems (Schluter, 2000), whose discrete boundaries and simple geological history provide constrained environments in which to examine the history of speciation (Whittaker & Fernandez-Palacios, 2006).

Although adaptive radiation may be fairly common on islands, as evidenced by Darwin's finches (Grant & Grant, 2008) and *Anolis* lizards (Losos, 2009), not all lineages on islands undergo adaptive radiation. For those organisms that have diversified, many have undergone non-adaptive radiation, in which closely related species are similar ecologically (Rundell & Price, 2009), as demonstrated for *Xerocrassa* snails in Crete (Sauer & Hausdorf, 2012) and *Orsonwelles* spiders in Hawaii (Hormiga *et al.*, 2003). The mechanism for non-adaptive radiation is believed to be genetic drift; for example, in an archipelago, a population of a given species disperses to a new island, and if gene flow is negligible, mutations accumulate which can eventually lead to reproductive isolation and speciation. If we have detailed data on a lineage's current distribution and natural history within an archipelago, we can use phylogenetics to test the hypothesis that speciation was adaptive vs. non-adaptive (*sensu* Rundell and Price 2009), or at the very least, support or refute the hypothesis that a given ecological trait has been correlated with speciation. In the current study, we explore the relative role of adaptive vs. non-adaptive radiation by examining the geographic distribution and plant affiliation of a group of plant-associated true bugs (Hemiptera: Heteroptera) in the genus *Pseudoloxops* Kirkaldy, 1905 (Heteroptera: Miridae: Orthotylinae: Orthotylini) in French Polynesia.

French Polynesia, located in the middle of the South Pacific Ocean, contains 118 islands in 5 archipelagoes formed by underwater volcanic eruptions and so-called "hot spots" in the Earth's crust along the Pacific plate (Figure 1; Clouard & Bonneville, 2001). These islands are oceanic, *i.e.*, have never been connected to the mainland, and thus all of their biota has been derived from overseas dispersal. In a recent integrative taxonomy study (Balukjian *et al*., in prep), 26 *Pseudoloxops* species were described from 12 of the 21 Society and Austral Islands of French Polynesia (Figure 2; Table 1), comprising a radiation descended from colonists from islands further west in the Pacific. *Pseudoloxops* belongs to the family Miridae, or plant bugs, which are the most diverse family of "true bugs" (Figure 3; Hemiptera: Heteroptera), with 11,020 described species (Cassis & Schuh, 2012) and thousands more awaiting discovery and documentation (Gerry Cassis, personal communication). Their diversity is likely related to their trophic range (a

wide range of herbivores and predators) and their ability to specialize on host plants, particularly angiosperms (Wheeler, 2001; Cassis & Schuh, 2012). Plant bugs comprise a significant part of the true bug fauna in French Polynesia, with 19 genera present and at least 4 having radiated within the archipelagoes (*Campylomma, Engytatus, Pseudoloxops,* and a new genus in the subfamily Mirinae; personal observation). Of these, *Pseudoloxops* has radiated the most extensively. The entire range of *Pseudoloxops* is across several zoogeographic regions (Afrotropical, Oriental, Palearctic, Sino-Japanese, Saharo-Arabian, and Oceania), with French Polynesia representing the eastern limit of its range in the Pacific (Holt *et al.*, 2013; Plant Bug Planetary Biodiversity Inventory, 2013).

Given that this radiation of plant bugs has just been documented and no experimental data have yet been collected, we use geographic isolation and plant affiliation as proxies for non-adaptive and adaptive processes. While this may be a crude estimate, it provides a first pass into uncovering the processes that have determined the pattern, and lays the groundwork for future experimental work and additional data collection. The framework of geographic isolation vs. plant affiliation has been used in several other islands systems, especially in Hawaii and the Canary Islands (Percy, 2003; Bennett & O'Grady, 2013). Three such studies have been performed on other plant bug radiations in Hawaii. In the *Nesiomiris* radiation, Gagne (1997) found highly specialized diversity, with 44 of 50 species endemic to a single island and 41 species specializing on a single host plant species (within only 3 plant families). Based on distributional data, host-plant records, and a hand-constructed phylogeny using morphological characters, both host-plant switching and geographic isolation were correlated with speciation, although speciation by geography was found to be more prevalent. In the radiation of *Sarona* plant bugs, distributional data, host records, and a morphology-based phylogeny were used to infer that 13 of 35 speciation events were correlated with host-switching; however, this lineage was even more specialized, with 39 of 40 species endemic to a single island and all having a single host species (Asquith, 1994, 1997). Here, a broader range of host phylogenetic diversity (19 species in 14 plant families) suggested ecological release followed by diversification, as the analysis supported several within-island speciation events accompanied by switching host plants (11 of 35 events; Asquith, 1995). Finally, the radiation of the genus *Orthotylus* in Hawaii is the most explosive of all plant bug radiations, with 95 described species (all single-island endemics) and many more awaiting description (Dan Polhemus, personal communication). Like *Sarona*, *Orthotylus* uses a broad range of hosts in 16 different plant families, and like the other plant bug radiations, they are highly specialized with almost all species having a single host plant. Several apparent sister species (based on examination of the morphology; no phylogenies have yet been constructed) are distributed on different islands, indicating that geography has played a role in several speciation events, but the high phylogenetic diversity of hosts also suggests that host-switching has played a role (Polhemus 2002; 2004; 2011). No such studies have been documented in the volcanic archipelagoes of French Polynesia despite the similarity of the system, especially the Society Islands [hot-spot formation with a linear progression of island age moving from northwest (oldest) to southeast (youngest)], although the Societies are much smaller, with less than 10% of the land area. Previous taxonomic work suggests *Pseudoloxops* may be more vagile and less specialized than the Hawaiian plant bugs, as 17 of the 26 species are endemic to a single island.

While the aforementioned Hawaiian radiations provide a baseline for comparison, phylogenies are not available for all of them, and no molecular data have been collected (existing phylogenies

are based on morphology alone). Phylogenetic reconstruction provides the necessary context to allow us to more stringently test hypotheses of relatedness within a radiation and provide the framework for testing the hypothesis that speciation was driven by geography vs. plant affiliation. In this study, we first document the plant affiliations of *Pseudoloxops* in French Polynesia through field collecting, with multiple individuals per species where possible. We do not use the term "host plant" here because considering a plant a true host requires collecting both adults and nymphs on the same plant. While we did collect nymphs, we did not have enough samples to make confident host designations for all the species we found. Therefore we use plant affliation as our measure of ecology by documenting the plants on which specimens were collected. We then construct a phylogeny of all specimens with plant affiliation data and reconstruct the ancestral character states for geography (island or locality) and plant affiliation (taxonomic order and family) in order to infer the potential role of each in speciation. Given the previous work on Hawaiian plant bugs and the similar nature of the French Polynesian islands, we expect both plant switching and geography to have contributed to speciation in this radiation, implying both adaptive and non-adaptive components.

Materials and Methods

Specimen Collection

Field searches for *Pseudoloxops* were conducted on 8 of the 14 Society Islands (Huahine, Maupiti, Mehetia, Moorea, Raiatea, Tahaa, Tahiti, and Tetiaroa) and 4 of the 7 Austral Islands (Raivavae, Rimatara, Rurutu and Tubuai) in 2007-09, and 2011. Of the islands not surveyed, most are atolls, flat coral-based islands with little floral diversity and no historical collections of *Pseudoloxops.* Bora Bora is the only island of considerable size and elevation that was not sampled, due to lack of time and funding. Field time on each island varied considerably depending on cost and access; for example, Moorea and Tahiti were sampled much more extensively because of the University of California at Berkeley's research station (the Richard B. Gump South Pacific Research Station) on Moorea, where the first author was based, and Tahiti's proximity to Moorea. On each island, every effort was made to sample in the greatest diversity of habitats and elevations as possible. The leaves, branches, and in particular, flowers (often the preferred habitat of plant bugs; Wheeler 2001) were beaten with a plastic PVC pipe into an insect collecting net, and trapped specimens were aspirated into collecting vials and killed the same day in a -20° freezer. The dead specimens were then transferred to 1.5 mL vials and stored in 95% ethanol in a -80° freezer for future DNA extraction. Each specimen was given its own vial, as plant bugs' legs easily fall off in ethanol (complicating both morphological and molecular work). Each plant on which *Pseudoloxops* was found ("plant affiliation") was considered a collecting locality and assigned a unique locality code. At each locality, the latitude, longitude, and elevation were recorded using a Garmin eTrex H GPS device. Samples and photographs of plants were taken in the field for later identification by local botanists.

Molecular Methods

Following identification to species using integrative taxonomy (Balukjian *et al*., in prep), specimens were prepared for DNA sequencing. Early attempts to extract sufficient DNA for amplification and sequencing from 2-3 legs per specimen failed. Therefore, to obtain enough total genomic DNA, each specimen was poked several times with a minuten pin and then soaked

in the DNAEasy® tissue kit's extraction buffer (with proteinase K) overnight, followed by completion of the manufacturer's DNA extraction protocol for animal tissue. Fragments of the mitochondrial cytochrome oxidase I (CO1; 814 base pairs) and 16S ribosomal sub-unit genes (508-516 base pairs, due to gaps and insertions) were amplified using the polymerase chain reaction (see Table 2 for PCR conditions and protocols); a fragment of the nuclear 28S ribosomal sub-unit gene (633-642 base pairs) was also amplified. DNA was amplified using the following primers: for CO1: CI-J-2195, or MTD10/MTD12 (Simon *et al.*, 1994); for 16S: 16Sa/16Sb (Xiong & Kocher, 1991); and for 28S: 28SD2F/28SD2R (Weirauch & Munro, 2009); see Table 3 for primer sequences. PCR products were cleaned up and Sanger sequenced at UC Berkeley's DNA Sequencing Facility. Sequences were aligned in the program Geneious Pro 5.6.2 using the Geneious Alignment function and its default settings (cost matrix: 65% similarity (5.0/-4.0); gap open penalty 12, gap extension penalty 3), and corrected by eye.

Given that individual gene trees often do not match species trees (Degnan & Rosenberg, 2009), combining genetic data from multiple independent loci often improves estimation of the species tree (Olmstead & Sweere, 1994). We therefore combined our three loci (16S, 28S, and CO1; although 16S and CO1 are not truly independent of each other, as they are both part of the mitochondrial genome) to infer a molecular phylogeny. We concatenated our alignments from all 3 genes into a single alignment in Mesquite (Maddison & Maddison, 2011) for a total dataset of 140 terminals and 1,973 base pairs. We used the program PartitionFinder (Lanfear *et al.*, 2012) to find the best model of evolution according to the Bayesian Information Criterion, which was GTR+I+G, and the best partitioning scheme, which was having no partitions. We then loaded the combined alignment into Mr. Bayes 3.1.2. on the CIPRES Science Gateway (Miller *et al.*, 2010) and performed two independent runs of four chains each under the GTR+I+G model for 20 million generations, sampling every 1,000 generations. After running to completion, we verified that the standard deviation of split frequencies fell below 0.01 to ensure convergence of the 2 runs. A 50%-majority rules consensus tree was then constructed, discarding the first 25% of trees as the burn-in. We examined a phylogeny from a previous study (Balukjian *et al.*, in prep; Figure 4) which included outgroups in order to find the most basal species and root the tree. Although a polytomy defines the ingroup, n. sp. 2 is at the base of the polytomy and is a species from the Austral Islands, the oldest archipelago geologically and therefore more likely to be ancestral to the rest of the radiation. Thus we rooted the tree for this analysis with one of the specimens representing n. sp. 2.

Ancestral Character State Reconstruction

Following construction of the phylogeny, we imported it into the program Mesquite 2.75 (Maddison & Maddison, 2011) and transformed it into a cladogram. We then mapped the characters of plant affiliation and geography onto the tree. Since we found *Pseudoloxops* to utilize a wide range of plants, with many species using multiple plant species, we coded plant affiliation to the taxonomic rank of division, order, and family in order to increase our chances of recovering phylogenetic signal. We also categorized our geographic distribution data in a similar way, coding island distribution at both the island level *(e.g.*, Tahiti, Moorea, etc.) and at the finer-scale of locality *(e.g.*, Mt. Aorai, Taravao Plateau, etc.). We then reconstructed ancestral character states using parsimony as our optimality criterion. For each character (plant division, plant order, plant family, island, and locality) and for each of the 12 well-supported nodes in our

tree corresponding to speciation events, we then compared the reconstructed ancestral states before and after splitting and documented if the characters changed state.

Results

Pseudoloxops specimens were collected in the field on 9 of the 12 islands surveyed; only Mehetia and Tetiaroa in the Society Is. and Raivavae in the Austral Is. did not yield any specimens. Specimens were found at 114 of 520 collecting localities on 27 different plant species, representing 25 families and 13 orders (Tables 4-5). We collected plant affiliation data for 25 of the 26 known species, missing only n. sp. 15 (Table 6). Of these, 13 were associated with multiple plant species, and 12 were restricted to a single plant. A complete list of the specimens collected for this study is given in Table 7.

A cladogram showing the relationships between all 140 specimens is shown in Figure 5, with the 15 nodes corresponding to speciation events labeled A-O (Table 8). Of these, only 12 were well-supported (posterior probability ≥ 0.80), so we excluded the 3 that were not supported from the remaining analyses. In our first ancestral state analysis, we reconstructed the evolutionary history of plant division affiliation (Angiospermae vs. Pteridophyta) throughout the phylogeny (Figure 6). The association with ferns (Pteridophyta) appeared to evolve independently in two major clades (nodes J and L or M), followed by subsequent gains/losses within each clade. We further divided plant association data by categorizing plants by taxonomic order, and reconstructed the ancestral states throughout the phylogeny (Figure 7). Of the 12 well-supported speciation events, the ancestral state before and after speciation could be unequivocally reconstructed for 7 of them. In 4 cases there was a switch in plant order, and in the other 3 plant order remained the same (Table 9). For the 3 speciation events in which plant order remained the same (nodes E,G, and L), we examined the ancestral reconstructions on the cladogram with plant family mapped on (Figure 8) and found no change at the family level associated with speciation.

In the analysis of geography and speciation, we were able to unequivocally reconstruct the ancestral states for island distribution at 8 of the 12 speciation events (Table 10). We found 6 cases where island distribution remained the same and 2 where it changed (Figure 9). Upon examining the cladogram with geography further divided into locality within islands, we found no change in locality associated with speciation for 5 of the 6 cases where speciation occurred within islands (ancestral states could not be unequivocally reconstructed for the sixth case; Figure 10).

When combining the analyses of ancestral plant order affiliation and island distribution, we found 5 speciation events in which both characters could be unequivocally reconstructed (Tables 11-12). In 3 of these cases, there was a plant switch without a change in island distribution, and in the other 2 cases, both plant affiliation and island distribution remained the same.

Discussion

Our analysis of plant affiliation and island distribution for the *Pseudoloxops* radiation in French Polynesia revealed that both plant-switching and island hopping are correlated with speciation, suggesting both adaptive and non-adaptive components to this radiation. This result matches the

findings of three plant bug radiations in Hawaii and several other studies demonstrating the combined role of geography and ecology in speciation (Pramual *et al.*, 2012; Surget-Groba *et al*., 2012). However, *Pseudoloxops* appears to be less specialized than the Hawaiian bug radiations, with more than half of the species studied here collected from multiple plant species and with 9 of 26 species occurring on multiple islands. Furthermore, *Pseudoloxops* utilizes an even wider array of plants than the Hawaiian groups, associating with plants in 25 different families and 13 different orders. Clearly these bugs have the physiological ability to use plants with a wide range of secondary compounds and chemical defenses, and perhaps this dietary versatility is why the lineage has been successful at colonizing remote islands across the Pacific Ocean. For example, n. sp. 19 uses both *Metrosideros collina* (Myrtales) and *Weinmannia parviflora* (Oxidales), two common cloud-forest trees which are phylogenetically distant. Although specialist lineages have also been successful island colonists (Hembry *et al.*, 2012), the expectation is that generalists would have a better chance of establishing due to their dietary flexibility (Carlquist, 1974), and *Pseudoloxops* appears to fit this expectation. In addition to being more generalist, *Pseudoloxops* also uses several introduced plants, which have allowed it to persist in some lowland areas where most other endemic insect biodiversity has gone extinct (Gillespie & Claridge, 2008). Although most *Pseudoloxops* species are confined to high-elevation native forest, some species can be found all the way down to sea level. By contrast, the three Hawaiian plant bug radiations are comprised of species exclusively associated with native flora in native forests.

Our reconstruction of ancestral character states on the phylogeny found five speciation events that occurred at the same locality within the same island. Three of these speciation events are also associated with a concomitant switch in plant affiliation. Plant-feeding insects appear to be particularly adept at speciating "sympatrically" by using different host plants (Drès & Mallet, 2002). For example, the speciation event represented by node H depicts the formation of n. sp. 11 and its split from n. sp. 12+13 (Figure H). The ancestor of this split was associated with a plant in the family Dennstaedtiaceae, a fern. Association with ferns appeared to evolve earlier in the tree, at node J, and then reversed here with a switch to the family Ericaceae. All of this occurred in the vicinity of Mt. Aorai, one of the highest peaks in French Polynesia, at 2,066 m. Aorai is clearly a cradle of diversity, as 3 speciation events were reconstructed to occur there alone. More generally, the island of Tahiti has been a hub for diversification, with six speciation events occurring within its shores. Given the species-area relationship and that Tahiti is about ten times larger than the next largest island in French Polynesia, it is not surprising that it hosts the most diversity and has been the site of the most diversification.

Ecology alone cannot explain all of the within-island speciation events observed, as two events were neither correlated with an ecological nor a geographic shift. Some other mechanisms were likely at play, such as sexual selection, which has played a role in diversification in several insular insect systems (Boake, 2005; Mendelson & Shaw, 2005), but is completely unexplored for plant bugs. To initiate mating, female plant bugs signal males with pheromones, which the males receive via tiny structures on their antennae called sensilla (Aldrich, 1988; Graham, 1988). An examination of the chemical profile used by females and males' antennal sensilla (visible using scanning electron microscopy) could provide evidence for sexual selection and reveal significant inter-specific differences. Furthermore, there is preliminary evidence that certain Orthotylini species (the tribe to which *Pseudoloxops* belongs) possess morphological structures that could be used for acoustic communication (Schaffner & Ferreira, 1995), which is important

for mating in certain other Hemipterans (Rodriguez *et al.*, 2007). Clearly several more types of natural history data could prove useful in refining our understanding of species boundaries and drivers of speciation in this radiation.

Our study used plant affiliation (the plant on which an insect was collected) as its main ecological variable, but further studies would be strengthened by collecting enough juveniles (nymphs) to justify the designation of a plant as a true host. Further natural history studies should also be conducted on the feeding behavior of *Pseudoloxops*, both within the French Polynesian radiation and across its entire range, to get a better understanding of the evolution of food choice across the lineage and its role in speciation. On oceanic islands, the phenomenon of ecological release can contribute to adaptive radiation, in which a colonizing lineage encounters ecologically "open" niche space due to the lack of competition and predation and expands its range to exploit these new niches (Yoder *et al*., 2010). With more data on *Pseudoloxops*' host plant affiliations across its entire range, we could test the hypothesis that the oligophagy observed in French Polynesia was due to such an expansion of niche use, versus the null hypothesis that *Pseudoloxops* is fairly generalist everywhere. A further wrinkle to the story is that while Orthotyline plant bugs are generally considered phytophagous (Cassis & Schuh, 2012), there is some preliminary evidence that *Pseudoloxops* in other parts of the world is predaceous, or at least facultatively predaceous (Stichel, 1958). While predation would not refute an association with a given plant, predatory habits imply a different kind of ecological relationship with a plant (more of a habitat than a locality for feeding and breeding). Given the difficulty of observing plant bugs in the field, experimental studies in the lab are needed to further examine diet in this group.

Perhaps the most surprising and exciting observation to emerge from this study is the evolution multiple times of an association with ferns. Despite being extraordinarily diverse, plant bugs are rarely associated with ferns (Wheeler, 2001). Like many other insects, the assumption is that plant bugs avoid ferns because of their secondary metabolites (defensive compounds), although this has rarely been tested empirically (Hendrix, 1980). Recent research suggests that ferns may also have insecticidal proteins that deter predators (Markham *et al.*, 2006). Nonetheless, 7 of the 26 species in this radiation are associated exclusively with ferns (there was one record of *P. tahiticus* from *Metrosideros collina*, but we consider this a sitting record in light of the overwhelming evidence for host association with ferns) with enough specimens for some of the species to designate them as host plants. Host-specificity within the ferns does not seem to be great, as 7 different species are utilized overall in the radiation and a single species, *P. tahiticus*, utilizes 5 of them. A switch from angiosperm to fern affiliation appears in two major clades in the radiation, once at the clade marked J and once at either L or M (depending on the ancestral reconstruction). In clade J, this switch appears to have spurred a burst of diversification, with subsequent speciation events marked at nodes F, G, H, I, and J, with H perhaps being driven by a switch back to angiosperms. Diversification within clade L or M is a little more unclear; although new species have formed, nodes M and N are poorly supported, and more data is needed to better resolve the structure within this clade. Thus it appears switching to ferns may have been a key innovation for this radiation in two different parts of the tree. Interestingly, there appears to be some color convergence between the two fern clades as well, as the species within these clades tend to be yellow with red markings, while many of the species associated with angiosperms are more green (some with and some without red markings). The switch from

angiosperms to ferns is also a bit surprising, as one might expect the reverse to happen on islands, where ferns tend to be among the early plant colonists (Whittaker & Fernandez-Palacios, 2006). But ferns often comprise a larger percentage of the flora on remote islands than they do on the mainland, and so it may be that ferns represented a greater proportion of the available niche space regardless of the timing of the bugs' colonization (Geiger *et al.*, 2007).

A key caveat to the interpretations of these data is our assumption that *Pseudoloxops* is monophyletic within French Polynesia. While this is a reasonable possibility given the isolation of these islands and their distance from the nearest archipelago where *Pseudoloxops* is found (Samoa, 1,500 miles to the west), this hypothesis has not been rigorously tested. Limitations on time and funding precluded us from sampling across the entire Pacific, but having such data would allow us to address this question. The outgroups included in the phylogeny in Figure 4 were from New Caledonia, Australia, Thailand, and Japan, places far distant from French Polynesia, and several of these specimens grouped with the French Polynesian radiation in a giant polytomy (Figure 4). Given the evidence for multiple colonizations of French Polynesia in other groups of arthropods (Claridge, 2006; Hembry, 2012), it is entirely plausible this is the case for *Pseudoloxops* as well.

We have provided preliminary evidence for the combined role of ecology and geography in the radiation of *Pseudoloxops* plant bugs in French Polynesia. More ecological data, specifically the collection of more nymphs to strengthen host plant affiliations, and more sampling outside of French Polynesia are necessary to improve upon this work. Nonetheless, we consider this study a significant first step towards unraveling a new system in evolutionary ecology and speciation research, exciting fields that are often dominated by work on model organisms. While our understanding of this system is still in its infancy, it is vital that we continue discovering and studying new lineages that add more data points to our attempt at understanding the common processes that shape biodiversity overall.

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Chapter 2 Tables and Figures

Table 1: Distribution and endemism of 26 species in French Polynesian *Pseudoloxops* radiation.

Species	# Specimens	Island Distribution	Archipelago or Single-Island Endemic	Species Elevational Range (m)
rubrocuneatus	15	Moorea, Tahiti	Archipelago	13.6-320.7
n sp. 1	11	Huahine, Maupiti	Archipelago	7.5-361.6
n. sp. 2	2	Rurutu, Tubuai	Archipealgo	324-388
n. sp. 3	8	Huahine	Island	345-469.5
n. sp. 4	4	Maupiti, Raiatea	Archipelago	8.5-16.5
n. sp. 5	2	Tahiti	Island	1215.2-1448.8
n. sp. 6	3	Tahiti	Island	1096.5-1120.8
n. sp. 7	1	Tahiti	Island	1120.8
n. sp. 8	7	Moorea	Island	475-1120
n. sp. 9	3	Tahaa	Island	171
n. sp. 10	3	Tahiti	Island	1885.7-1913.1
n. sp. 11	7	Tahiti	Island	1433-2028.5
n. sp. 12	2	Tahiti	Island	1873
n. sp. 13	11	Moorea, Tahiti	Archipelago	716.5-1628.6
n. sp. 14	7	Raiatea	Archipelago	227-722.3
n. sp. 15	1	Moorea	Island	449.8
n. sp. 16	1	Rimatara	Island	0.8
n. sp. 17	1	Huahine	Island	414
n. sp. 18	5	Tahiti	Island	792-1119.3
n. sp. 19	33	Moorea, Tahiti	Archipelago	480-1448.6

Species	# Specimens	Island Distribution	Archipelago or Single-Island Endemic	Species Elevational Range (m)
rubroclavus	4	Moorea	Island	287.6-470
tahiticus	32	Moorea, Tahiti	Archipelago	237.8-1863.9
n. sp. 20	1	Huahine	Island	419
n. sp. 21	8	Moorea	Island	240-790
n. sp. 22	3	Tahiti	Island	623.3-1451.5
n. sp. 23	3	Moorea, Tahiti	Archipelago	744.9-840

Table 2: PCR Conditions used for amplifying genes 16S, 28S, and CO1.

Gene/Protocol	Reagent	Volume
16S	Water	5.75 uL
	10X Buffer	2.0 uL
Denature: 95° for 2 min	$MgCl_2$	3.5 uL
95° for 1 min	Q Solution	4.0 uL
55° for 1 min	2.5 mM dNTPs	2.0 uL
Extension: 72° for 1 min	1X BSA	1.0 uL
35X	10uM Primer 16Sa	1.25 uL
Final Extension: 72° for 10 min	10uM Primer 16Sb	1.25 uL
12° final hold	Taq	0.25 uL
	DNA template	4.0 uL
	Total	25 uL
28S	Water	12.75 uL
	10X Buffer	2.0 uL
Denature: 95° for 2 min	$MgCl_2$	2.5 uL
95° for 1 min	2.5 mM dNTPs	2.0 uL
58° for 1 min	1X BSA	1.0 uL
Extension: 72° for 1 min	10uM Primer 28SF	1.25 uL
35X	10uM Primer 28SR	1.25 uL
Final Extension: 72° for 10 min	Taq	0.25 uL
12° final hold	DNA template	2.0 uL
	Total volume per sample :	25 uL
CO1	Water	12.25 uL
	10X Buffer	2.5 uL
Denature: 95° for 2 min	$MgCl_2$	2.0 uL
95° for 1 min	2.5 mM dNTPs	1.5 uL
55° for 1 min	1X BSA	1.0 uL
Extension: 72° for 1 min	10uM Primer MTD10	0.75 uL
35X	10uM Primer MTD12	0.75 uL
Final Extension: 72° for 10 min	Taq	0.25 uL
12° final hold	DNA template	4.0 uL
	Total volume per sample :	25 uL

Table 3: Primers used for DNA amplification.

Gene	Primer	Primer Sequence (5’ to 3’)	Reference
CO1	MTD10	TTGATTTTTTGGTCATCCAGAAGT	Simon *et al.*, 1994
	MTD12	TCCATTGCACTAATCTGCCATATTA	
16S	16Sa	CGCCTGTTTATCAAAAACAT	Xiong & Kocher, 1991
	16Sb	CTCCGGTTTGAACTCAGATCA	
28S	28SD2F	CGGGTTGCTTGAGAGTGC	Weirauch & Munro, 2009
	28SD2R	CTCCTTGGTCCGTGTTTC	

Table 4 : Plants associated with *Pseudoloxops* in French Polynesia, with their distributional status (indigenous, introduced, or equivocal). Plant names were verified by French Polynesian botanists (Ravahere Taputuarai and Jean-Yves Meyer, personal communication) and checked against the French Polynesian Herbarium online database (Herbier de la Polynésie française, 2013).

Species	Division	Order	Family	Status
Adiantum capillus-veneris	Pteridophyta	Polypodiales	Pteridaceae	Equivocal
Allophylus rhomboidalis	Angiospermae	Sapindales	Sapindaceae	Indigenous
Alstonia costata	Angiospermae	Gentianales	Apocynaceae	Indigenous
Alyxia sp.	Angiospermae	Gentianales	Apocynaceae	Indigenous
Arachniodes aristata	Pteridophyta	Polypodiales	Dryopteridaceae	Indigenous
Ascarina polystachya	Angiospermae	Chloranthales	Chloranthaceae	Indigenous
Astronidium saccatum	Angiospermae	Myrtales	Melastomataceae	Indigenous
Blechnum orientale	Pteridophyta	Polypodiales	Blechnaceae	Indigenous
Davallia sp.	Pteridophyta	Polypodiales	Davalliaceae	Indigenous
Decaspermum fruticosum	Angiospermae	Myrtales	Myrtaceae	Indigenous
Dicranopteris linearis	Pteridophyta	Gleicheniales	Gleicheniaceae	Indigenous
Glochidion sp.	Angiospermae	Malpighiales	Euphorbiaceae	Indigenous
Hibiscus tiliaceus	Angiospermae	Malvales	Malvaceae	Indigenous
Inga feuillei	Angiospermae	Fabales	Mimosaceae	Introduced
Inocarpus fagifer	Angiospermae	Fabales	Fabaceae	Introduced
Mangifera indica	Angiospermae	Sapindales	Anacardiaceae	Introduced

Species	Division	Order	Family	Status
Metrosideros collina	Angiospermae	Myrtales	Myrtaceae	Indigenous
Myrsine sp.	Angiospermae	Ericales	Myrsinaceae	Indigenous
Nephrolepis hirsutula	Pteridophyta	Polypodiales	Nephrolepidaceae	Indigenous
Paesia divaricatissima	Pteridophyta	Polypodiales	Dennstaedtiaceae	Indigenous
Parasponia andersonii	Angiospermae	Rosales	Ulmaceae	Indigenous
Persea americana	Angiospermae	Laurales	Lauraceae	Introduced
Leptecophylla pomarae	Angiospermae	Ericales	Ericaceae	Indigenous
Terminalia catappa	Angiospermae	Myrtales	Combretaceae	Introduced
Triumfetta rhomboidea	Angiospermae	Malvales	Malvaceae	Introduced
Vaccinium cereum	Angiospermae	Ericales	Ericaceae	Indigenous
Weinmannia parviflora	Angiospermae	Oxidales	Cunoniaceae	Indigenous

Table 5: Geographic data for islands where *Pseudoloxops* was collected.

Island	Archipelago	Age (ma)	Area (km^2)	Altitude (m)
Tahiti	Society	0.19-1.37*	1,042	2,241
Moorea	Society	1.72	135	1,207
Huahine	Society	2.65	74.8	670
Raiatea	Society	2.75	171.4	1,017
Maupiti	Society	4.51	12	372
Tahaa	Society	3.4	90.2	590
Rimatara	Austral	28.6-4.78**	8.7	99
Rurutu	Austral	13-0.2**	38.5	389
Tubuai	Austral	10.6-7.23	45	410

*Evidence for multiple phases of volcanism

**Evidence for multiple phases of volcanism and secondary uplift

Table 6: Plant affiliations for the 25 *Pseudoloxops* species included in this study.

Species	Affiliated Plants
rubrocuneatus	*Hibiscus tiliaceus, Terminalia catappa*
n. sp. 1	*Allophylus rhomboidalis, Hibiscus tiliaceus, Triumfetta rhomboidea*
n. sp. 2	*Metrosideros collina*
n. sp. 3	*Glochidion* sp., *Mangifera indica, Metrosideros collina*
n. sp. 4	*Inga feuillei, Persea americana*
n. sp. 5	*Ascarina polystachya, Weinmannia parviflora*
n. sp. 6	*Myrsine* sp., *Vaccinium cereum*
n. sp. 7	*Myrsine* sp.
n. sp . 8	*Alyxia* sp., *Metrosideros collina*
n. sp. 9	*Nephrolepis hirsutula*
n. sp. 10	*Paesia divaricatissima*
n. sp. 11	*Leptecophylla pomarae*
n. sp. 12	*Paesia divaricatissima*
n. sp. 13	*Blechnum orientale, Dicranopteris linearis, Paesia divaricatissima*
n. sp. 14	*Glochidion* sp., *Myrsine* sp.
n. sp. 16	*Hibiscus tiliaceus*
n. sp. 17	*Glochidion temehaniense*
n. sp. 18	*Metrosideros collina, Parasponia andersonii, Weinmannia parviflora*
n. sp. 19	*Alyxia* sp., *Metrosideros collina, Weinmannia parviflora*
rubroclavus	Unidentified ferns
tahiticus	*Adiantum capillus-veneris, Arachniodes aristata, Davallia denticulata, Dicranopteris linearis, Metrosideros collina, Paesia*

Species	Affiliated Plants
	divaricatissima
n. sp. 20	*Metrosideros collina*
n. sp 21	*Alstonia costata*
n. sp. 22	*Adiantum capillus-veneris, Dicranopteris linearis*
n. sp. 23	*Metrosideros collina*

Table 7 : Locality and plant association data for the 140 *Pseudoloxops* specimens included in this study.

Specimen Code/ GenBank Acc. #	AMNH	Locality	Island	Latitude (°)	Longitude (°)	Elevation (m)	Plant Association	Plant Division	CO 1	16S	28S	Morph.
INGROUP												
Z5	384431	Motu Uta	Tahiti	-17.5342	-149.5774	17.67	*Terminalia catappa*	Angiospermae	X	X	X	X
Z9	384427	Temehani	Raiatea	-16.7794	-151.4502	722.31	*Myrsine* sp.	Angiospermae				X
Z10	384426	Mt. Aorai	Tahiti	-17.5793	-149.51843	1019.36	*Weinmannia parviflora*	Angiospermae	X	X	X	X
Z11	384425	Mt. Taitaa	Tubuai	-23.3702	-149.46973	324.1	*Metrosideros collina*	Angiospermae	X	X	X	X
Z12	384424	Motu Pitiahe	Maupiti	-16.4811	-152.2479	16.95	*Hibiscus tiliaceus*	Angiospermae	X	X	X	X
Z13	384423	Mt. Nuupure	Maupiti	-16.446	-152.2506	133.99	*Triumfetta rhomboidea*	Angiospermae	X	X	X	X
Z14	384422	Mt. Pohuarahi	Huahine	-16.7809	-150.9763	469.49	*Mangifera indica*	Angiospermae	X	X	X	X
Z15	384421	Mt. Pohuarahi	Huahine	-16.7811	-150.9724	345	*Glochidion* sp.	Angiospermae	X	X	X	X
Z16	384420	Amaru	Rimatara	-22.6566	-152.7993	0.75	*Hibiscus tiliaceus*	Angiospermae	X	X	X	X
Z17	384445	Shore road	Huahine	-16.7296	-151.037	7.5	*Hibiscus tiliaceus*	Angiospermae		X	X	X
Z18	384444	Temehani	Raiatea	-16.7794	-151.4502	722.31	*Myrsine* sp.	Angiospermae	X	X	X	X
Z20	384442	Pic Vert	Tahiti	-17.5920	-149.5402	1131.83	*Weinmannia parviflora*	Angiospermae	X	X	X	X
Z21	384441	Mt. Aorai	Tahiti	-17.5798	-149.5179	1060.69	*Weinmannia parviflora*	Angiospermae	X	X	X	
Z25	384438	Pic Vert	Tahiti	-17.5892	-149.54218	1059.25	*Metrosideros collina*	Angiospermae	X	X	X	X
Z26	384437	Mt. Marau	Tahiti	-17.6142	-149.5297	1441.37	*Weinmannia parviflora*	Angiospermae	X	X	X	
Z28	384435	Mt. Pohuarahi	Huahine	-16.7809	-150.9763	469.49	*Mangifera indica*	Angiospermae	X	X	X	X
Z29	384434	Mt. Pohuarahi	Huahine	-16.7811	-150.9724	345	*Glochidion* sp.	Angiospermae	X	X	X	X
Z30	384433	Mt. Pohuarahi	Huahine	-16.7809	-150.9763	469.49	*Mangifera indica*	Angiospermae	X	X	X	X
Z31	384458	Mt. Pohuarahi	Huahine	-16.7807	-150.9736	375.28	*Metrosideros collina*	Angiospermae	X	X	X	X
Z32	384457	Shore road	Huahine	-16.7296	-151.037	7.5	*Hibiscus tiliaceus*	Angiospermae	X	X	X	X
Z33	384456	Mt. Pohuarahi	Huahine	-16.7809	-150.9763	469.49	*Mangifera indica*	Angiospermae	X	X	X	X
Z34	384455	Shore road	Huahine	-16.7331	-151.0008	90.25	*Hibiscus tiliaceus*	Angiospermae	X	X	X	X
Z36	384453	Shore road	Huahine	-16.7331	-151.0008	90.25	*Hibiscus tiliaceus*	Angiospermae	X	X	X	X
Z37	384452	Shore road	Huahine	-16.7331	-151.0008	90.25	*Hibiscus tiliaceus*	Angiospermae	X	X	X	X
Z38	384451	Shore road	Huahine	-16.7331	-151.0008	90.25	*Hibiscus tiliaceus*	Angiospermae		X	X	X
Z40	384449	Shore road	Raiatea	-16.8892	-151.4586	12.86	*Inocarpus fagifer*	Angiospermae	X	X	X	X
Z41	384448	Baie Faaroa	Raiatea	-16.8383	-151.4205	16.47	*Persea americana*	Angiospermae	X	X		X
Z46	384469	Mt. Aorai	Tahiti	-17.5792	-149.51844	1024.40	*Metrosoderos collina*	Angiospermae	X	X	X	X
Z48	384467	Mt. Aorai	Tahiti	-17.5792	-149.51844	1024.40	*Metrosoderos collina*	Angiospermae	X	X	X	X
Z49	384466	Mt. Aorai	Tahiti	-17.58	-149.51767	1049.16	*Weinmannia parviflora*	Angiospermae	X	X	X	X
Z50	384465	Mt. Aorai	Tahiti	-17.5792	-149.51849	1023.44	*Weinmannia parviflora*	Angiospermae	X	X	X	X
Z51	384464	Pic Vert	Tahiti	-17.5918	-149.54047	1120.77	*Myrsine* sp.	Angiospermae	X	X	X	X
Z54	384461	Mt. Pohuarahi	Huahine	-16.7809	-150.9763	469.49	*Mangifera indica*	Angiospermae	X	X	X	X
Z55	384460	Shore road	Huahine	-16.7296	-151.037	7.5	*Hibiscus tiliaceus*	Angiospermae	X	X	X	X
Z56	384459	Mt. Nuupure	Maupiti	-16.447	-152.2552	361.58	*Allophylus rhomboidalis*	Angiospermae	X	X	X	X

Specimen Code/ GenBank Acc. #	AMNH	Locality	Island	Latitude (°)	Longitude (°)	Elevation (m)	Plant Association	Plant Division	CO 1	16S	28S	Morph.
Z57	384484	Motu Pitiahe	Maupiti	-16.4811	-152.2479	16.95	*Hibiscus tiliaceus*	Angiospermae	X	X	X	X
Z58	384483	Shore road	Maupiti	-16.4508	-152.2512	71.51	*Inga feuillei*	Angiospermae		X	X	X
Z60	384482	Mt. Rotui	Moorea	-17.5087	-149.83916	875.88	*Metrosideros collina*	Angiospermae	X	X	X	X
Z61	384481	Temehani	Raiatea	-16.7749	-151.4537	661.03	*Myrsine* sp.	Angiospermae	X	X	X	X
Z62	384480	Temehani	Raiatea	-16.7794	-151.4502	722.31	*Myrsine* sp.	Angiospermae	X	X	X	X
Z63	384479	Baie Faaroa	Raiatea	-16.8329	-151.4206	8.54	*Inga feuillei*	Angiospermae	X	X	X	X
Z64	384478	Motu Uta	Tahiti	-17.5342	-149.5774	17.67	*Terminalia catappa*	Angiospermae	X	X	X	X
Z65	384477	Fare Hape	Tahiti	-17.6424	-149.4429	320.73	*Hibiscus tiliaceus*	Angiospermae	X	X	X	X
Z66	384476	Mt. Aorai	Tahiti	-17.5795	-149.51831	1043.15	*Metrosideros collina*	Angiospermae	X	X	X	X
Z67	384475	Pic Vert	Tahiti	-17.5918	-149.54047	1120.77	*Myrsine* sp.	Angiospermae		X		X
Z68	384474	Mt. Aorai	Tahiti	-17.58	-149.5179	1060.69	*Weinmannia parviflora*	Angiospermae	X	X	X	X
Z72	384496	Mt. Atiati	Moorea	-17.5364	-149.8697	420	*Alstonia costata*	Angiospermae	X	X	X	X
Z77	384491	Mt. Atiati	Moorea	-17.5369	-149.86831	449.8	Grasses	Angiospermae	X	X	X	X
Z78	384490	3 Cocos Trail	Moorea	-17.5488	-149.84109	287.6	Ferns	Pteridophyta	X	X	X	X
Z79	384489	Pihaena	Moorea	-17.4894	-149.84723	13.6	*Terminalia catappa*	Angiospermae	X	X	X	X
Z81	384487	Mt. Atiati	Moorea	-17.5360	-149.87161	470	Ferns	Pteridophyta	X	X	X	X
Z82	384486	Mt. Rotui	Moorea	-17.5077	-149.84005	845	*Alyxia* sp.	Angiospermae		X	X	X
Z84	384510	Temehani	Raiatea	-16.7749	-151.4537	661	*Myrsine* sp.	Angiospermae				X
Z85	384509	Temehani	Raiatea	-16.7727	-151.471	227	*Glochidion* sp.	Angiospermae		X		X
Z94	384507	Mt. Tohiea	Moorea	-17.5552	-159.81239	480	*Alyxia* sp.	Angiospermae	X	X	X	X
Z97	384504	Belvedere	Moorea	-17.5412	-149.82705	237.8	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z98	384503	Belvedere	Moorea	-17.5412	-149.82705	237.8	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z99	384502	Belvedere	Moorea	-17.5412	-149.82705	237.8	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z100	384501	Lava Tubes	Tahiti	-17.6289	-149.34993	716.5	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z101	384500	Lava Tubes	Tahiti	-17.6287	-149.35143	744.9	*Metrosideros collina*	Angiospermae	X	X	X	X
Z102	384499	Mt. Marau	Tahiti	-17.6126	-149.5306	1451.5	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z103	384498	Mt. Marau	Tahiti	-17.6129	-149.53053	1448.6	*Weinmannia parviflora*	Angiospermae	X	X	X	X
Z104	384523	Mt. Marau	Tahiti	-17.6117	-149.53122	1425.5	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z105	384522	Lava Tubes	Tahiti	-17.629	-149.33946	553.1	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z106	384521	Mt. Marau	Tahiti	-17.6117	-149.53122	1425.5	*Dicranopteris linearis*	Pteridophyta		X	X	X
Z107	384520	Mt. Marau	Tahiti	-17.6124	-149.53074	1443.3	*Weinmannia parviflora*	Angiospermae	X	X	X	X
Z108	384519	Mt. Marau	Tahiti	-17.6063	-149.54003	1328.7	*Davallia* sp.	Pteridophyta	X	X	X	X
Z109	384518	Lava Tubes	Tahiti	-17.6289	-149.34993	716.5	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z110	384517	Mt. Marau	Tahiti	-17.6107	-149.53191	1411.3	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z111	384516	Mt. Marau	Tahiti	-17.6117	-149.53122	1425.5	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z112	384515	Mt. Marau	Tahiti	-17.6126	-149.5306	1451.5	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z113	384514	Mt. Marau	Tahiti	-17.6074	-149.53719	1395.9	*Blechnum orientale*	Pteridophyta	X	X	X	X
Z114	384432	Lava Tubes	Tahiti	-17.6289	-149.34993	716.5	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z115	384513	Lava Tubes	Tahiti	-17.6288	-149.34806	696.4	*Metrosideros collina*	Angiospermae	X	X	X	X
Z116	384512	Mt. Marau	Tahiti	-17.6063	-149.53967	1327.7	*Weinmannia parviflora*	Angiospermae	X	X	X	X
Z117	384511	Lava Tubes	Tahiti	-17.629	-149.33946	553.1	*Dicranopteris linearis*	Pteridophyta	X	X	X	X

Specimen Code/ GenBank Acc. #	AMNH	Locality	Island	Latitude (°)	Longitude (°)	Elevation (m)	Plant Association	Plant Division	CO 1	16S	28S	Morph.
Z118	384536	Mt. Marau	Tahiti	-17.6117	-149.53122	1425.5	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z119	384535	Lava Tubes	Tahiti	-17.6288	-149.34806	696.4	*Metrosideros collina*	Angiospermae	X	X	X	X
Z120	384534	Lava Tubes	Tahiti	-17.629	-149.33946	553.1	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z121	384533	Mt. Aorai	Tahiti	-17.5933	-149.50104	1433	*Leptecophylla pomarae*	Angiospermae	X	X	X	X
Z122	384532	Mt. Aorai	Tahiti	-17.5933	-149.50104	1433	*Leptecophylla pomarae*	Angiospermae	X	X	X	X
Z123	384531	Mt. Aorai	Tahiti	-17.5933	-149.50104	1433	*Leptecophylla pomarae*	Angiospermae	X	X	X	X
Z124	384530	Mt. Aorai	Tahiti	-17.5937	-149.50056	1448.8	*Weinmannia parviflora*	Angiospermae	X	X	X	X
Z125	384529	Mt. Aorai	Tahiti	-17.596	-149.49832	1628.6	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z126	384528	Mt. Aorai	Tahiti	-17.601	-149.49371	1863.9	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z127	384527	Mille Sources	Tahiti	-17.5859	-149.46795	863.6	*Arachniodes aristata*	Pteridophyta	X	X	X	X
Z128	384526	Mille Sources	Tahiti	-17.5872	-149.46644	1119.3	*Weinmannia parviflora*	Angiospermae	X	X		X
Z129	384525	Mille Sources	Tahiti	-17.5859	-149.46795	863.6	*Davallia denticulata*	Pteridophyta	X	X	X	X
Z130	384524	Mt. Aorai	Tahiti	-17.6108	-149.49447	2028.5	*Leptecophylla pomarae*	Angiospermae	X	X	X	X
Z131	384549	Pic Vert	Tahiti	-17.5909	-149.54143	1096.5	*Vaccinium cereum*	Angiospermae		X	X	X
Z132	384548	Taravao	Tahiti	-17.7985	-149.23677	1215.2	*Ascarina polystachya*	Angiospermae	X	X	X	X
Z133	384547	Mille Sources	Tahiti	-17.5872	-149.46645	1119.3	*Parasponia andersonii*	Angiospermae	X	X	X	X
Z134	384546	Taravao	Tahiti	-17.7835	-149.2482	760.3	*Metrosideros collina*	Angiospermae	X	X	X	X
Z135	384545	Mt. Aorai	Tahiti	-17.5943	-149.5001	1490.2	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z136	384544	Mt. Aorai	Tahiti	-17.5966	-149.4981	1663.4	*Paesia divaricatissima*	Pteridophyta				X
Z137	384543	Taravao	Tahiti	-17.7868	-149.2475	792	*Metrosideros collina*	Angiospermae	X	X	X	X
Z138	384542	Mt. Aorai	Tahiti	-17.601	-149.49371	1863.9	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z139	384541	Mt. Aorai	Tahiti	-17.601	-149.49371	1863.9	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z140	384540	Mt. Aorai	Tahiti	-17.6033	-149.49396	1885.7	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z141	384539	Pic Vert	Tahiti	-17.5921	-149.54014	1107.1	*Paesia divaricatissima*	Pteridophyta	X		X	X
Z142	384538	Mt. Aorai	Tahiti	-17.601	-149.49371	1863.9	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z143	384537	Mille Sources	Tahiti	-17.5501	-149.47223	623.3	*Adiantum capillus-veneris*	Pteridophyta	X	X	X	X
Z144	384692	Mille Sources	Tahiti	-17.5873	-149.46629	1141	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z145	384691	Mille Sources	Tahiti	-17.5501	-149.47223	623.3	*Adiantum capillus-veneris*	Pteridophyta	X	X	X	X
Z146	384690	Mille Sources	Tahiti	-17.5501	-149.47223	623.3	*Adiantum capillus-veneris*	Pteridophyta	X	X	X	X
Z147	384689	Mt. Aorai	Tahiti	-17.6018	-149.4937	1873	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z148	384688	Mt. Aorai	Tahiti	-17.5957	-149.4984	1615.4	*Leptecophylla pomarae*	Angiospermae	X	X	X	X
Z149	384687	Mt. Aorai	Tahiti	-17.5957	-149.4984	1615.4	*Leptecophylla pomarae*	Angiospermae	X	X	X	X
Z150	384686	Taravao	Tahiti	-17.7882	-149.24886	837.2	*Metrosideros collina*	Angiospermae	X	X	X	X
Z151	384685	Taravao	Tahiti	-17.7868	-149.24749	792	*Metrosideros collina*	Angiospermae	X	X	X	X
Z152	384684	Mille Sources	Tahiti	-17.576	-149.47	864.8	*Adiantum capillus-veneris*	Pteridophyta	X	X	X	X
Z153	384683	Mille Sources	Tahiti	-17.5859	-149.46795	863.6	*Arachniodes aristata*	Pteridophyta	X	X	X	X
Z154	384682	Mille Sources	Tahiti	-17.5872	-149.46644	1119.3	*Weinmannia parviflora*	Angiospermae	X	X	X	X
Z155	384681	Mille Sources	Tahiti	-17.5872	-149.46644	1119.3	*Parasponia andersonii*	Angiospermae	X	X	X	X
Z156	384680	Mille Sources	Tahiti	-17.5872	-149.46644	1119.3	*Metrosideros collina*	Angiospermae	X	X	X	X
Z157	384705	Mille Sources	Tahiti	-17.5872	-149.46644	1119.3	*Parasponia andersonii*	Angiospermae	X	X	X	X

Specimen Code/ GenBank Acc. #	AMNH	Locality	Island	Latitude (°)	Longitude (°)	Elevation (m)	Plant Association	Plant Division	CO 1	16S	28S	Morph.
Z158	384704	Taravao	Tahiti	-17.7868	-149.24749	792	*Metrosideros collina*	Angiospermae	X	X	X	X
Z159	384703	Taravao	Tahiti	-17.7868	-149.24749	792	*Metrosideros collina*	Angiospermae	X	X	X	X
Z160	384702	Taravao	Tahiti	-17.7868	-149.24749	792	*Metrosideros collina*	Angiospermae	X	X	X	X
Z161	384701	Taravao	Tahiti	-17.7868	-149.24749	792	*Metrosideros collina*	Angiospermae	X	X	X	X
Z162	384700	Taravao	Tahiti	-17.7868	-149.24749	792	*Metrosideros collina*	Angiospermae	X	X	X	X
Z163	384699	Mt. Aorai	Tahiti	-17.601	-149.49371	1863.9	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z164	384698	Taravao	Tahiti	-17.7868	-149.24749	792	*Metrosideros collina*	Angiospermae	X	X	X	X
Z165	384697	Taravao	Tahiti	-17.7868	-149.24749	792	*Metrosideros collina*	Angiospermae	X	X	X	X
Z166	384696	Taravao	Tahiti	-17.7868	-149.24749	792	*Metrosideros collina*	Angiospermae	X	X	X	X
Z167	384695	Taravao	Tahiti	-17.7868	-149.24749	792	*Metrosideros collina*	Angiospermae	X	X	X	X
Z168	384694	Taravao	Tahiti	-17.7868	-149.24749	792	*Metrosideros collina*	Angiospermae	X	X	X	X
Z169	384963	Taravao	Tahiti	-17.7868	-149.24749	792	*Metrosideros collina*	Angiospermae	X	X	X	X
Z170	384718	Mt. Aorai	Tahiti	-17.601	-149.49371	1863.9	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z171	384717	Mt. Aorai	Tahiti	-17.5943	-149.50006	1490.2	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z172	384716	Mt. Aorai	Tahiti	-17.601	-149.49371	1863.9	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z173	384715	Mt. Aorai	Tahiti	-17.5957	-149.49840	1615.4	*Leptecophylla pomarae*	Angiospermae	X	X	X	X
Z201	384714	Mt. Aorai	Tahiti	-17.596	-149.49832	1628.6	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z203	384713	Mt. Aorai	Tahiti	-17.596	-149.49832	1628.6	*Dicranopteris linearis*	Pteridophyta	X	X	X	X
Z204	384712	Mt. Aorai	Tahiti	-17.6037	-149.49423	1913.1	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z205	384711	Tapuamu	Tahaa	-16.6265	-151.52383	171	*Nephrolepis hirsutula*	Pteridophyta		X	X	X
Z206	384710	Tapuamu	Tahaa	-16.6265	-151.52383	171	*Nephrolepis hirsutula*	Pteridophyta	X	X	X	X
Z208	384709	Mt. Aorai	Tahiti	-17.6018	-149.49371	1873	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z210	384708	Mt. Aorai	Tahiti	-17.6033	-149.49396	1885.7	*Paesia divaricatissima*	Pteridophyta	X	X	X	X
Z211	384707	Mt. Turi	Huahine	-16.7211	-151.0158	419	*Metrosideros collina*	Angiospermae	X	X	X	X
Z212	384731	Mt. Pohuarahi	Huahine	-16.7806	-150.9746	414	*Glochidion temehaniense*	Angiospermae	X	X		X
Z213	384706	Tapuamu	Tahaa	-16.6265	-151.52383	171	*Nephrolepis hirsutula*	Pteridophyta	X	X	X	X
Z313	N/A	Temehani	Raiatea	N/A	N/A	660	*Astronidium saccatum*	Angiospermae				X

Table 8: Support and character transformation at each speciation event.

Speciation Event	Posterior Probability	Plant Order Affiliation	Island Distribution
A	1.0	Switch	Equivocal
B	0.93	Equivocal	Equivocal
C	1.0	Equivocal	No Change
D	0.98	Equivocal	Switch
E	0.86	No Change	No Change
F	0.60	Not Supported	Not Supported
G	1.0	No Change	No Change
H	0.87	Switch	No Change
I	0.98	Switch	No Change
J	0.81	Equivocal	Switch
K	1.0	Eqivocal	Equivocal
L	1.0	No Change	Equivocal
M	0.69	Not Supported	Not Supported
N	0.50	Not Supported	Not Supported
O	1.0	Switch	No Change

Table 9 : Transformation of plant order affiliation associated with speciation events.

Node/Speciation Event	Before Speciation	After Speciation
A	Myrtales	Malvales
E	Ericales	Ericales
G	Polypodiales	Polypodiales
H	Polypodiales	Ericales
I	Polypodiales	Glecheniales
L	Myrtales	Myrtales
O	Myrtales	Rosales

Table 10: Transformation of ancestral island distribution associated with speciation events

Node/Speciation Event	Before Speciation	After Speciation
C	Tahiti	Tahiti
D	Tahiti	Moorea
E	Tahiti	Tahiti
G	Tahiti	Tahiti
H	Tahiti	Tahiti
I	Tahiti	Tahiti
J	Tahiti	Raiatea
O	Tahiti	Tahiti

Table 11: Contingency Table showing character transformations for both plant order affiliation and island distribution for all 12 statistically supported speciation events.

	Plant Switch	Plant No Change	Plant Equivocal
Island Switch	0	0	2
Island No Change	3	2	1
Island Equivocal	1	1	2

Table 12: Plant order affiliation and island distribution character states associated with speciation (→ symbol separates character states before and after speciation)

Node	Plant Order	Island Distribution
E	Ericales→Ericales	Tahiti→Tahiti
G	Polypodiales→Polypodiales	Tahiti→Tahiti
H	Polypodiales→Ericales	Tahiti→Tahiti
I	Polypodiales→Glecheniales	Tahiti→Tahiti
O	Myrtales→Rosales	Tahiti→Tahiti

Figure 1: Map of French Polynesia; inset map shows location of French Polynesia in the Pacific Ocean.

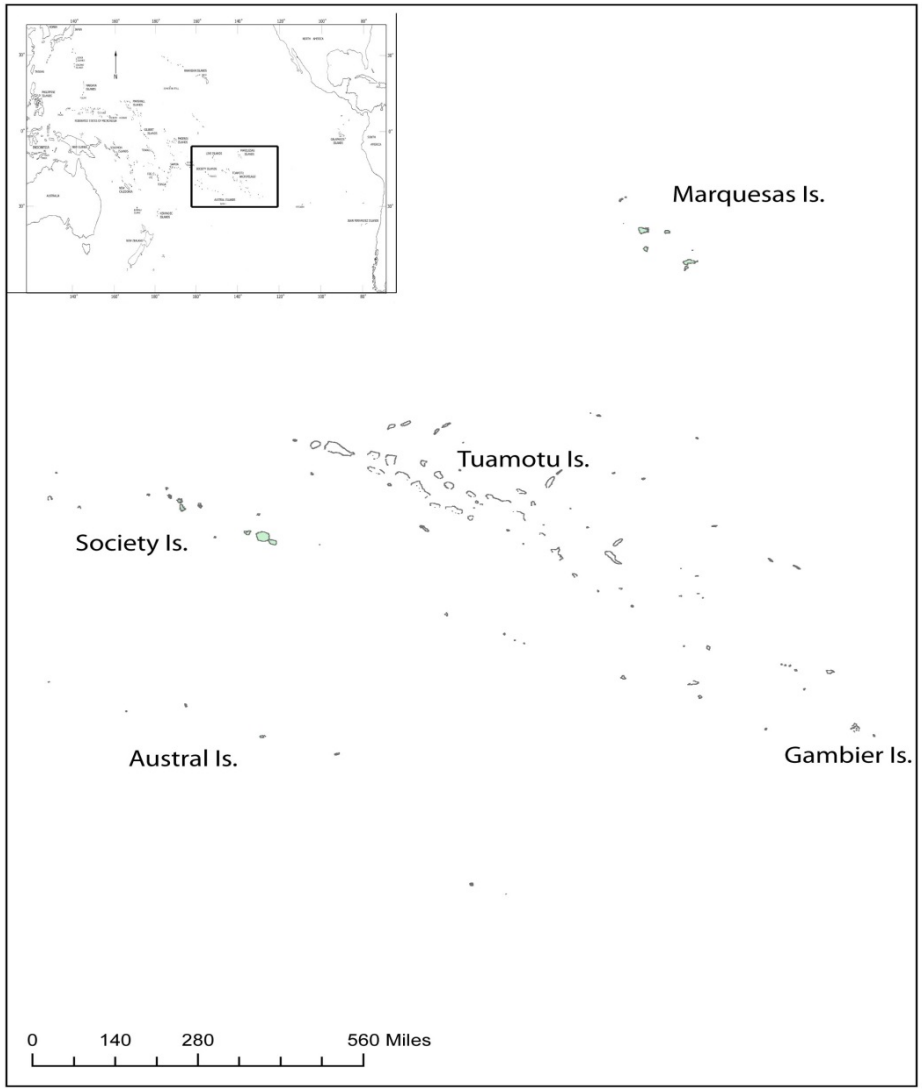

Figure 2: Map of the (a) Society and (b) Austral Islands.

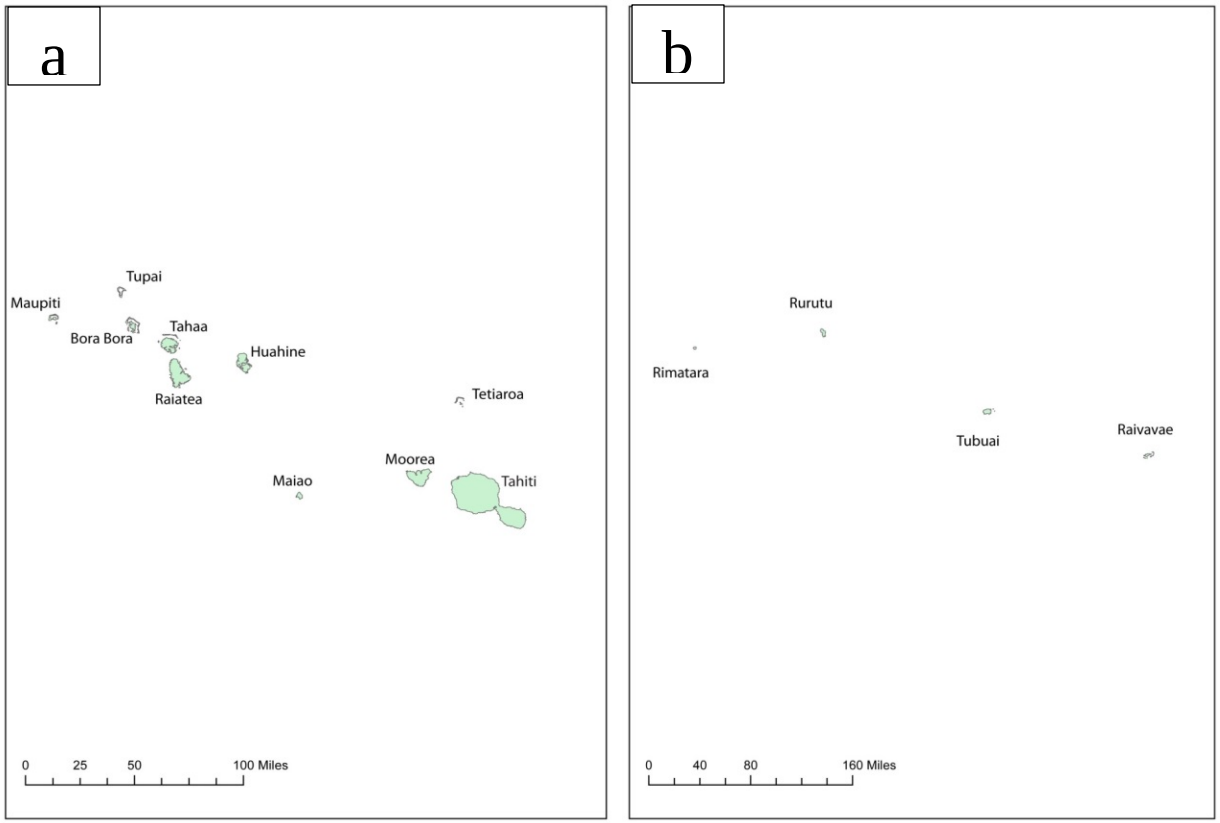

Figure 3: *Pseudoloxops tahiticus*, one of 26 species endemic to French Polynesia.

Figure 4: 50% majority-rules consensus molecular Bayesian tree (3 genes combined) for all ingroup and outgroup specimens. Outgroups are coded with letters as follows: A=*Lopidea bullata*; B=*Pseudoloxops ayutthaya*; C=*Orthotylus sophoroides*; D=*Pseudoloxops sp.*; E=*Pseudopsallus angularis*; F=*Blepharidopteris chlorionis*; G=*Orthotylus rossi*; H=*Pseudopsallus viridicans*; I=*Pseudoloxops takaii*; J=*Pseudoloxops sp.;* K=*Pseudoloxops sp.*

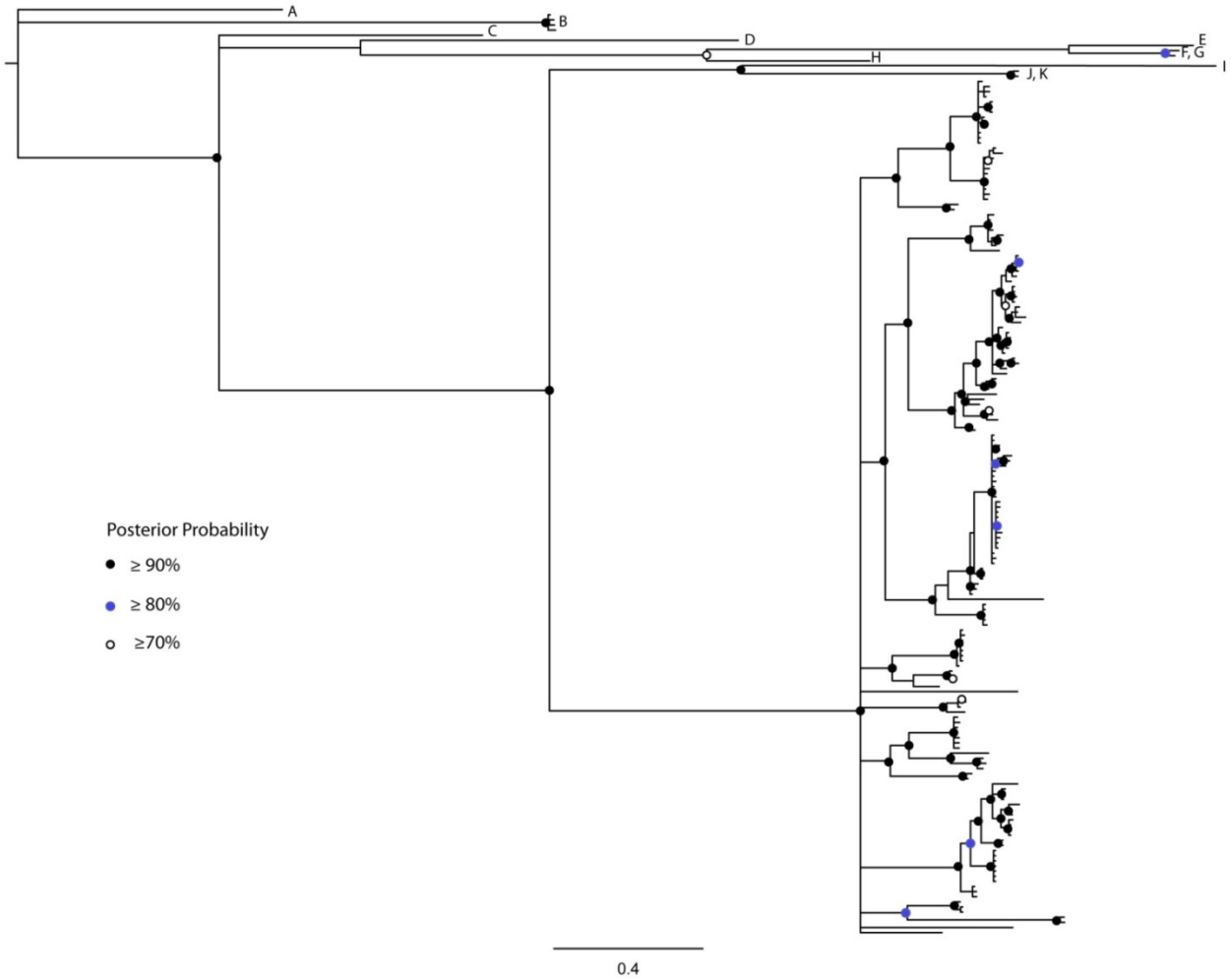

Figure 5: Cladogram of all 140 specimens with plant association data. Speciation events are labeled A-O at nodes. Posterior probabilites are given at each node.

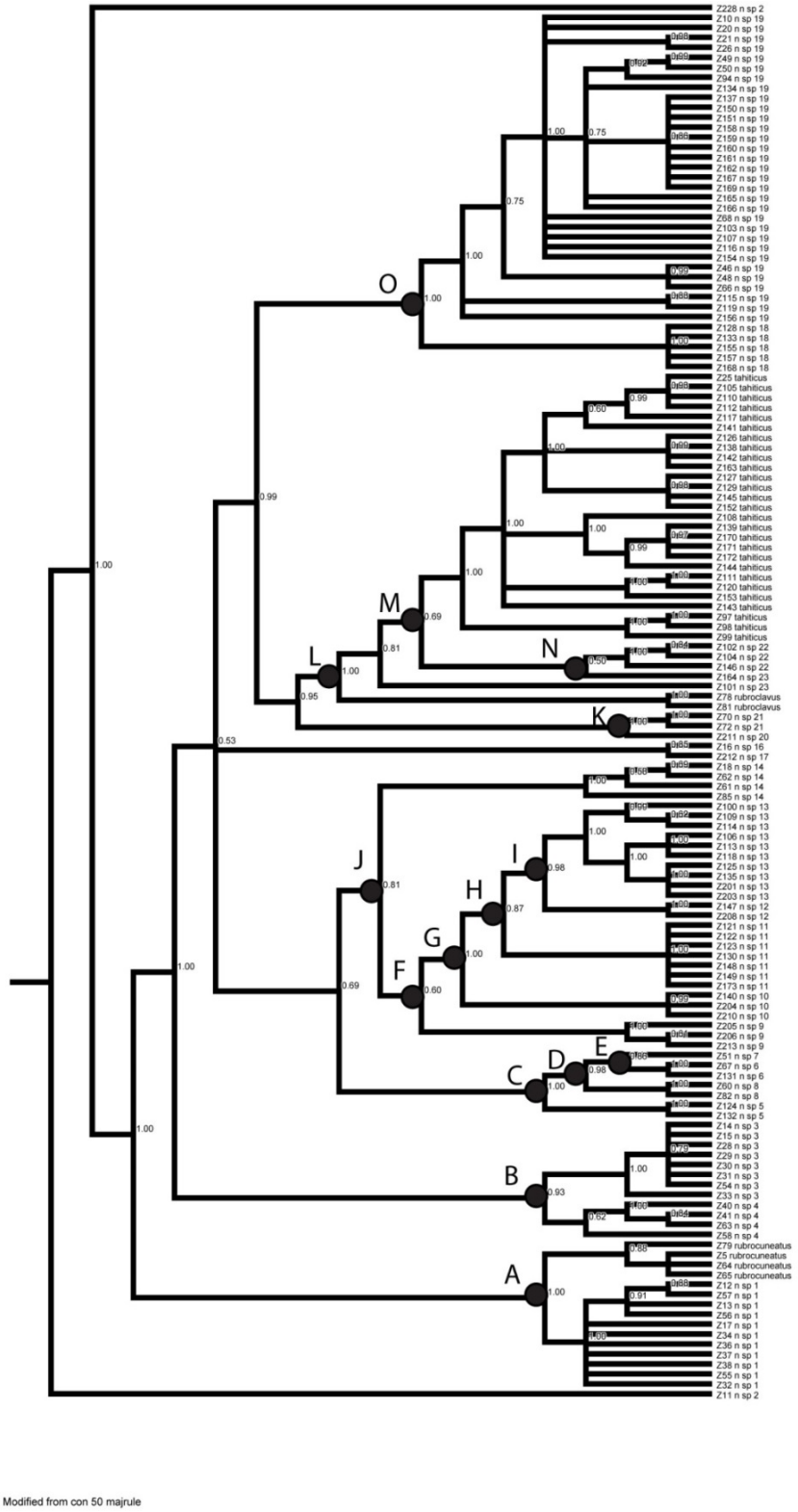

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Figure 6: Cladogram with the character of plant division association mapped on and ancestral states reconstructed. Speciation events are marked A-O and posterior probabilites are indicated at nodes.

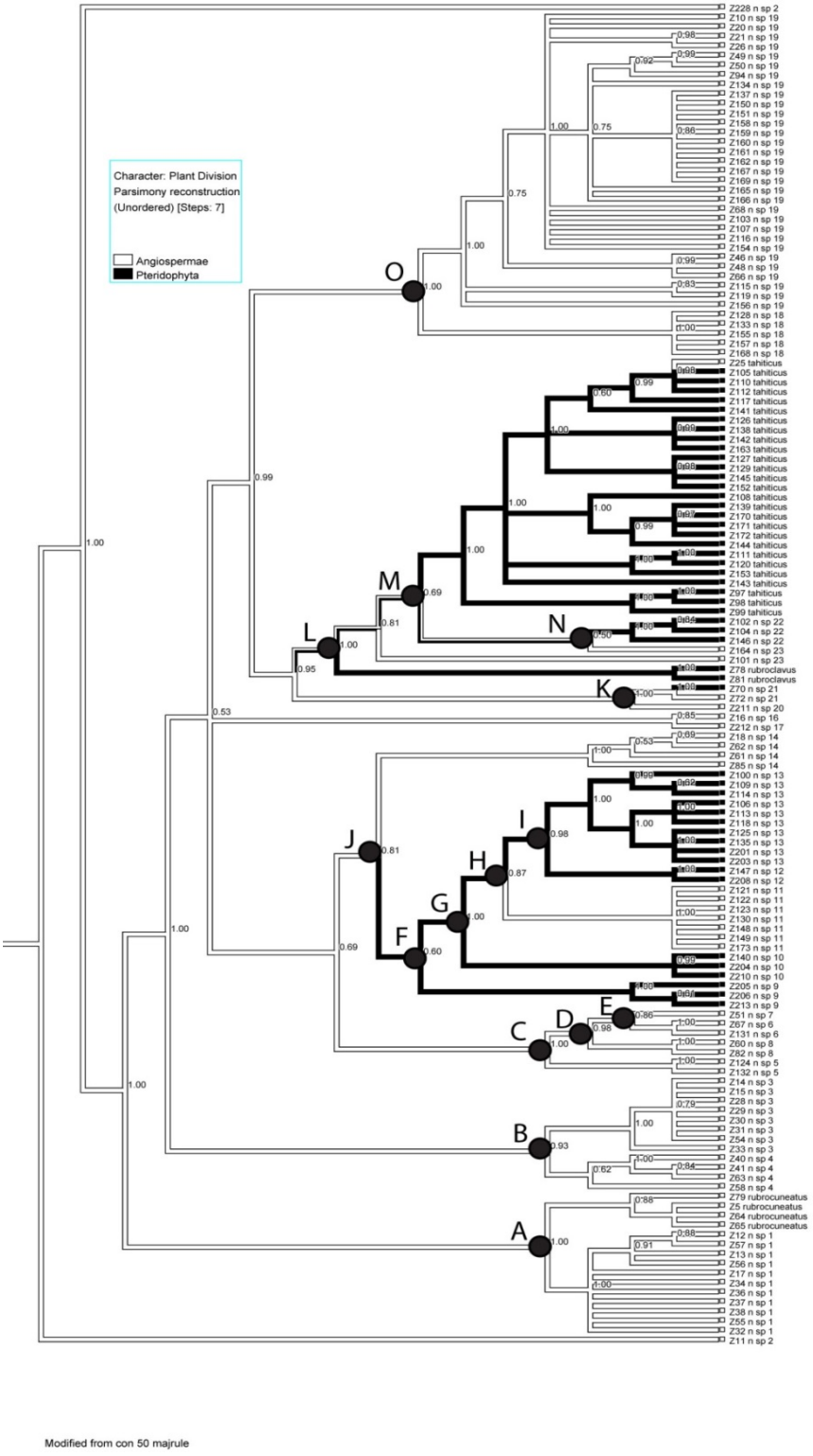


Figure 7: Cladogram with the character of plant order association mapped on and ancestral states reconstructed. Speciation events are marked A-O and posterior probabilites are indicated at nodes.

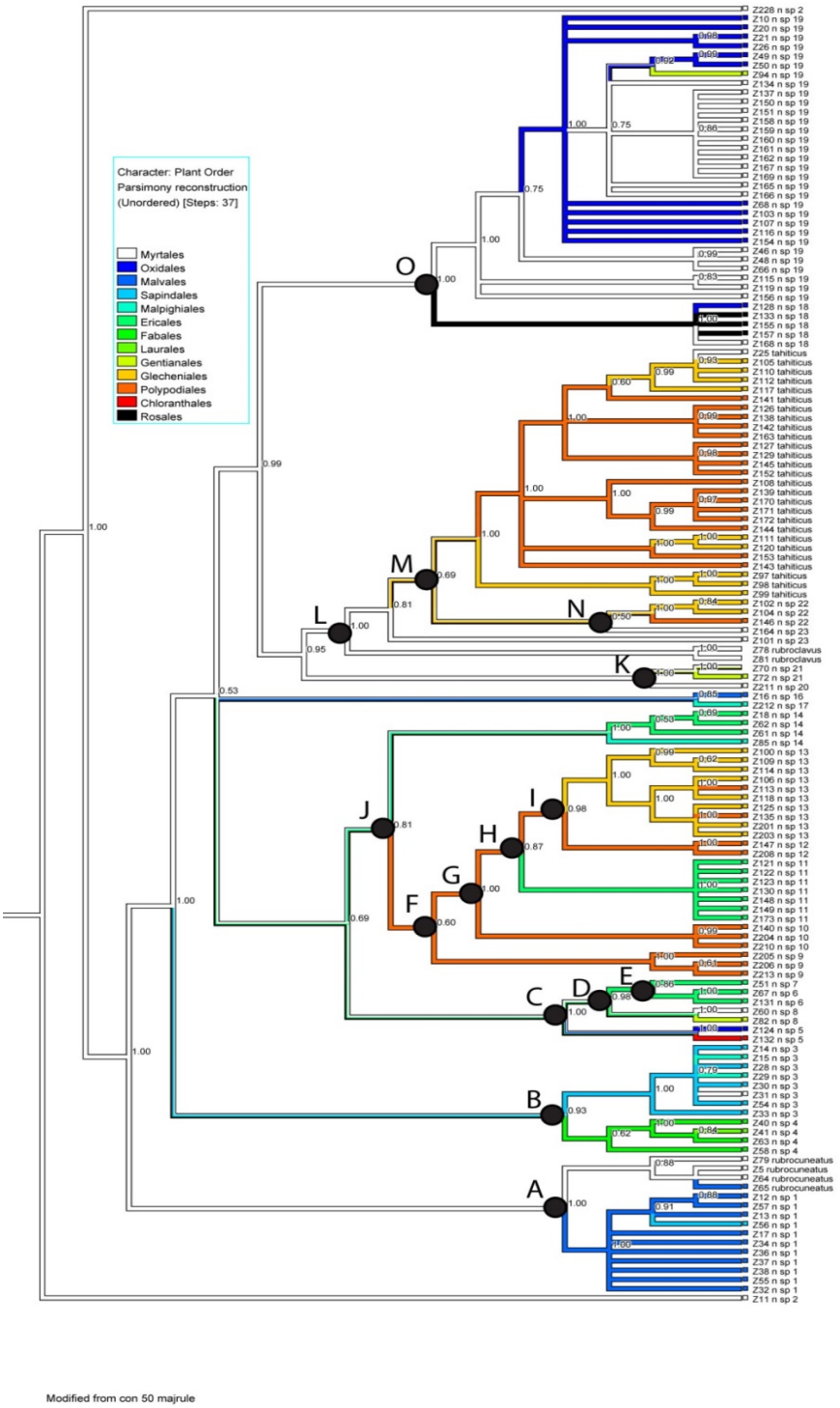


Figure 8: Cladogram with the character of plant family association mapped on and ancestral states reconstructed. Speciation events are marked A-O and posterior probabilites are indicated at nodes.

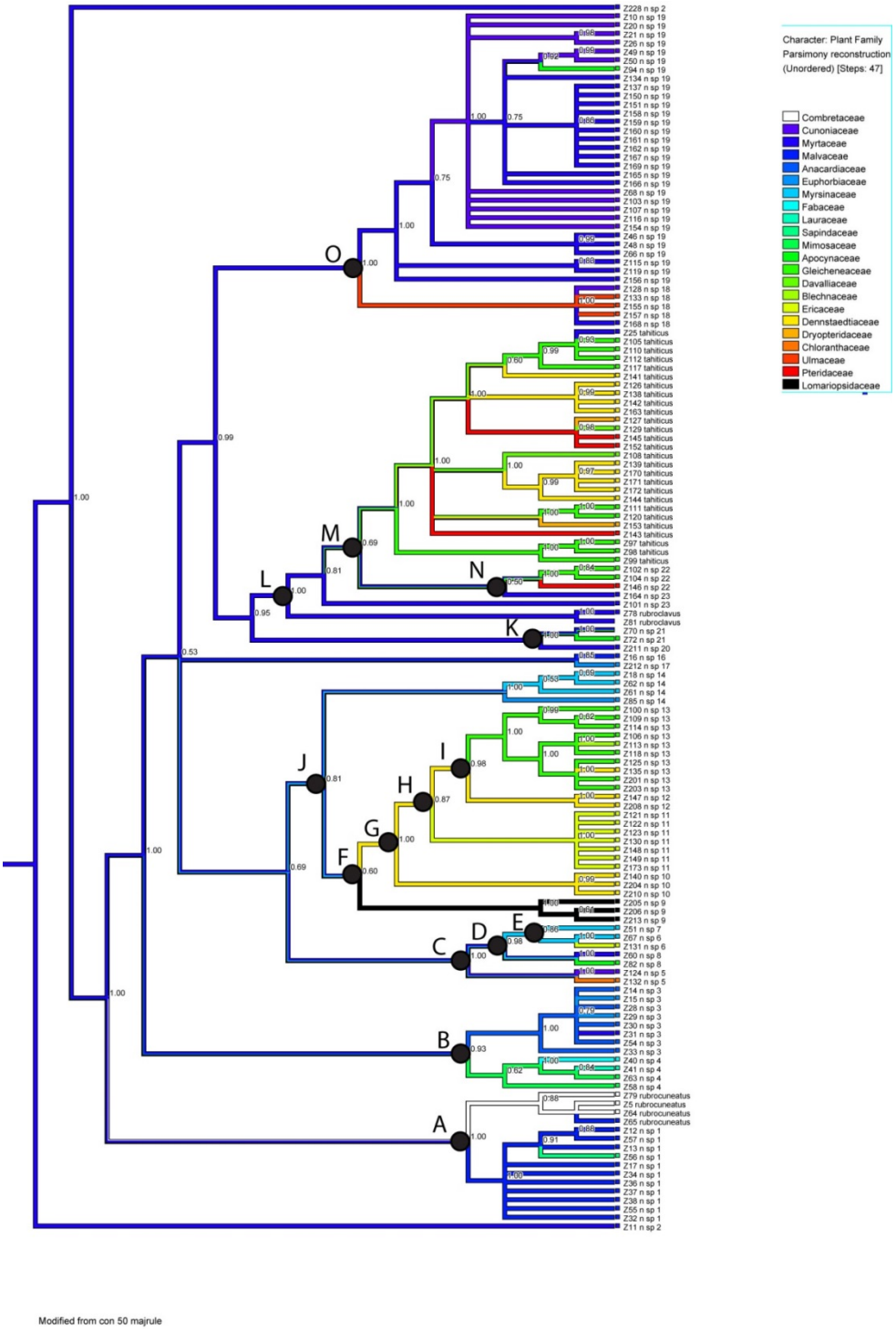


Figure 9: Cladogram with the character of island distribution mapped on and ancestral states reconstructed. Speciation events are marked A-O and posterior probabilites are indicated at nodes.

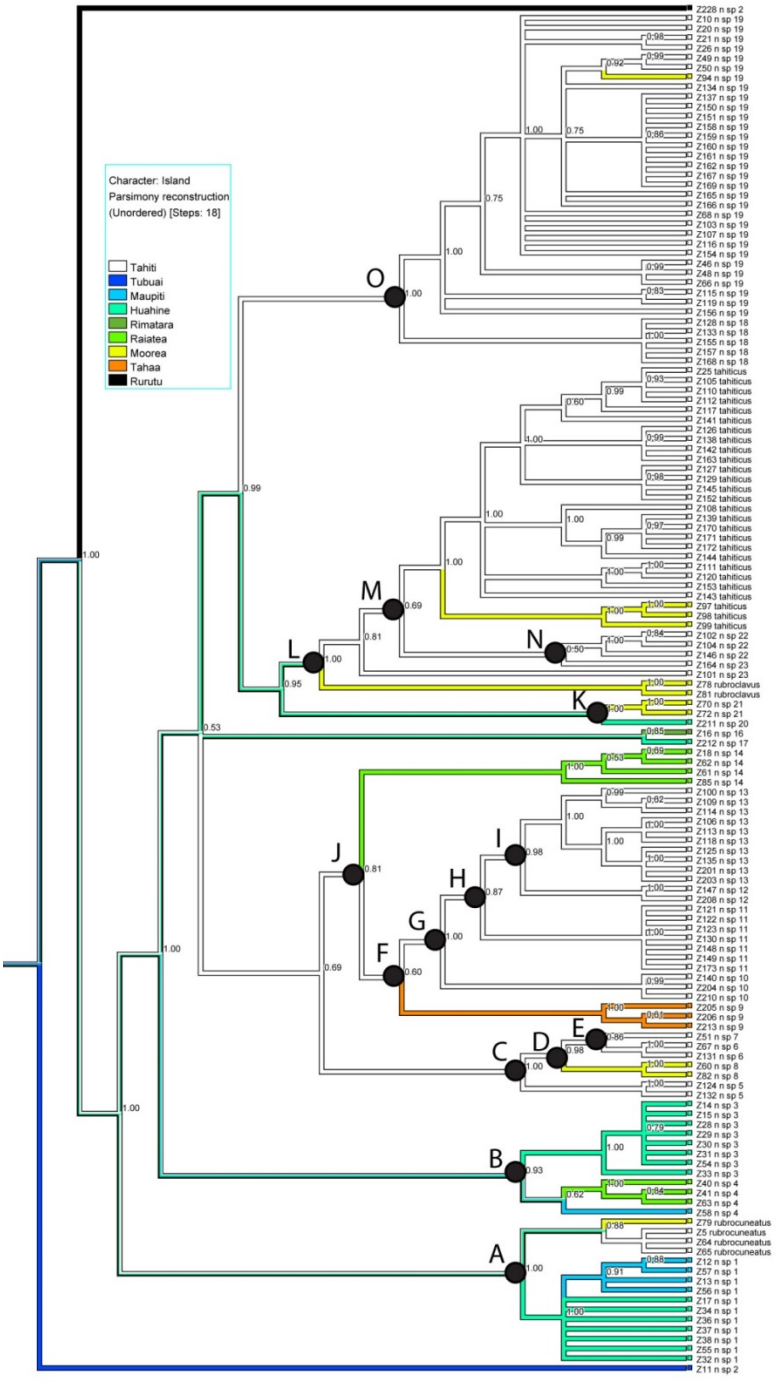
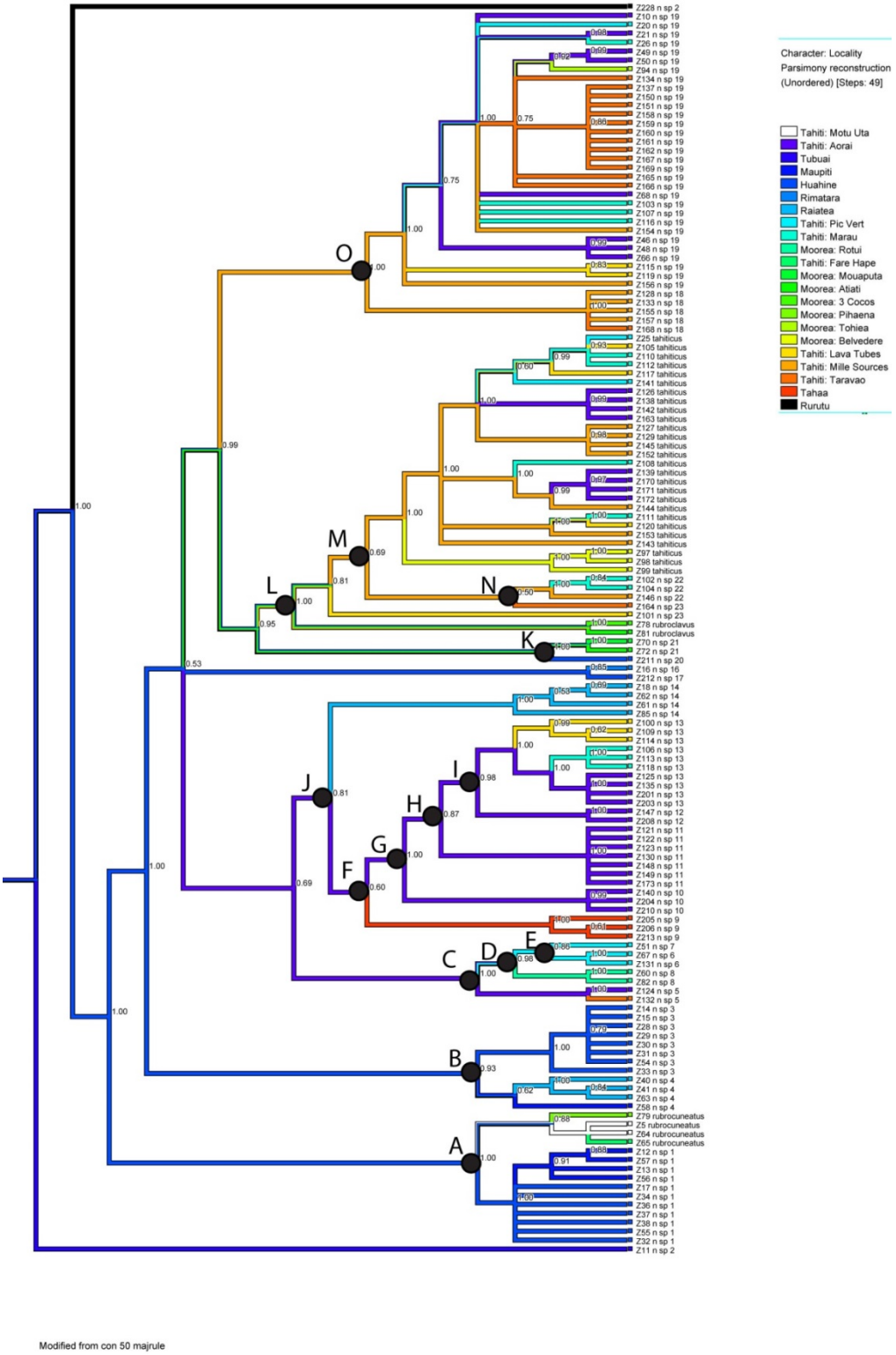


Figure 10: Cladogram with the character of locality mapped on and ancestral states reconstructed. Speciation events are marked A-O and posterior probabilites are indicated at nodes.



CHAPTER 3

A natural-history based curriculum focusing on (formerly!) uncharismatic organisms increases scientific knowledge in elementary-school children in French Polynesia

Introduction

Natural history, the observation and description of biodiversity and the natural world, provides the foundation for all of the rest of the biological sciences (Ricklefs, 2012). Despite being marginalized by much of the university academic community (Wilcove & Eisner, 2000; Cotterill & Foissner, 2010), natural history remains an important part of science education, especially at the elementary school level, when children demonstrate an innate curiosity and affinity for nature (Kahn & Kellert, 2002). As Schmidley (2005) writes in an essay on natural history's future:

> Another important step would be to reinstate natural history studies in elementary and secondary schools. Many children are fascinated by plants and animals, and, if nurtured by adults, this can become a lifelong joy or even a career path. Untended, it usually atrophies as a child grows older. Meanwhile, the demise of natural history goes unnoticed, increasing the likelihood that future generations of schoolchildren will spend even more time indoors, clicking away on their plastic mice, happily viewing images of the very plants and animals they could be finding in the woods, streams, and meadows they no longer visit. (p. 454)

Despite the onslaught of technological distractions produced by our increasingly urbanized society (Louv, 2005), direct experience with natural history has been shown to have a positive effect on children; for example, a group of fifth-graders in Washington State felt an increased connection and more positive outlook on nature after spending three days at an environmental education program in North Cascades National Park (Burgess & Mayer-Smith, 2011). In addition to shifts in attitude, experience with nature and organisms can also lead to increases in environmental or scientific knowledge. In one study of fifth-graders in rural California, a two-to-three-day outdoor science education program including such activities as collecting grasshoppers and tracking nocturnal mammals led to increases in knowledge of local biodiversity (Migliarese, 2011). Even short experiences in nature, such as a one-day field trip to the Smoky Mountains National Park, yielded substantial long-term gains, as a group of fourth-graders from Tennessee retained much of the scientific knowledge gained from the experience when tested a year later (Farmer *et al.*, 2007). These studies support the biophilia hypothesis, the notion that human beings have an innate fondness for the natural world because of our evolutionary connection to it (Kellert & Wilson, 1995), and demonstrate that appeals to biophilia can produce gains in knowledge in addition to changes in attitude.

Much of the research on the effect of natural history on scientific knowledge has occurred in areas where Western science is the prevailing paradigm. We sought to extend this area of research by testing for this effect in a place that combines Western science with indigenous culture. The 118 islands of French Polynesia are a territory of France (officially an "overseas collectivity;" Central Intelligence Agency, 2013) located in the southern Pacific Ocean (Figure 1), approximately 6,000 km from the nearest continent (Gabrie *et al.*, 2006). These islands were initially colonized by Polynesians around 800 A.D. (Kirch & Kahn, 2007) and were not settled by Europeans until Samuel Wallis' arrival in Tahiti in 1767 (Pearson, 1969). The French have had possession of the islands since 1842, and despite suppressing indigenous Tahitian culture for most of the time since, a renaissance of these traditions in the past 30 years has created a truly hybrid culture (Saura, 2008). Unlike in places like Hawaii, where the indigenous language and a

genetically distinct Hawaiian lineage are highly endangered, 78% of French Polynesians are ethnically Tahitian (CIA, 2013; these data are approximate because the national census no longer collects data on race) and speak both a Polynesian language (there are several) and French fluently.

The educational system in French Polynesia is modeled after that of France, with some local modifications (Ministère de l'Education, de la Jeunesse et des Sports, 2013). Of the 23 Pacific Island countries and territories, French Polynesia's educational system has produced one of the highest literacy rates, at 98% (CIA, 2013). This is largely due to the enormous amount of financial aid from France, while many of the independent Pacific Island nations struggle for adequate funding (Coxon & Munce, 2008). In 1992, French Polynesia adopted a charter of education ("*la Charte de l'education*") that outlined the territory's educational commitment and goals, and mandated that all children between the ages of 5 and 16 be enrolled in school.

The public education system in French Polynesia is divided into three phases: *primaire* (elementary, grades 1-5); *collège* (middle school, grades 6-9); and *lycée* (high school, grades 10-12). The ultimate degree in this system is the *Baccalauréat* (*bac*), or high school diploma. For those students with learning difficulties or vocational career goals, there is an alternate path that ends with a different type of degree (Ministère de l'Education, de la Jeunesse et des Sports, 2013). Those wishing to continue into higher education enroll at the Université de la Polynésie française (University of French Polynesia) or go abroad for their university education.

Although data on the efficacy of the public education system are not easy to find (and data specific to science were unavailable), certain publicly available statistics provide a general sense of its status. The most recent territorial census, conducted in 2007, indicated that of people between the ages of 20-29, only 33.8% had their *bac* (Institut de la statistique de la Polynésie française, 2013a). While this may seem low, it represents a large improvement over past generations; for example, of people aged 50-59, only 21.1% had their *bac* (ISPF, 2013a). However, there is still much room for improvement, as only half as many French Polynesians between the ages of 20-24 have earned their *bac* as have in mainland France (Merceron, 2011). The downstream effect of not earning the *bac* is also evident, as the unemployment rate for those without a *bac* is about 1.5 times higher than those with a *bac* (15.9% vs. 10.8%; Merceron, 2011). In particular, the transition from elementary school into middle school is a precarious time for many French Polynesian schoolchildren. A recent study of dropout rates showed that the rate is higher in middle school (8.32%) than in high school (7.42%), and both are higher than in mainland France (5.71% and 2.71% respectively; Pastor & Taeatua, 2009). Due to the importance of this age group, we focused our study on students in the final year of elementary school, or fifth grade (*CM2*). The aforementioned statistics illustrate the need for improvement in local education overall, with our study aimed at addressing science education at the elementary school level.

Study Site and Local Scientific Infrastructure

The island of Moorea is the third largest of French Polynesia's Society Islands, and is only 16 km from the capital island of Tahiti (Demougeot, 2007; Figure 2). There are seven elementary schools on the island, including the Pao Pao elementary school, the site for this study; the eponymous town has a population of 4,583 (ISPF, 2013b; Commune de Moorea-Maiao, 2013).

The Pao Pao school was chosen for its proximity to UC Berkeley's Gump Biological Research Station. This study was conducted during the 2008-09 school year under the auspices of the National Science Foundation's GK-12 program ("GK-12: Exploring Moorea's Biodiversity"). The lead author was the sole science instructor from October 2008-June 2009, comprising most of the academic year.

The science curriculum in elementary school is limited to a minimum of one hour per week taught by a single teacher, who is also responsible for other subjects (French, social studies, math, reading, writing; Direction de l'Enseignement Primaire, 2013). The territory's Ministry of Education provides guidelines and standards for the subjects to be covered in fifth-grade science, although there is no national standardized testing on science at this level. Furthermore, science is grouped with technology, and therefore there is little opportunity to cover specialized topics in any great depth. Outside of this limited classroom exposure, there is little opportunity for students to engage with science in the local area. Scientific infrastructure in French Polynesia is generally poor, especially for general biology and natural history. What does exist is geared towards the marine realm (understandably so, as marine diversity is proportionally much higher here than terrestrial) and towards the practical utility of biodiversity (biomedical research, plant chemistry for commercial products) rather than basic scientific knowledge. For example, at the University of French Polynesia (the only higher education institution in the country), there are no professors specializing in the biodiversity of terrestrial animals or plants (l'Université de la Polynésie française, 2013). The only professional organization dedicated to basic scientific research is the government's *Délégation à la Recherche*, which employs one full-time biologist and one full-time chemist.

While French Polynesian children may have a limited understanding of Western science and its methods, they do have an intrinsic appreciation for biodiversity, due largely to the importance of many plants and animals in indigenous Tahitian culture. There is a strong ethnobotanical tradition in the culture, and marine fish and invertebrates provided important food sources in ancient times (Petard & Florence, 1986). One of our goals in this project was to merge Western scientific knowledge of local biodiversity with the existing appreciation for that biodiversity, with the potential to boost scientific understanding overall.

In addition to testing the utility of natural history in a novel educational environment, we also sought to examine the appeal of groups of organisms that are often considered less interesting or desirable to children. Children tend to prefer large animals like mammals over organisms like insects, and generally, prefer animals over plants (Kellert, 1993; Ward *et al.*, 1998). Yet plants and insects are among the most tractable organisms for collection, handling, and study. We focused our curriculum on the natural history and biodiversity of insects and plants to see how students would respond, given the taxonomic biases noted in the literature. Although depauperate when compared to mainland ecosystems in similar biomes, Moorea contains considerable insect and plant diversity, with 900 known flowering plant species and an estimated 600 insect species (George Roderick, personal communication). The course we taught included several field trips and emphasized hands-on experience collecting, identifying, and curating insect and plant specimens. Each lesson addressed some aspect of the national education standards for science education while exposing students to factual, conceptual, and procedural forms of knowledge (Krathwohl, 2002). A short evaluation covering all three types of scientific knowledge was given

to an experimental and a control group before and after the course. The experimental group was also given the same evaluation three years after the end of the course ("delayed post-test") to test for their long-term retention, as well as a qualitative survey addressing their attitudes towards science. We tested, as the central hypothesis, that the students participating in the course (the experimental group) would have significantly greater gains in scientific knowledge than the control group.

Materials and Methods

At the start of October, 2008, the lead author began teaching weekly science lessons in French (not his native language) to two fifth-grade classes ("CM2A" and "CM2B") at the Pao Pao elementary school and continued through the end of June, 2009. Lessons were an hour long and grouped into two units: plants and insects. In addition to 27 one-hour lessons, three field trips were organized to collect specimens and to visit the country's natural history museum, along with two special science exposition days [*La Fête des Plantes* (The Celebration of Plants) and *L'Exposition des Sciences* (The Science Fair)]. Fewer lessons were taught than originally planned due to several labor strikes and unplanned school closures throughout the year. The lesson plans and personal recaps for all 13 unique lessons (several lessons spanned more than one class session) are included in Appendix A, and the topics are listed in Table 1.

An evaluation testing scientific knowledge was devised at the onset of the program. It consisted of 8 questions testing a mix of factual, procedural, and conceptual types of knowledge (Table 2). For the rest of the course, the material on the evaluation was covered through various lessons using insect and plant natural history as the foci. For example, one of the test questions was "Devise an experiment to test the hypothesis that plants need light," and lessons included such activities as plant curation, identification, and morphology, and an experiment in which the effect of pollution on plant germination was tested. At the start of the program, 21 students in CM2A and 25 students in CM2B took the evaluation ("pre test"). Following its conclusion in June, 2009, they were given the same evaluation ("post test"), along with a simple one-question survey asking: "Did you like the science class this year?" Since both classes were included in the experimental group, and due to delays in getting the necessary permits, we did not establish a control group for comparison until the Fall of 2011. We were able to work with the same fifth-grade teacher at Pao Pao elementary school, who gave the evaluation to her 20 students once in October, 2011 ("pre test") and again at the end of June, 2012 ("post test"). These students ("CM2C") received the traditional science curriculum as designated by the national education standards, and were considered our control group. However, they received a one-day lesson in insect biodiversity taught by the lead author at the end of June, 2012, which included a period of insect collecting, and we therefore expect their scientific knowledge to be slightly higher on the post-test than the pre-, although we hypothesize their gains not to be as great as the experimental group's. (Although we recognize this potential bias in the results, this educational intervention was necessary in order to facilitate access to the students, as determined by local school policy).

During the lead author's visit to Moorea in June of 2012, 25 of the students in the experimental group (a mix of CM2A and CM2B) were given the same evaluation as a three-year follow-up ("delayed post-test"). These students were now in the eighth grade (*quatrième*), and had had three years of middle school science, in which they had a designated science teacher and science

class every day. We tested them as an exploratory measure to examine their long-term retention and to look for possible increases over their post-test scores. In addition, they were given a short qualitative survey asking about their interest in science and their memories of our program in 2008-09 (Table 3).

Data Coding, Scoring, and Analysis

We coded all of the evaluations (n=82) and surveys to mask students' identities, both for their protection and to not influence the scoring of the data. The lead author then read through all of the responses to the evaluation to get a sense of the range of answers provided, and then created a scoring rubric (see Table 4) for each question. Two undergraduate assistants and the lead author provisionally scored the first 30 of the evaluations and compared scores to ensure that there was high inter-scorer reliability. Once this was verified, we proceeded to grade the remaining evaluations and assigned each with a final score out of 8 points (each of us graded all 82 evaluations). We then averaged the three scores for each evaluation to come up with a final score. In reading through the responses, we also noticed several interesting trends that we had not anticipated, and so we reviewed the evaluations again to qualitatively code the responses to questions 6 and 8 (Table 5).

Since the sample size for each group at each testing event was not equal, we only considered those data for which we had paired comparisons (n=21 for CM2A; n=25 for CM2B; n=20 for CM2C; overall experimental group n=46, control group n=20). We calculated the mean and standard deviation pre- and post-evaluation scores for each group, and then tested each distribution for normality. For those groups that were normally distributed, we conducted a paired two-tailed t-test on each group to test for a significant difference between the pre- and post-evaluation scores. For those not normally distributed, we performed a two-tailed Wilcoxon signed rank test. To test for differences between the experimental and control group, we calculated the pre/post difference for each student (post score minus pre score) in each group, and then tested for normality. We then conducted a two-sample t-test on the differences to test for significance. All statistical analyses were performed in the program PAST 2.16 (Hammer *et al.*, 2001).

For the experimental group, we also collected and scored evaluation data at three years following the end of the class (n=30). Of these, 25 could be matched with pre- and post-scores. We conducted a one-way ANOVA on these three groups ("pre-test," "post-test," and "delayed post-test") to test for significant inter-group differences, and then conducted *post-hoc* Tukey HSD tests to see which pairs of groups differed significantly.

Several qualitative data sets were also collected and analyzed. For the one-question satisfaction survey given to the experimental group at the end of the class, we counted the number who said they enjoyed the class versus those who didn't. For the three-question open-ended survey given to the experimental group as part of the delayed post-test treatment, we read through all of their responses and then created a categorical coding scheme to document trends in their responses (Table 3). We counted the number of respondents in each category and provide the results as raw numbers and percentages. Finally, we used the same type of categorical coding scheme for the trends that emerged in answers on the evaluation and analyzed those data in a similar way.

Results

We first examined the distribution of pre- and post-test scores for each of the three test groups (2 experimental, 1 control) to determine if they were normally distributed. We calculated the normality statistic Anderson-Darling's A^2 for each distribution. All distributions except the CM2B pre-test were found to be normally distributed (Table 6). We therefore conducted paired t-tests for the pre- and post-test scores for CM2A and CM2C, and rejected the null hypothesis of equal group means (Table 7). For the non-parametric distribution (CM2B), we performed a Wilcoxon signed-rank test on the pre- and post-test scores and rejected the null hypothesis of equal medians (Table 8).

Differences between pre- and post-test scores were significant for all 3 groups, and there was a gain in the mean evaluation score for each of the 3 (Table 6; Figures 3-5). In the experimental groups, CM2A's mean score increased by 1.18 points, a 38.1% increase; CM2B's score increased by 2.42 points, a 157.1% increase; and CM2C's score increased by 0.65 points, a 30.5% increase. In order to look for a significant difference in the gains of the experimental and control groups, we combined the CM2A and CM2B data (n=46) to comprise the "experimental" group and compared it to the "control" group of CM2C (n=20). We tested each group for normality (Table 9), and finding both to be normally distributed, performed two-sample t and F-tests to test the null hypothesis that the two groups have the same variance and mean. We rejected the null hypothesis of equal means and accepted the null hypothesis of equal variances (Table 10), indicating a significant difference in experimental and control gains (Figure 6).

For the final part of our statistical analysis, we performed a one-way ANOVA to test for significant differences between the experimental group's evaluation scores on the pre-, post-, and delayed post-test treatments. We found variances to be statistically equal and rejected the null hypothesis of equal means, indicating at least one significant difference between groups (Table 11; Figure 7). We then conducted *post-hoc* Tukey HSD tests to look for significant differences between each possible pair of groups, and found the pre- vs. post-test and pre- vs. delayed post-test comparisons to be significant (Table 12).

In our qualitative assessment of students' attitudes, we found 100% (n=42) of the experimental group surveyed had positive feelings towards the course, answering the question "Did you like the science course this year" with "yes." In our delayed post-test survey (n=30), we found 66.67% of students had a favorable impression of science, 20% had neither positive nor negative feelings, and 13.33% had a negative impression (Figure 8).

The results of the qualitative coding for both the 8-question post-test and the 3-question delayed post-test survey are given in Tables 13-14. Notable results include that pollution/littering was as the most commonly cited environmental problem in French Polynesia, with 72% of respondents providing it as their example. On question 8, 24% of respondents incorrectly provided an introduced plant as an example of a native plant, and 22% volunteered a complete scientific name (genus and species) in citing their example. In the 3-question delayed post-test survey, both insects and plants were regarded favorably, with a slight advantage to insects. 50% percent of respondents cited insects as their favorite subject in science, with 70% of them mentioning

insects among their recollection of the GK-12 course. 26.7% of students cited plants as their favorite subject, with 56.7% mentioning plants among their memories of the course.

Discussion

Our findings support the hypothesis that a natural history-driven curriculum can increase scientific knowledge in fifth-graders. The students who received the curriculum saw substantially greater improvement in their evaluation scores than those in the control group (82.2% gain vs. 30.5% gain). The evaluation scores at that time were still significantly greater than the pre-test scores and not significantly less than on the pre-test, indicating long-term improvement in knowledge. This study adds to the growing literature on the efficacy of direct experience with nature and organisms to increase scientific knowledge and attitudes regarding nature, from the early elementary school years through college (Krupa, 2000; Vadala, 2004). Our curriculum addressed the French Polynesian educational standards while using real organisms as vehicles for teaching conceptual, factual, and procedural scientific knowledge. The key to the curriculum's success was likely its appeal to children's biophilia, their innate curiosity about the natural world. This affection for organisms was demonstrated not only in their improved evaluation scores, but also their responses to our qualitative surveys. When asked at the delayed post-test for their favorite subject in science, 50% mentioned insects while another 26.7% mentioned plants. When asked for specific memories of the curriculum, 70% mentioned insects and 56.7% mentioned plants. Their direct experience with organisms was substantial and memorable enough for students to have favorable impressions of these groups of taxa three years after the conclusion of the program, despite the literature suggesting that insects and plants are among the least popular organisms to schoolchildren (Kellert, 1993; Ward *et al.*, 1998). The field trips to collect organisms were clearly memorable as well, with 36.7% of students citing those excursions among their collections of memories. Their overall impression of science at the delayed post-test was also favorable, with two-thirds of respondents saying they like science.

It is worth noting that among the experimental group, the CM2B class experienced a much larger gain in knowledge as the CM2A class (157.1% gain vs. 38.1% gain). We attribute this difference to a difference in the leadership of each class. CM2B was taught by a single teacher year-round who was particularly invested in our program and who allowed her students to work on science-related projects even when the lead author was not present. On the other hand, there was considerable turnover in the teaching of CM2A, as the initial teacher was promoted to school principal shortly after our program began. He was followed by an ineffective substitute who had little control over the class, and following his dismissal, another substitute. The lack of stability and leadership showed in this class' inferior performance on the evaluation; despite starting with considerably higher scores than CM2B, the CM2A students did not improve nearly as much (Figures 3-4). This finding underscores the importance of having stable, reliable collaborations with the main classroom teachers in order for programs such as this one to be effective. Only with the proper investment from the partner school can such programs work.

Another unexpected finding from this study was that pollution/littering was the most oft-cited example of an environmental problem in French Polynesia. A possible explanation for this is the success of the country's *Direction de l'environnement* (Directorate of the Environment, the government's environmental management agency) in highlighting the challenge of waste

removal on these remote islands with limited space (Murzilli, 2012). However, there are several other important environmental issues that were hardly recognized, such as climate change (especially for the atolls barely above sea level), coral bleaching, invasive species, and habitat destruction. While there have been local initiatives targeting each of these issues, our findings suggest that they should be emphasized greater in local education and media.

The lessons taught introduced students to scientific terminology for the biodiversity that surrounds them. Much of that biodiversity knowledge was entirely new to them, especially the insects, but many of them already had some folk knowledge of the plants because of their traditional importance in Polynesian society. The original Polynesian settlers of these islands brought several "canoe species" of plants when they arrived around 800 A.D. (Whistler, 1991) that became vital parts of indigenous Tahitian culture and diet. Several of these, most notably breadfruit (*Artocarpus altilis*) and Tahitian chestnut (*Inocarpus fagifer*), were incorrectly cited by students as examples of native plant species in question 8 of the evaluation. Despite having focused on these species as examples of introduced species in our curriculum, 24% of students gave them or another Polynesian introduction as their examples of native species, indicating the strong cultural bias towards associating the Polynesian culture with being native. Further effort should be made in local scientific education to separate the truly native flora and fauna (those species that arrived on their own) with those introduced by humans.

Taxonomy also featured prominently in our inclusion of scientific terminology. Students learned the scientific (Latin) names of several species of plants, along with the scientific names for several orders of insects. Despite the difficulty and length of scientific names, our students displayed a penchant for retaining them. During the post-test period, 22% of students provided a complete scientific name when asked for examples of introduced and native plants. Perhaps more impressively, 3 years later, 20% of survey respondents listed the full scientific name (genus and species) of a plant when asked for their memories of the course. Clearly the names had a lasting impression for many of the students.

Although not explicitly quantified in this study, the local community's reaction to the program was highly favorable. Moorea is a small island with a small but tight-knit community, and word spread fast about our work. It is unusual to have this type of collaboration on such a remote island, but the positive impact was clear. By the end of the program, principals from the other elementary schools on the island were clamoring to be included in future projects, and in the second year of the program, the graduate student fellow taught classes in three different schools, extending the curriculum to include marine organisms. Unfortunately, the program ended after just two years, as funding ran out and the National Science Foundation cancelled the entire GK-12 program in spite of many encouraging results (Mervis, 2011; Page *et al*., 2011).

Despite the program's termination, we are especially encouraged by the findings of the delayed. 3-year, post-test. The students retained much of their gains in scientific knowledge, expressed clear and fond memories of their experiences working directly with organisms, and had a favorable overall impression of science. We highly encourage the future development of similar programs in French Polynesia, in which natural history is used as a teaching tool for increasing scientific knowledge in an effort to help the educational system catch up with that of mainland France. Clearly students in this age group respond well to the incorporation of such

“uncharismatic” taxa as insects and plants into their science curriculum, and this affinity for nature and organisms should be leveraged to increase scientific knowledge overall.

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Chapter 3 Tables and Figures

Table 1: Lesson titles, topics, and activities covered in the GK-12: Exploring Moorea's Biodiversity course.

Lesson Title	Topics/Concepts Covered	Activity
Biodiversity of Moorea's plants	Biodiversity; taxonomy; classification; native vs. introduced species.	Observe freshly collected plant specimens and take notes in field notebooks on observations and potential scientific questions.
Characters, Dichotomous Keys, and Plant Morphology	Classification; identification; characters; simple vs. compound leaves.	Identify 7 local plant species using dichotomous keys.
Becoming Scientists	Definition of science; experimental design; water pollution.	Set up control and experimental treatments for experiment testing the effect of water pollution on seed germination.
Introduction to Biocode and genetics	Genes; DNA barcoding; heredity.	Figure out the identity of a plant based on DNA sequences coding for different traits.
Visualization of Data	Graphs; tables; charts.	Depict results of seed germination experiment in a graph.
Creating Herbarium Specimens	Curation; museum archives; plant diversity.	Mount a plant specimen collected on the recent field trip for deposition in an herbarium.
Build a Bug	Insect diversity; characteristics of insects; evolution; adaptation.	Build a fictional insect out of household materials according to the insect body plan and explain how its morphology is adapted to its environment.
Insect Identification	Insect orders; characteristics of Coleoptera, Hymenoptera, Dermaptera, Blattaria, Diptera Lepidoptera, and Orthoptera	Rotate among stations filling out worksheets for each order of insect.

Lesson Title	Topics/Concepts Covered	Activity
Cricket Jumping Experiment	Hypothesis; experimental design; insect morphology.	Observe crickets and design an experiment to test that body size is correlated with the distance a cricket can jump.
Insect Curation	Curation; insect diversity.	Create and curate an insect collection representing all 7 orders we studied in class.
Cricket Jumping II	Anatomy; behavior.	Finish data analysis of cricket experiment and create research poster including introduction, methods, results, and conclusion.
Rimatara Pen Pals	Endemism; hot-spots; island formation; communication and collaboration in science.	Write letter to pen pal on Rimatara Island discussing the natural history of Moorea and talking about themselves.
Island Biogeography	Native vs. introduced species; volcanism; formation of islands; colonization of islands.	Play game to simulate the colonization of Moorea by different types of plants and animals.

Table 2: The 8-question evaluation given to students at pre-, post-, and delayed-post time periods. Knowledge types of each question (following Krathwohl, 2002).

1. What does the word biodiversity mean? [Conceptual knowledge]
2. Come up with an experiment to test the hypothesis that plants need light. Briefly describe the experiment. What materials would you use? [Procedural knowledge]
3. Explain the geological origin of Moorea. How did the island form? [Conceptual/Factual knowledge]
4. Why do we collect organisms and put them in museums? [Conceptual knowledge]
5. What characteristics do all insects have in common? [Factual knowledge]
6. Give an example of an environmental problem in French Polynesia. Who is it a problem for? How can we resolve it? [Conceptual and Procedural knowledge]
7. How old is the island of Moorea? [Factual knowledge]
8. What is the difference between a native species and an introduced species? Give an example of a native plant species and an introduced plant species. [Conceptual knowledge, Factual knowledge]

Table 3: Qualitative survey (free-form, not multiple choice) and coding rubric given to experimental group (CM2A & CM2B), delayed post-test.

Question/Code	Key
Question 1: Do you like science? Explain your response.	
1A	Yes
1B	No
1C	Sort of/equivocal response
Question 2: What is your favorite subject in science?	
PL	Specifically mentions plants
IN	Specifically mentions insects
BOTH	Specifically mentions both insects and animals
DSC	Mentions discovery in some way (discovery of species, new information, etc.)
OUT	Mentions a field of science outside of natural history/biodiversity/biology *(i.e.*, chemistry, math)
Question 3: Do you have memories of the teaching done by Brad? If so, what are they?	
FIELD	Mentions field trips
EXPO	Mentions the Exposition des Sciences or the trip to Berkeley's research station to present their research on plants
IN	Mentions catching or studying insects
PL	Mentions catching or studying plants
TAX	Mentions a specific scientific name (genus and species)

Table 4: Scoring rubric for 8-question evaluation, including explanation of partial credit.

QUESTION/CREDIT	RESPONSE
Question 1	What does the word biodiversity mean?
Full Credit (1 point)	The variety and number/abundance of species in the world.
Partial Credit (0.5 points)	Mentions variety or variation of organisms or species.
Partial Credit (0.5 points)	Mentions number/abundance of organisms or species.
Partial Credit (0.5 points)	Defines biodiversity correctly, but limits definition to only a subset of taxa (*i.e.*, only plants or only insects).
Question 2	Come up with an experiment to test the hypothesis that plants need light. Briefly describe the experiment. What materials would you use?
Full Credit (1 point)	Must mention seeds or plants and a light source as materials; must demonstrate understanding of the control vs. experimental research design, with the control receiving light and the experimental not receiving light (placement in a location where there is no light or where light is obscured are both acceptable). Answers with drawings and no text are acceptable.
Partial Credit (variable)	Demonstrates understanding of experimental design but adds unnecessary detail that dilutes response.
Question 3	Explain the geological origin of Moorea. How did the island form?
Full Credit (1 point)	The island originated from a hot spot in the Earth's crust under the ocean, and the island formed when the lava from volcanic eruptions through the hot spot cooled and hardened. (Answer does not have to include the term hot spot for full credit, but does have to mention volcanism.)
Partial Credit (0.5-0.75)	Correctly explains volcanic origin but adds incorrect information, such as the island first having been an atoll or providing a wildly inaccurate number for the age of the volcano/island.
Question 4	Why do we collect organisms and put them in museums?
Full Credit (1 point)	We collect organisms and put them in museums in order to study them more closely, to create a historical record of what has existed in certain places and at certain times, and to display them to educate the general public.
Partial Credit (0.75 points)	Mentions 2 of the 3 above reasons.
Partial Credit (0.50 points)	Mentions 1 of the 3 above reasons
Partial Credit (0.25 points)	Provides some other reasonable answer.
Partial Credit (Subtract 0.25 points)	Provides correct answer but limits the type of organisms mentioned to a particular taxon *(i.e.*, only plants, only insects).

QUESTION/CREDIT	RESPONSE
Question 5	What characteristics do all insects have in common?
Full Credit (1 point)	All insects have 3 body parts (a thorax, abdomen, and head), six legs, and a pair of antennae.
Partial Credit (0.80 points)	Mentions 4 of the above 5
Partial Credit (0.60 points)	Mentions 3 of the above 5
Partial Credit (0.40 points)	Mentions 2 of the above 5
Partial Credit (0.20 points)	Mentions 1 of the above 5
Question 6	Give an example of an environmental problem in French Polynesia. Who is it a problem for? How can we resolve it?
Full Credit (1 point)	Answers will vary; examples of acceptable answers are pollution/littering, invasive species, climate change, deforestation/habitat destruction, coral bleaching.
Partial Credit (0.50 points)	Provides an acceptable environmental problem but does not say who it is a problem for or how it can be resolved.
Partial Credit (0.75 points)	Provides an acceptable environmental problem and explains who it is a problem for, but not how to resolve it.
Partial Credit (0.75 points)	Provides an acceptable environmental problem and how to resolve it, but does not explain who it is a problem for.
Question 7	How old is the island of Moorea?
Full Credit (1 point)	The island is 1.5 million years old.
Partial Credit (0.50 points)	Says island is 1-1.5 million years old.
Partial Credit (0.50 points)	Says island is 1.5-2 million years old.
Question 8	What is the difference between a native species and an introduced species? Give an example of a native plant species and an introduced plant species.
Full Credit (1 point)	A native species is a species that colonized a place naturally, through the wind, by the sea, or with non-human organisms. An introduced species is a species that was brought to a place by humans. Answers to plant examples vary.
Partial Credit (0.25 points)	Correctly defines a native species.
Partial Credit (0.25 points)	Correctly defines an introduced species.
Partial Credit (0.25 points)	Gives a correct example of a native species.
Partial Credit (0.25 points)	Gives a correct example of an introduced species.
Partial Credit (Subtract 0.25 points)	Defines introduced and/or native species as a specific subset of taxa *(i.e.*, only plants, only insects).

Table 5: Qualitative codes for Questions 6 and 8 on evaluation.

Question/Code	**Key**
Question 6	Give an example of an environmental problem in French Polynesia. Who is it a problem for? How can we resolve it?
6A	Gives some form of pollution/littering as their example of an environmental problem.
6B	Gives *Miconia* as their example.
Question 8	What is the difference between a native species and an introduced species? Give an example of a native plant species and an introduced plant species.
8A	For the native plant example, mentions a plant that was introduced by the Polynesians.
8B	Defines a native species as a specific kind of taxon rather than being inclusive of all biodiversity (*i.e.*, a native plant is…).
8C	Gives a complete scientific name for a plant (genus and species).

Table 6: Univariate statistics and tests for normality for experimental (CM2A and CM2B) and control groups' (CM2C) scores on evaluation; null hypothesis is that distributions are normal. P-values less than 0.05 are in boldface indicating rejection of null hypothesis *(i.e.*, non-normal distribution). Raw gains in score and percentage gains are also indicated in boldface.

Group	N	Mean (±S.D.)	Anderson-Darling's A^2	p-value
CM2A Pre	21	3.1±1.64	0.7193	0.0513
CM2A Post	21	4.28±1.3	0.5448	0.1419
Change in Mean		**1.18 (38.1%)**		
CM2B Pre	25	1.54±1.5	1.806	**9.14×10^{-5}**
CM2B Post	25	3.96±1.87	0.3315	0.4915
Change in Mean		**2.42 (157.1%)**		
CM2C Pre	20	2.13±0.951	0.1352	0.9733
CM2C Post	20	2.78±1.08	0.3643	0.4035
Change in Mean		**0.65 (30.5%)**		

Table 7: Paired t-tests for pre- and post-test scores for CM2A (experimental) and CM2C (control); the null hypothesis is that the means are the same. P-values less than 0.05 are in boldface, indicating group means are significantly different from each other.

Group	N	t	p-value
CM2A	21	-4.427	**0.0002594**
CM2C	20	-2.624	**0.01671**

Table 8: Wilcoxon signed-rank test for pre- and post-test scores for CM2B (experimental); null hypothesis is that the medians are the same.

Group	W	p-value
CM2B	324	**1.49×10^{-7}**

Table 9: Univariate statistics and tests for normality for gain (post-test score minus pre-test score) in evaluation scores for experimental and control groups scores on evaluation; null hypothesis is that distributions are normal.

Group	N	Mean Gain (±S.D.)	Percent Increase	Anderson-Darling's A^2	p-value
Experimental	46	1.85±1.42	82.2%	0.603	0.11
Control	20	0.65±1.11	30.5%	0.217	0.81

Table 10: Two-sample t and F tests for testing the null hypothesis that the experimental and control gains (post-test score minus pre-test score) are from a distribution with the same mean (t-test) and variance (F-test). P-values less than 0.05 are in boldface indicating rejection of null hypothesis.

t	p-value	F	p-value
3.30	**0.002**	1.64	0.24

Table 11: One-way ANOVA results for experimental group's scores on pre-, post-, and follow-up evaluations, with null hypothesis that samples are taken from a distribution with the same mean. Levene's test for variance (null hypothesis that variances are the same): p=0.4999. P-values less than 0.05 are in boldface indicating rejection of null hypothesis.

	Sum of squares	df	Mean squares	F	p-value
Between-groups	43.0376	2	21.5188	7.198	**0.001413**
Within-groups	215.245	72	2.98952		
Total	258.283	74			

Table 12: Tukey HSD *post-hoc* comparison tests for differences between specific groups. P-values less than 0.05 are in boldface indicating rejection of null hypothesis.

Comparison	Q	p-value
Pre vs. Post	5.293	**0.001141**
Pre vs. Follow-Up	3.409	**0.04806**
Post vs. Follow-Up	1.884	0.3821

Table 13: Percentages of experimental group students fitting qualitatively coded categories on post evaluation; percentages do not add up to 100 because a given response could be coded in more than 1 category.

Question Number/Code	Category	Percentage
6A	Gave some form of pollution/littering as their example of an environmental problem	72
6B	Gave *Miconia* as their example	2
8A	For the native plant example, mentioned a plant that was introduced by the Polynesians	24
8B	Defined a native species as a specific kind of taxon rather than being inclusive of all biodiversity (*i.e.*, a native plant is…)	14
8C	Gave a complete scientific name for a plant (genus and species)	22

Table 14: Percentages of experimental group students fitting qualitatively coded categories on follow-up survey; percentages do not add up to 100 because a given response could be coded in more than 1 category.

Question Number/Code	Category	Percentage
Question 2: What is your favorite subject in science?		
2/IN	Specifically mentioned insects	50
2/PL	Specifically mentioned plants	26.7
2/BOTH	Specifically mentioned both insects and animals	0
2/DSC	Mentioned discovery in some way (discovery of species, new information, etc.)	10
2/OUT	Mentioned a field of science outside of natural history/biodiversity/biology *(i.e.*, chemistry, math)	10
Question 3: Do you have memories of the teaching done by Brad? If so, what are they?		
3/FIELD	Mentioned field trips	36.7

Question Number/Code	Category	Percentage
3/TAX	Mentioned a specific scientific name (genus and species)	20
3/EXPO	Mentioned the Exposition des Sciences or the trip to Berkeley's research station to present their research on plants	16.7
3/IN	Mentions catching or studying insects	70
3/PL	Mentions catching or studying plants	56.7

Figure 1: Map of French Polynesia; inset map shows location of French Polynesia in the Pacific Ocean.

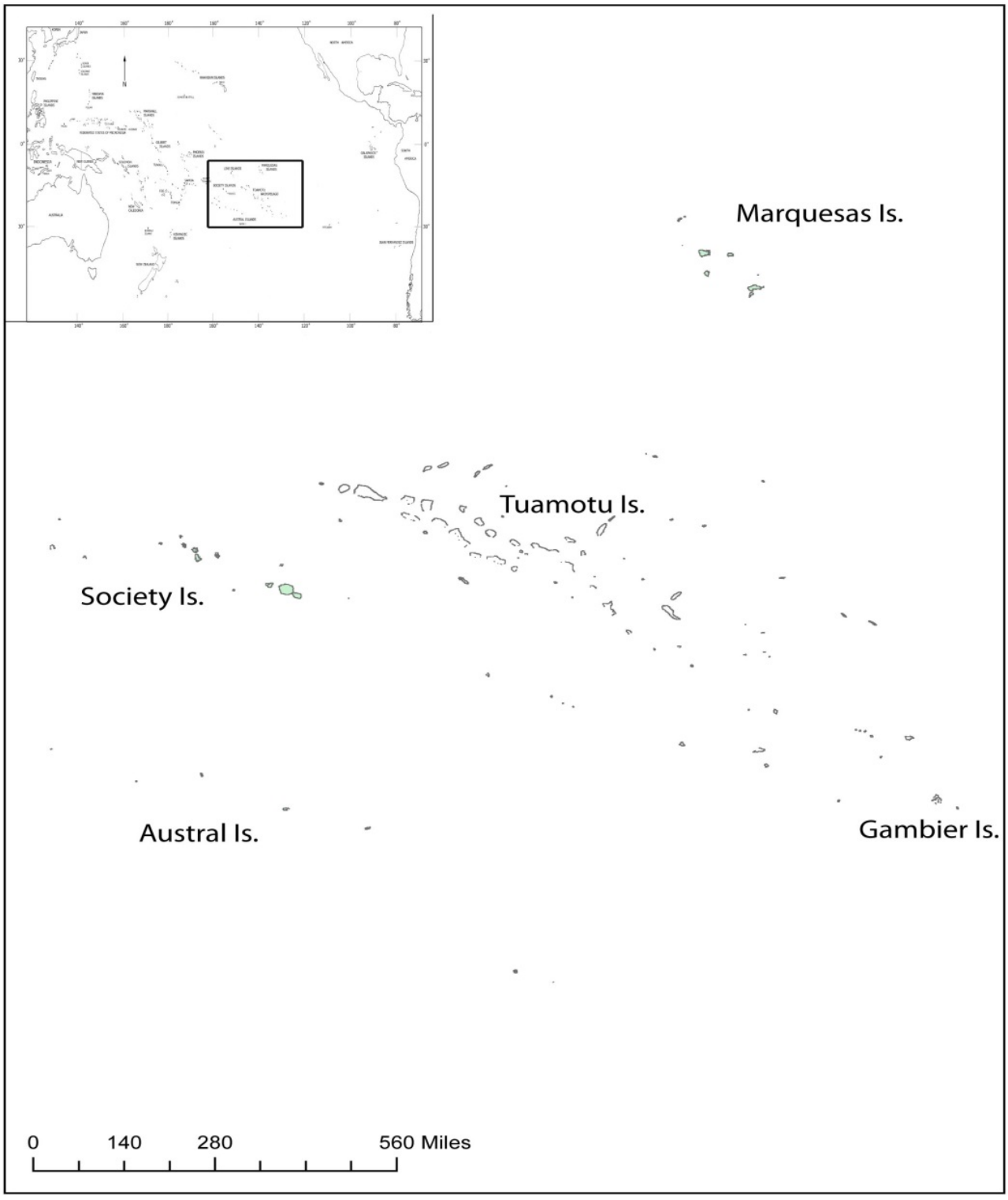


Figure 2: Map of the Society Islands, including Moorea, the site for this study.

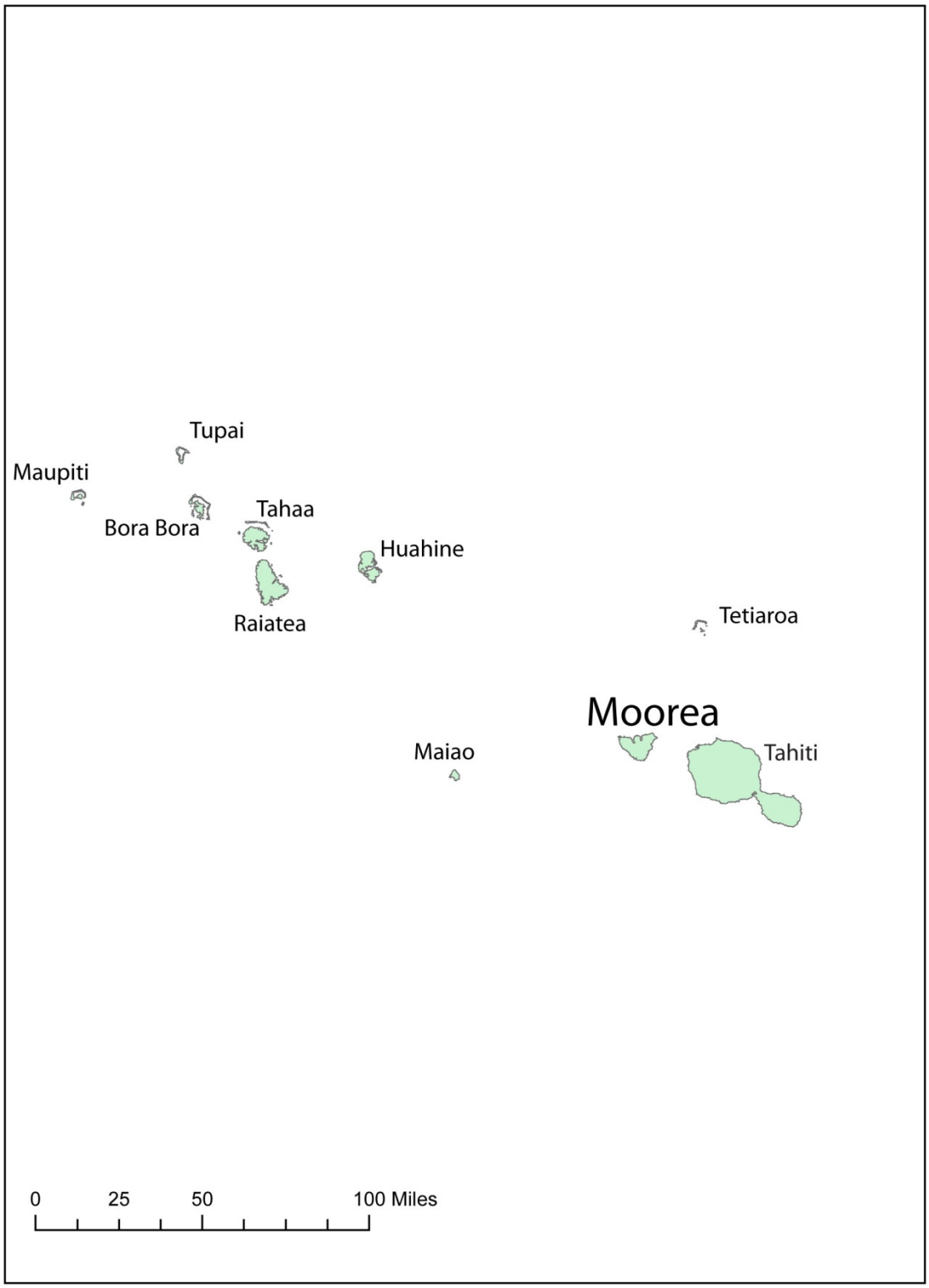


Figure 3: Comparison of pre- vs. post-test scores for CM2A on 8-question evaluation; error bars indicate standard deviation.

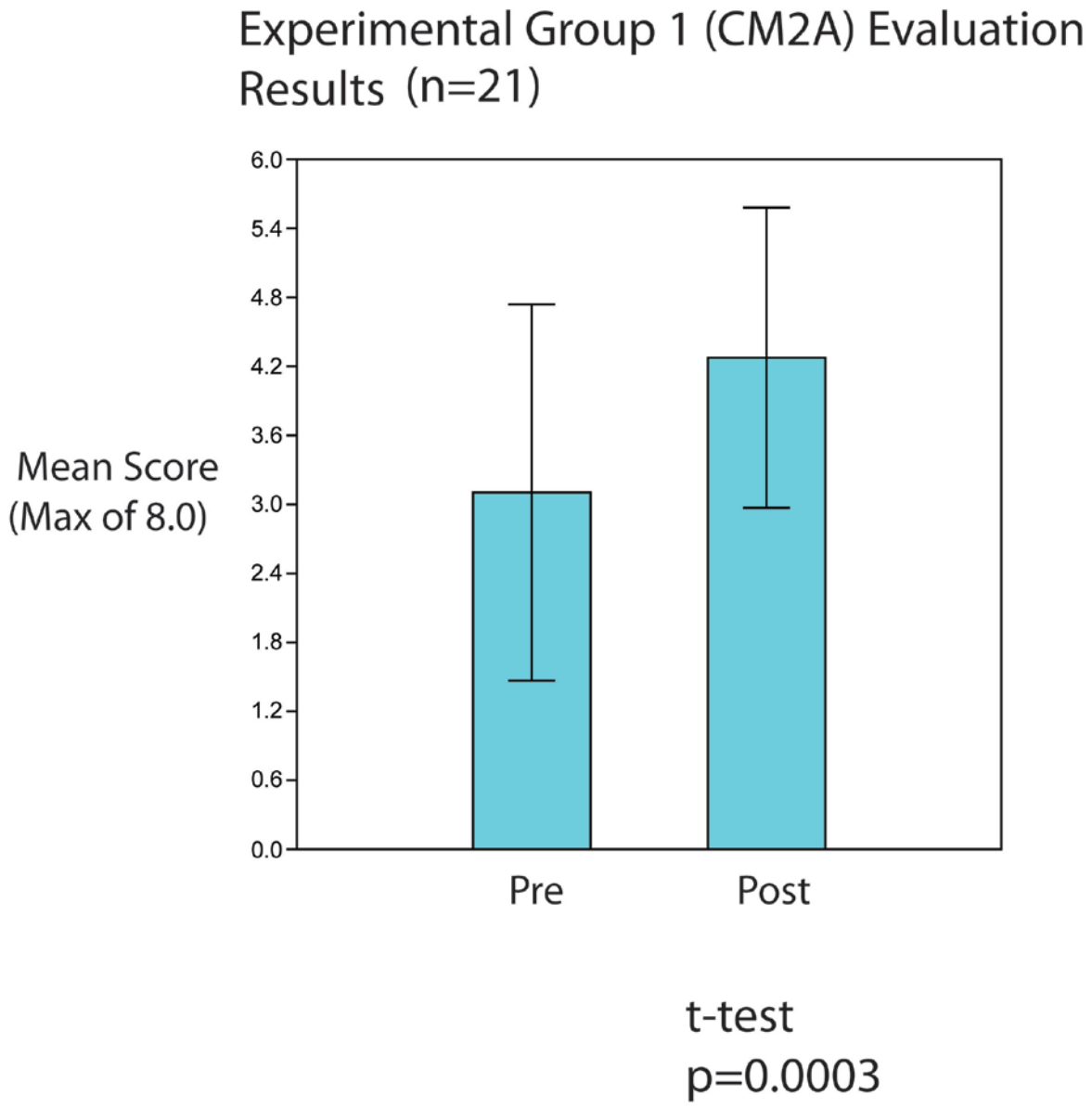


Figure 4: Comparison of pre- vs. post-test scores for CM2B on 8-question evaluation; error bars indicate standard deviation.

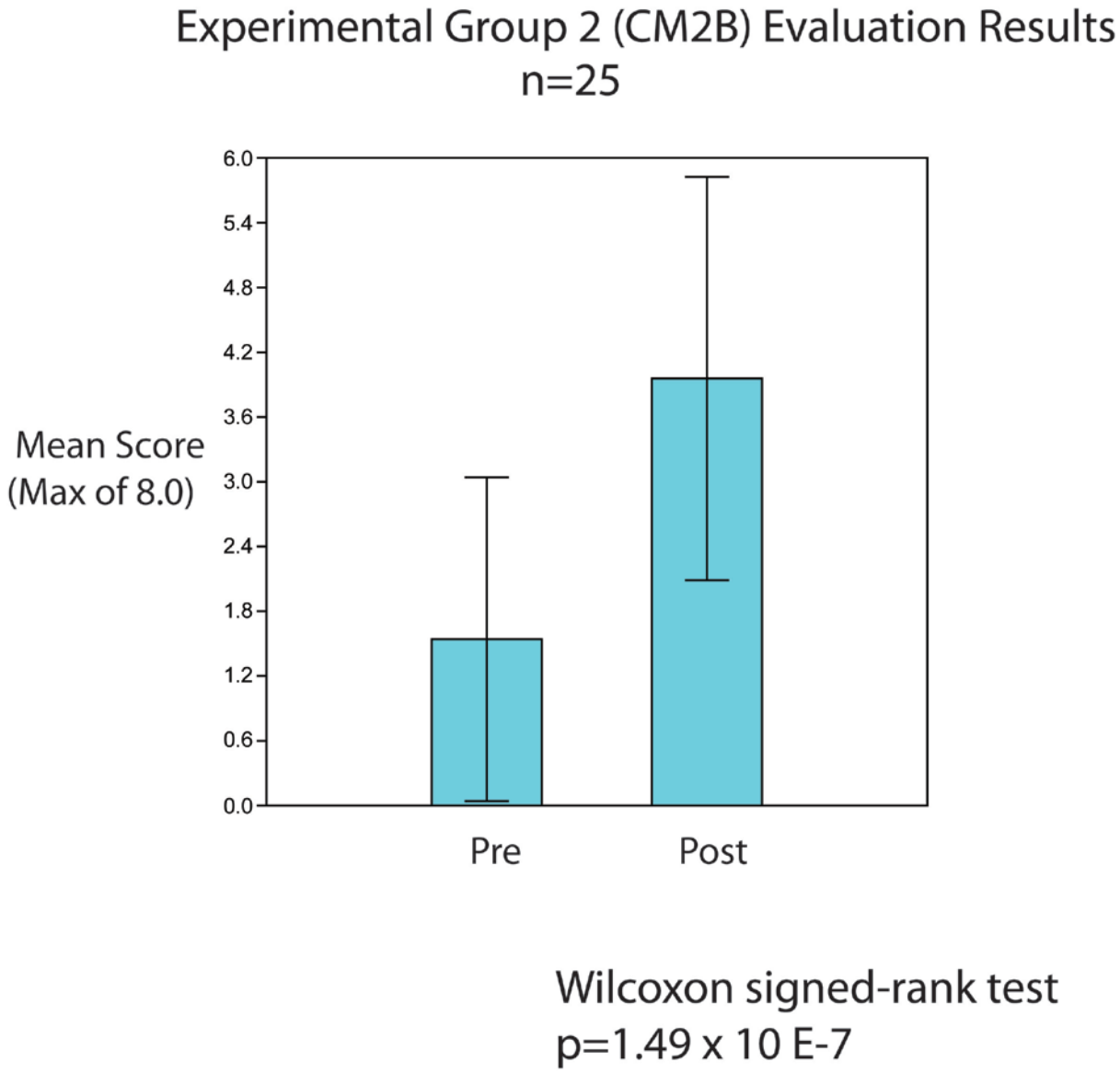


Figure 5: Comparison of pre- vs. post-test scores for CM2C on 8-question evaluation; error bars indicate standard deviation.

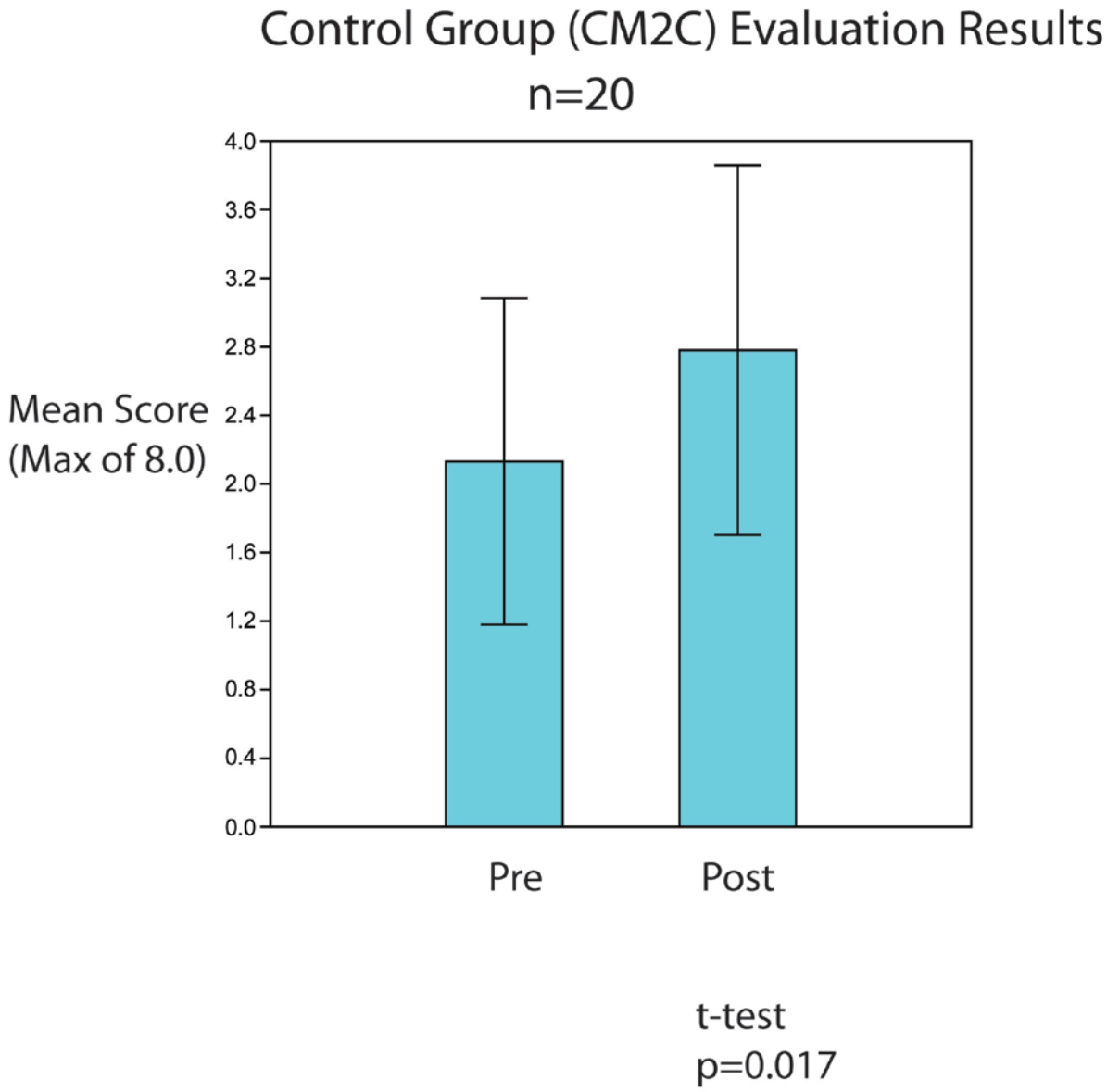


Figure 6: Comparison of gains in mean scores on 8-question evaluation between experimental and control groups; error bars indicate standard deviation.

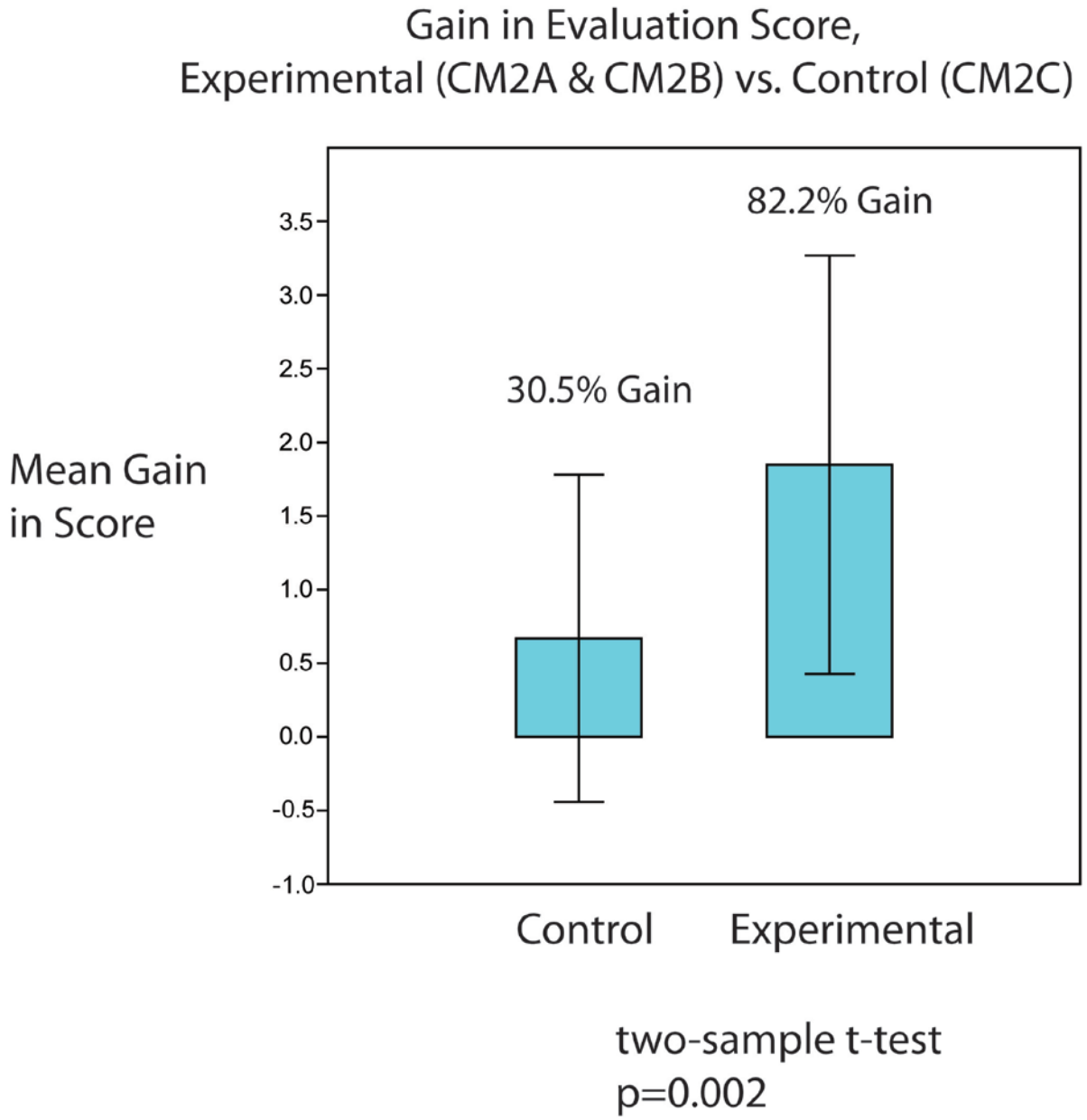


Figure 7: Comparison of mean scores at three time periods for experimental group on 8-question evaluation; error bars indicate standard deviation.

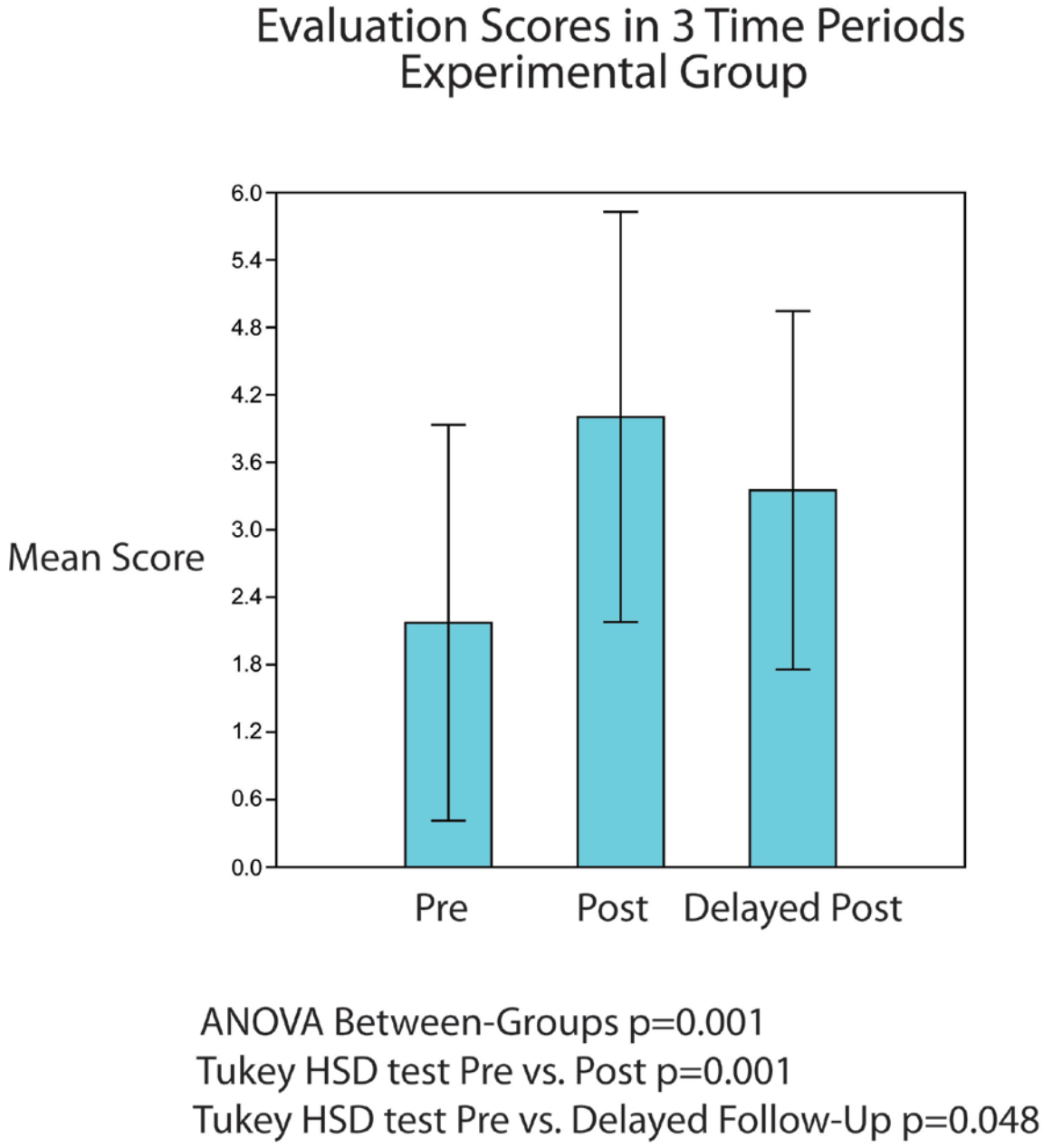
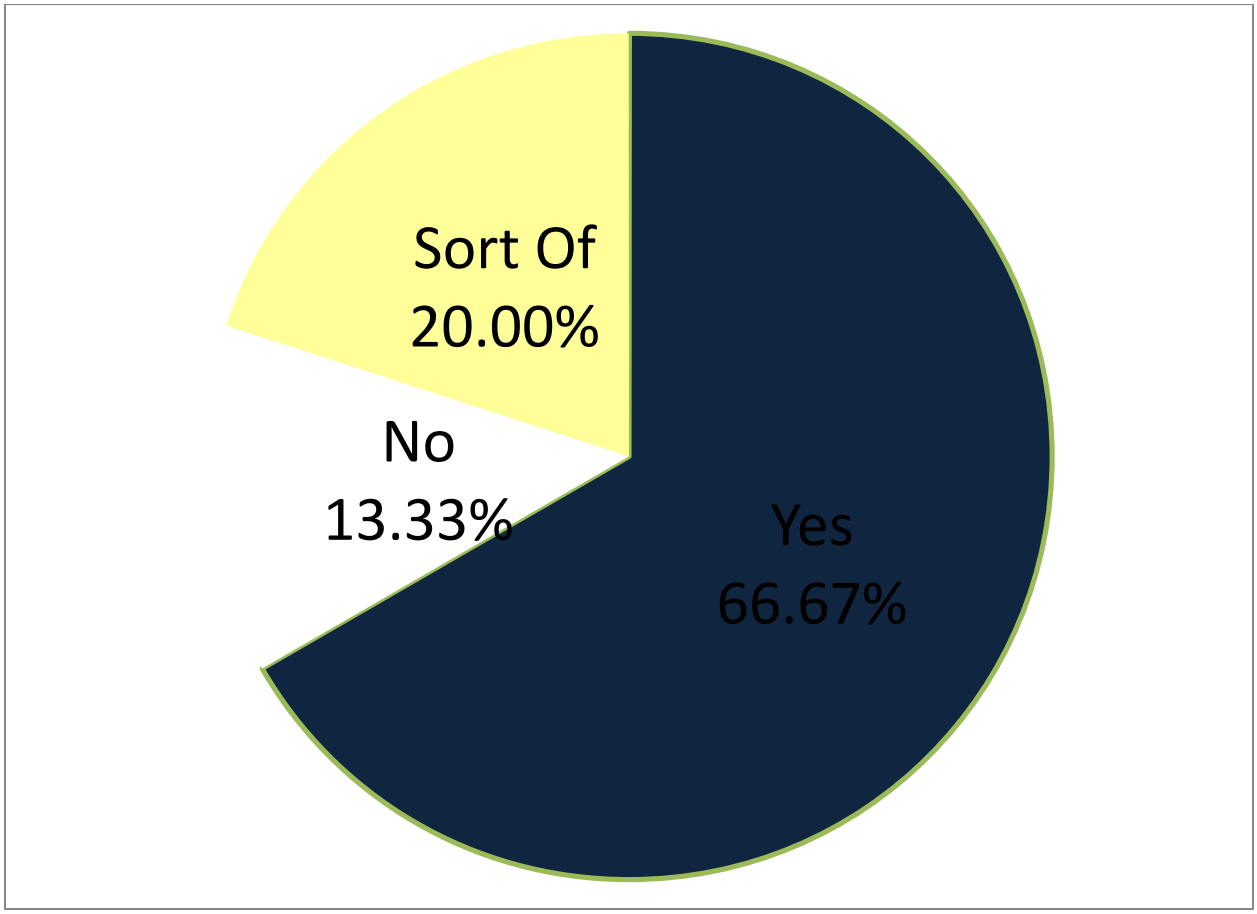


Figure 8: Experimental group response to delayed follow-up survey question 1 (“Do you like science?”).



Appendix

Appendix A: Lesson Plans and Reflections

Lesson 1

Title: The Biodiversity of Moorea's Plants

Author: Brad Balukjian

Overview: In this lesson, students will get a broad overview of Moorea's biodiversity, with specific focus on the plants. We want them to leave with an understanding of the concept of biodiversity and an appreciation for Moorea as a unique and special place. Students will be exposed to the inquiry-based learning process, as they are asked to form questions based on direct observations of Moorea's plants.

Concepts:
-Biodiversity is the number and variety of living things
-Because of its isolation, Moorea is a very special and unique place, with organisms that are found nowhere else in the world.
-A species is the basic unit of biodiversity, and is a group of organisms that all have certain characters in common and are closely related to each other.
-In order to organize biodiversity and to communicate, scientists give Latin names to species and classify them according to how closely related they are to each other.
-Observation is the important first step in science; once we observe biodiversity, we can form questions that we want to answer through the scientific method.
-Scientists record their observations and data in field notebooks, which are kept as records for future scientists to use.

Vocabulary:
Biodiversity
Organism
Species
Genus
Classification
Observation
Field Notebook

Grade Span: CM2 in the French system (kids are generally 10-11 years old)

Materials:
-Plant specimens
-Field notebooks
-Colored pencils
-Handouts

Advanced Preparation: Collect specimens, buy field notebooks, photocopy handouts

Time: Lesson planned for 50 minutes for a 60 minute class (10 minutes allotted for going longer than expected)

Grouping: Groups of 3-4

Procedure:

1. Introduction

Introduce ourselves to the class (Brad Balukjian and Erica Spotswood). Give them handouts, and explain that we are scientists but that we are still students just like them, with reports and homework, except we get paid to be students. Encourage them to consider science as a career. Tell them that we are going to work with them for the whole year and that we will do lots of fun projects. Tell them that at the beginning of every lesson, we are going to ask a question or two from the previous lesson, and the person who answers the question gets a prize. Ask if a student can point out on a map or globe where we are from originally (Rhode Island and New York), and where we live now (California). (5 min)

2. Activity

Go to the whiteboard and tell the class that today we are going to learn about the word biodiversity. Ask if anyone knows what the word means. If not, break it into bio and diversity, and explain that bio means life, just like biology is the study of living things. Ask them to call out what they think of when they hear the word biology. Write all of these things on the board, and then explain that all of them fall under the topic of biodiversity. Give them the definition that biodiversity is the number and variety of living things. (5 min)

3. Lecture

Give a brief (brief!) lecture covering the main concepts of the lesson. Start by telling them how special and unique Moorea is, and how so many people where we come from think of it as paradise. Emphasize that Moorea's isolation makes it very special, as all the organisms either got here by crossing the ocean or were brought by man. Say that there are some organisms that are found nowhere else in the world. Introduce the concepts of species and classification, and then explain the importance of observation in science. Tell them that today's activity is going to be about making observations of plants. Some people might think that plants are boring because they don't move, but there is a lot we can observe even if something doesn't move. Hand out field notebooks. (5 min)

4. Activity

Separate class into groups of 3-4. Give each group a collection of specimens to observe, and tell them that they are to share the specimens and take turns observing them, drawing them, and describing them. Emphasize that they are to handle the specimens carefully! Give them a handout with some basic questions to guide their observation. Ask each group to choose one plant, and to write down why they chose that plant and what questions they are interested in answering about that plant. (25 min)

5. Discussion and Wrap-Up

Explain that we are going to do a project for the next several weeks called "Adopt A Plant," in which each group will do research on the plant that they chose. They will learn about

where the plant grows, what it looks like, how it reproduces, and how Tahitians used the plant in the past or still use it today. Each group will make a poster of their plant, and then before Christmas vacation, we will have a special day where they give a presentation of their plants to the local cultural association Te Pu ‘Atiti’a. (10 min).

Homework: Ask them to look for their plant around their house or anywhere they go outside. If they find it, tell them to write down in their field notebook where they found it.

Lesson 1 Recap

DATE TAUGHT: October 16, 2008
DATE OF REFLECTION: October 20, 2008

Learning goals: what were the goals of this lesson?
The main goal of the lesson was to introduce the concept of biodiversity and to get the students to appreciate the variety of Moorea’s biodiversity by examining some common island plants. A secondary goal was to introduce the concepts of species and classification, and to emphasize that many species found in French Polynesia are found nowhere else in the world.

Do you feel these goals were successfully achieved? How could you tell?
I think that our success was modest. For an introductory lesson, I think things went pretty smoothly and the students grasped the general idea that biodiversity includes the number and variety of organisms in a given place. Based on their answers to questions, I think they understood that species are separate and discrete entities, and that organisms are classified according to their similarity, but I don’t think they have a very good handle on the notion of relatedness when it comes to classification.

How did you wrap up the lesson (assessment, discussion, etc)?
We wrapped up with a brief discussion. I asked who picked each of the seven species of plant, and then asked if anyone knew the name of the plant. Generally someone knew either the Tahitian or the French name, so I took the opportunity to introduce the concept of scientific names. I also provided an English name where possible, so that they were given up to four different names for one plant. I finished by urging them to continue the drawings they had begun by looking for their plant around their house and recording any information they found in their field notebooks.

What worked well?
I think the main activity of drawing and describing the plant specimens worked well. They were clearly excited to hold the specimens, and many displayed a flair for artistic talent. They were enthusiastic and attentive, and even concerned about not having completed all of the questions on the handout I gave them. I was also impressed by many of their answers on the handout, in which they were asked to describe the plant and to pose a research question they’re interested in. When asked for the size of the plant, 11 of the 55 students took out rulers and measured their specimens on their own accord. Furthermore, several of the students displayed a penchant for inquiry-based learning in their proposed research questions. Some examples include, “For how many years does this tree grow?” “Does it grow in all countries?” “What are these little brown

points under the leaves [spores]?" And for the invasive Miconia plant, "Does this plant kill other plants? (without being told anything about Miconia)"

What did the students like about the lesson? What did they dislike? (How could you tell?)
As I mentioned above, the students liked the activity. I think I started to lose them a little bit in the "lecture" portion of the class, especially in the first class. I was trying to cram too much material into too short a period of basically straight oration, as I explained the concepts of biodiversity, species, and classification. I had scripted all of my presentation in French, because my French is still shaky. While this may have been helpful in my preparation, I may have relied too heavily on the script during the lecture portion instead of thinking more on my feet and allowing myself to be more interactive with the students. I could tell based on the glazed looks on their faces that I had exceeded their attention-span window, and so I moved on to the activity without having fully explained all of the concepts. All of this went more smoothly in the second class, which immediately followed the first, except it was 15 minutes shorter. Despite having less time, I felt more comfortable with the material and language, and while I was able to fit in less conceptual information, I feel that what I did cover was explained more clearly.

What was most difficult for the students? (How could you tell?)
Aside from my butchered French, I'd say that the hardest parts were understanding what a species is, and the third question on the handout, which asked them to think of a question they were interested in about their plant species.

What was most difficult for you?
Teaching the entire lesson in French was clearly difficult, but also trying to fit everything in while gauging their general skill level. This was the first time I had seen the students engaged in a science lesson (when I informally asked the students if they have had any science thus far this year, she said, "No." Note: the school year started August 11), and so I wasn't sure what to expect. I was impressed by their working knowledge of local plants, as many could identify the plants we brought in from the leaves alone. I imagine this might be one clear difference from the kids in Richmond, as the Moorea kids have grown up playing outside. However, they do not seem to know much about biodiversity in an explicitly scientific context.

If you were to do this activity again, or were designing a similar one, what would you do differently?
I would probably not rely so heavily on my script, and would try to have more "give-and-take" with the kids in reviewing concepts to make sure that they have properly understood.

Further comments about the logistics of running this lesson?

Further comments about the materials (worksheet, specimens)?
I ended up tweaking the lesson at the last minute, so that each class was divided into seven groups, and each group got the same set of 7 plants (2 indigenous species, 3 Polynesian introductions, and 2 modern introductions). We will focus on these 7 species for the remainder of the unit. The worksheet was effective.

Other comments?

One thing to note, and an interesting commentary on deep-rooted cultural issues—while explaining why it's important for species to have scientific names in Latin, we asked the students if there are French scientists in the world? They said yes. We asked if there are American scientists? Yes. Japanese scientists? Yes. Tahitian scientists? No. It appears the Tahitians' inferiority complex is so deep that they don't believe that there's such thing as a Tahitian scientist. There's the perception that scientists can only be from somewhere else. We did our best to correct this misconception by saying that there are Tahitian scientists, and in fact that they themselves are going to be scientists this year.

Lesson 2

Title: Characters, Dichotomous Keys, and Plant Morphology

Author: Brad Balukjian

Overview: This lesson builds on its predecessor ("The Biodiversity of Moorea Plants") by reviewing the concepts of classification, taxonomy and biodiversity in the context of plant morphology, using the same 7 plant species from the previous lesson. Students will be introduced to the critical concept of characters, and then taught how to use characters to identify species using dichotomous keys. They will be expected to grasp some basic botanical terms (e.g. simple vs. compound leaves; herbaceous vs. woody plants) while examining the plant specimens.

Concepts:
-Scientists organize biodiversity through the process of classification, in which they group organisms according to their similarity and how closely related they are.
-A species is a group of organisms that share certain characters and are closely related to each other.
-Every species has a scientific name in Latin; the first name is for the genus, and the second name is for the species.
-A character is a quality that a species possesses that is used to identify it; all members of a species share certain characters that were inherited from a common ancestor.
-A dichotomous key is a guide that scientists use to identify species.
-Plants can be classified based on their characters, such as simple vs. compound leaves or opposite vs. alternate leaves.

Vocabulary:
Species
Classification
Scientific Name
Biodiversity
Dichotomous Key
Simple vs. Compound Leaves
Opposite vs. Alternate vs. Whorled Leaves
Herbaceous Plant
Character

French Polynesian Education Standards Addressed:
Parler:
1) Utiliser le lexique spécifique des sciences dans les différentes situations didactiques mises en jeu.
2) Utiliser à bon escient les connecteurs logiques dans le cadre d'un raisonnement rigoureux.
Lire:

1) Trouver sur la toile des informations scientifiques simples, les apprécier de manière critique et les comprendre.
2) Traiter une information complexe comprenant du texte, des images, des schemas, des tableaux, etc.
Ecrire:
1) Prendre des notes lors d'une observation, d'une experience, d'une enquête, d'une visite.

Grade Span: CM2 (kids are generally 10-11 years old)

Materials:
-Specimens of 7 plant species
-Laptop and Projector for PowerPoint
-Dichotmous key worksheet
-Reference sheets for dichotomous key
-Vocabulary sheet
-Lesson explanation sheet
-Flagging tape for plant specimens

Advanced Preparation: Collect specimens, create PowerPoint presentation, create worksheets

Time: Lesson planned for 50 minutes for a 60 minute class

Grouping: 7 groups of 3-4

Procedure:
1. Introduction (5 min)

Welcome the class, and have them sit in their Adopt A Plant groups. Start with the review question of the week: What is biodiversity? (The winner gets a small prize, in this case a Cal pencil, sticker, and magnet).

2. Adopt a Plant explanation (5 min)

Before getting into today's lesson, take five minutes to explain the Adopt a Plant project, which will be ongoing throughout the plant unit. Hand out the Adopt A Plant sheet.

3. Presentation (5 min)

Hand out the vocabulary sheet. Ask them if they remember the concepts of species and classification. If not, explain them again and emphasize that we use classification to group biodiversity. Introduce the most important concept of the lesson: Defining a character, which is some quality that is used to identify species. Once we have classified species, we create an identification guide called a dichotomous key, which allows us to identify species based on their characters. The key is kind of like a game that we can play to identify species. Show them the PowerPoint slide of an example of a dichotomous key, which we will use to identify some of the students. Explain that we are going to use a similar kind of key to identify the seven plant species that we examined in the last lesson.

4. Activity (25 min)

Hand out the assignment sheet, dichotomous keys, and reference sheets. Each group will get leaves of 7 species of plant, each marked with flagging tape and a number. Using the dichotomous key and reference sheets provided, the students will be asked to identify all 7 plant species, and to make their answers on 1 group worksheet to be handed in. For each identification, they will be asked to indicate the path that they took in the dichotomous key using numbers.

5. Discussion and Wrap-Up (10 min)

Students will be asked if they had fun, and what they learned today. We will then test their retention of plant morphology by asking them to point out an example of simple leaves, or of an herbaceous plant. They will be asked to write a one-paragraph reflection of the activity as homework.

Lesson 2 Recap

DATE TAUGHT: 10/23/08
DATE OF REFLECTION: 10/25/08

Learning goals: what were the goals of this lesson?
After introducing the general diversity of Moorea plants in the previous lesson, this lesson aimed to deepen the kids' understanding of plants by teaching them about the specific characters (specifically morphology) that are used to tell them apart. We wanted them to understand that plants vary in characters the same way people do, and that it is this variation that is used to distinguish species from each other. We used the dichotomous key as a fun and interactive way to teach basic plant morphology. When presented as a kind of "Choose Your Own Adventure" game, dichotomous keys can be a lot of fun for kids.

Do you feel these goals were successfully achieved? How could you tell?
I feel that the results were mixed. On the negative side, I tried to teach the concept of characters at too sophisticated a level, and as a result, it took a lot of time to get them to understand it. Not having worked with such young kids before, I sometimes make the mistake of adding unnecessary complexity to simple concepts. For example, I should have used the word "traits" or even "characteristics" to introduce the idea of variation between species, rather than "characters." While characters might be more technically correct in phylogenetic terms, it is the kind of word that is easily confused with the layman definition of character (i.e. someone's character, in the personality sense). I was overly ambitious is trying to be too technically correct, and as a result, the students didn't really grasp what I was getting at. I did adjust on the fly, and changed the word to characteristics; also, for the second class (I teach back-to-back classes), I used characteristics from the beginning. Once we got past this bit of confusion, the lesson went much better. The kids followed my example of a dichotomous key well (I had created a PowerPoint presentation of a dichotomous key in which the kids were taxa and the characters were simple things like curly vs. straight hair). They seemed to transition well from the dichotomous key example to using a dichotomous key to identify plant species. I had to walk through an example of using the key with some groups before they got it, but generally most groups were able to identify the 7 plant species in the time allotted.

How did you wrap up the lesson (assessment, discussion, etc)?

I wrapped up the lesson by reviewing what a scientific name is. They had each gone through the key and come up with scientific names for the plants, so to ensure that they were making the proper connections, I asked them how many words are in a scientific name, what each word stands for (i.e. genus vs. species), what language it is in, and why we need scientific names. In these first two lessons, I have been using repetition to make sure they understand the concepts of biodiversity, classification, and species, and the utility of scientific names and dichotomous keys. I also asked them to give me examples of plants with various characteristics (such as simple leaves, or opposite leaves).

What worked well?
The dichotomous key activity worked very well. The students worked together to figure out different characters, and were very pleased when they decided on the correct species name. In general, I think teaching them about scientific names and taxonomy was a very useful activity; although many of the species we used are common (i.e. breadfruit), before this activity the students had no idea what the scientific names were or what distinguishes a given species.

What did the students like about the lesson? What did they dislike? (How could you tell?)
The students clearly like working with actual plant specimens, being able to hold them and examine them up close.

What was most difficult for the students? (How could you tell?)
Despite my attempts to make them as clear as possible, some of the conceptual terms like classification, biodiversity, species, and character are still difficult to grasp. While they generally get the idea of classifying things based on similarity, they are not yet grasping the importance of shared common ancestry (homology) for classification. This is particularly difficult to teach, however, before having explained the general principles of evolution, and therefore I am not going to worry too much about it. Homology is a hard concept to grasp for a graduate student, let alone a fifth grader.

What was most difficult for you?
Having finished two lessons, I'd say the two biggest challenges for me are trying to squeeze everything into an hour, and trying to remain attentive to the psychological and sociological aspects of teaching. The first is pretty self-explanatory; despite planning lessons for 50 minutes for a 60-minute class, students' questions and lack of comprehension have slowed me down. The latter has to do with the cultural and linguistic challenges of teaching in such a foreign environment, especially with my lack of pedagogical experience. Since teaching in French is still a challenge to me, much of my energy is often focused on making sure I am being understood, giving me less time to consider some of the deeper responsibilities of teaching at the elementary education level. For example, although the Polynesian kids easily outnumber the French kids, the French kids are more vocal and quick to raise their hands to answer questions. Rather than allow more time to pass before taking answers, I tended to go with the kids who already had their hands up. I also need to start praising the students more when they do something well.

If you were to do this activity again, or were designing a similar one, what would you do differently?
I would definitely simplify my explanation of characters, using the words traits instead.

Further comments about the logistics of running this lesson?

Further comments about the materials (worksheet, specimens)?

Other comments?

Lesson 3

Title: Becoming Scientists

Author: Brad Balukjian

Overview: While the students have been exposed to concrete concepts and activities (plant morphology, classification) in the past two lessons, we have not yet addressed the the meaning of science in general. In this lesson, we introduce the concept of science as a process and adapt its main tenets to the fifth-grade level. The goal is for the students to understand how making observations, asking questions, and setting up experiments are all parts of the process of science. We will use a simple seed germination experiment to address the question: "What is the effect of water pollution on plants?"

Concepts:
-Science is a process, not a collection of facts, that seeks to explain the natural world.
-In doing science, we pose questions about the natural world, and then use experiments and observations to test predictions addressing those questions.
-In doing an experiment, we compare two or more different treatments in order to test for an effect.
-Plants rely on water, among other things, for survival.
-Water pollution is a serious problem for small island communities like Moorea. In order to test for the effect of water pollution on plants, we can design an experiment.

Vocabulary:
Science
Observation
Experiment

French Polynesian Education Standards Addressed:
Parler:
1. Utiliser le lexique spécifique des sciences dans les différentes situations didactiques mises en jeu (Use scientific lexicon in different teaching contexts and environments)
2. Formuler des questions pertinentes (Formulate pertinent questions)
3. Utiliser à bon escient les connecteurs logiques dans le cadre d'un raisonnement rigoureux (Use logical connections in order to achieve rigorous reasoning)

Ecrire :
1. Prendre des notes lors d'une observation, d'une expérience, d'une enquête, d'une visite (Take notes on an observation, an experiment, a survey, or a field trip)
2. Rédiger, avec l'aide du maître, un compte rendu d'expérience ou d'observation (texte à statut scientifique) (Write up, with the help of the teacher, a summary of an experiment or observation in scientific language)

Grade Span: CM2 (roughly 5th grade)

Materials:
Petri dishes
Filter paper for Petri dishes
Seeds
Water
Polluted water (mixed with motor oil)
Spray bottles
Microscope
Laptop
Screen for projection
Field notebooks
Lesson explanation handout

Advanced Preparation: Create worksheets, gather materials.

Time: Lesson planned for 50 minutes for a 60 minute lesson

Groups: 7 groups of 3-4

Procedure:
1. Introduction (5 min)

Welcome the class back from vacation, and ask them to hand in their dichotomous key worksheets from last time. Start with the review questions of the week: Hold up *Hibiscus tiliaceus* and ask if they can describe the leaves (either simple or alternate is correct). Then ask if anyone knows the scientific name. Give prizes to the winners.

2. Lecture and Presentation (15 min)

Hand out the lesson sheets. Tell them that today they will have the opportunity to participate in an investigation in which they will be scientists. Initiate a conversation about what that means by asking them what scientists do. What are some of the things that scientists are interested in? Emphasize that all they need to do to be scientists is to be curious, to observe, and to ask questions. Ask for some examples of questions, such as, “Why is the sky blue?” “What do caterpillars eat?” and “How do plants use sunlight?” Ask them what questions they have, and how they might answer those questions. Ask for specific predictions about what they would expect to find.

Introduce the topic of plants, and ask them what plants need to survive (they will almost certainly mention water, among other things). Ask what they would expect to happen if a plant’s water was dirty and polluted. Ask them what else could happen? What kinds of pollutants could affect the quality of the water? Why is this important to know? Tell them we are going to design an experiment to answer the question: What is the effect of water pollution on plants?

Show an example of a seed and a germinated seed under the microscope using the laptop and projector so they appreciate the morphological complexity of seeds, see what a germinated seed looks like, and get experience using a microscope. Have them break into their Adopt-A-

Plant groups, and hand out the materials for setting up the experiment. Explain that they are to record what they do in their field notebooks, and provide an example of how scientists take notes.

3. Activity (25 min)

Each group should set up 1 "control treatment" Petri dish and 1 "experimental treatment" dish, with 10 seeds in each dish. Ask them to record their materials and methods in their field notebooks as they set up the experiment, in which they will water their seeds with either clean water or polluted water. Ask them what they could measure to try and document the effect of water pollution. Show them the chart that they will use to track the germination of their seeds, and explain how they are to monitor and record their data. The chart will hang in the classroom on display. Explain that in an experiment such as this one, we test for an effect by comparing two different treatments.

4. Wrap-Up (5 min)

We will reiterate the main concepts of the lesson by asking them how they behaved like scientists. Ask them why studying water pollution is important. We will answer any questions, and then ask them to write a five-line recap of the lesson in their field notebooks for homework (see handout for specific assignment).

Lesson Recap

DATE TAUGHT: 11/20/08
DATE OF REFLECTION: 11/20/08
Learning goals: what were the goals of this lesson?
In this lesson, we wanted to take a step back and get the kids thinking about what science really is and what scientists actually do. Our main concepts were that science is a process, and that science involves making observations, posing questions, making predictions, and conducting experiments. We wanted them to figure out for themselves how an experiment is designed and how we choose the data to collect in conducting an experiment. We used plant germination and water pollution as our vehicles for teaching the meaning of science and experimentation, thus tying together biodiversity, plant biology, and conservation.

Do you feel these goals were successfully achieved? How could you tell?
As usual, I feel we accomplished some of what we set out to do. Every group successfully set up their experiment, and so on a practical level, we accomplished our goal. Since this was the first class we have taught in almost a month (due to the vacation and strike), and since only about half the class was there (since the strike is still ongoing), I decided to take a more relaxed pace in the discussion part of the class instead of rushing into the activity. I recognized the tradeoff here—if I spent more time on the discussion, I knew that we might not finish the activity and not have enough time for a wrap-up; sure enough, my suspicions were confirmed. But I think it was worth it. I wanted to have more time to let my questions sink in before fielding answers, and to see how long they could go in a discussion before they started to get restless. I was pleasantly surprised. Most of the students raised their hands several times and patiently waited to be called on. I would even get 4-5 responses for each question. I made a strong effort to not call on the first hand that shot up, and to distribute their speaking time evenly. I did not call on anyone; perhaps I should

try this strategy with the quieter kids? We spent most of our discussion figuring out what scientists do. They identified the process of observing the natural world and asking questions, but they were not so easily led to the notion of creating an experiment and making comparisons. Also, I did not explicitly discuss the concept of science as a process, rather than a collection of facts. They may have figured that out intuitively, but perhaps I should have been more direct with that point. They seemed to grasp the importance of studying water pollution easily enough, and once I explained the concept of an experiment, they were able to give examples of how to set up other types of experiments and controls (e.g. how would you test for the effect of light on plants?)

How did you wrap up the lesson (assessment, discussion, etc)?
Poorly. Since we spent so much time on the discussion, we had just enough time to finish the activity and for me to hurriedly explain the homework assignment. My plan was to end with a 5-minute discussion in which I asked them questions like, "How did we behave like scientists?" and "Why is studying water pollution important?" But, I still think it was worth sacrificing the wrap-up in order to have more time for the discussion.

What worked well?
I started off with a little English lesson in which I taught them how to say their name and age. The teachers have been keen on us incorporating a bit of English into the lessons, since the kids are now taking English courses. I also began the lesson with the question of the week, which is always a question recapping the previous lesson (with the incentive of small prizes—this week, an American football and several Cal items). The kids seem to like the English lesson and question of the week, and they serve as nice transitions into the lesson. In terms of the actual lesson, they demonstrated an understanding that science is based on observations, and seemed to grasp how an experiment works. While they may not yet fully appreciate the scope of the experiment, as they water their seeds and record the germination data on the large sheet we posted in the classroom, I think they will benefit enormously from seeing a project through from the beginning to completion.

What did the students like about the lesson? What did they dislike? (How could you tell?)
I think the students liked all the gadgetry we presented. I brought in a microscope set up to a laptop which I projected to show them what a germinated seed looks like. I asked some of them before class if they had ever used a microscope before, and they said no. They also seemed to really like the hands-on activity of setting up the experiment, counting out the seeds, and spraying them with water and motor oil. They didn't seem to dislike anything, except for a couple of them appearing bored.

What was most difficult for the students? (How could you tell?)
They have a hard time multi-tasking and need to be told very clearly and explicitly exactly what they should do. Not many of them are able to work very independently. Even when I try to emphasize things like following directions, writing their names on their work, and writing down notes in their field notebooks, they get easily distracted and off-task. There are, of course, those few exceptional students who follow all directions to the letter, but I suppose every class has a few of those.

What was most difficult for you?
For me, the hardest part is thinking like a fifth-grader. With every lesson that passes, I have a deeper and deeper appreciation for the job of an elementary school teacher. I am used to speaking about and listening to science in professional, adult terms, and it is difficult to adjust to the broader and more desultory way in which fifth graders think. Throw the language and cultural barriers on top of that, and it can be very difficult to lead the discussions effectively. The trick seems to be finding the line of questioning that guides the students to figuring out the key concepts on their own. Erica and the teachers have been very helpful in this regard, supplementing my lectures with questions for clarification and further discussion.

If you were to do this activity again, or were designing a similar one, what would you do differently?
I would probably spend at least a little bit of time emphasizing explicitly that science is not just a collection of facts. I also might talk more extensively about the importance of water pollution in a place like Moorea.

Further comments about the logistics of running this lesson?

Further comments about the materials (worksheet, specimens)?

Other comments?
It was nice to finally get back in the classroom today after almost a month layoff due to the vacation and strike. Any momentum we had was slayed by the work stoppage, and even today, we only taught one class (Patrick is still striking) and almost half the students were absent. We have had to reshuffle the syllabus, but I think we're back on track. One thing is for certain—the educational system here is very fly-by-the-seat-of-your-pants. Already, we have had two strikes, one of the teachers (Patrick) has been promoted to school principal, we've had classes cancelled at the last minute, classes taught at the sailing school, field trips cancelled, and the school principal is still MIA. In the classroom, the teachers (Patrick and Caroline) are very helpful with clarifying things, disciplining, and answering questions. But they can also be very flaky and do not seem too eager to devote much time out of the class to the project. For example, I have asked Patrick at least 3 times to provide a simple list of the students in his class and their assigned plant groups, with no results. I send every lesson plan ahead of time to both of them,
and never get feedback beyond "this looks good." Patrick has never responded to any of my e-mails, and when I asked him about it, he says he doesn't really bother with most of his e-mail. I have to be very specific and firm if I want them to do anything. Some of this seems to stem from cultural differences—unlike us Americans with our often-unhealthily diligent work ethic, the people here seem to want to "leave it at the office," so to speak. I don't mean to complain, I just wanted to give you an overall understanding of the situation on the ground here. Overall, Caroline and Patrick have been good to work with, and despite the setbacks thus far, I feel good about the program overall. It's those little things that make it all so rewarding. For example, one of the locals who works as a field assistant to a researcher here told me that one of her neighbors is a student in the class, and that he came home after class and announced to his parents that he wants to be a botanist. That's why we're in this business—to inspire.

Lesson 4

Title: Introduction to Biocode and Genetics

Author: Brad Balukjian

Overview: One of the yearlong goals for the program is to involve the students with the Moorea Biocode Project (MBP), a massive inter-institutional project whose goal is to catalogue every macrospecies on Moorea (and some microscopic species as well). We want the students to understand how special their island is in terms of biodiversity, and also to appreciate how scientists can compile data on an entire ecosystem. Later in the year, the students will collect plant and animal specimens that will go directly into the MBP database. For now, we would like to introduce them to the basic goals of the MBP. In next week's lesson, the last before the Christmas holiday, the students will present their Adopt-A-Plant species at "La Fête Des Plantes," in which GK-12, MBP, and the local cultural center Te Pu 'Atiti'a will participate. In order to prepare them for the presentation that the MBP people will give on that day, we decided it would be best to introduce that MBP ahead of time. And in order for them to better understand the MBP, we will introduce the concept of genetics here. Our goal is for the students to understand that genes are tiny bits of information stored inside cells, that genes are heritable, and that genes determine the appearance, function, and behavior of all organisms. We also will introduce DNA as the universal code that make up genes, and will apply the concept of genes through a game aimed at identifying a mystery plant. We will connect the concept of genes to the MBP by explaining how genes can be used to identify species.

Concepts:
-A gene is a tiny piece of information stored inside cells that is heritable and that determines the appearance, function, and behavior of organisms.
-Genes consist of a code of molecules called DNA.
-Every species has a different sequence of DNA that can be used to distinguish it.

Vocabulary:
Gene
DNA

French Polynesian Education Standards Addressed:
Parler:
1. Utiliser le lexique spécifique des sciences dans les différentes situations didactiques mises en jeu (Use scientific lexicon in different teaching contexts and environments)
2. Formuler des questions pertinentes (Formulate pertinent questions)
3. Utiliser à bon escient les connecteurs logiques dans le cadre d'un raisonnement rigoureux (Use logical connections in order to achieve rigorous reasoning)

Lire:
1. Traiter une information complexe comprenant du texte, des images, des schemas, des tableaux, etc. (Work with complex information comprised of text, images, tables, etc.)

Grade Span: CM2 (roughly 5th grade)

Materials:
Laptop with projector
Mystery box
Mystery plant (Inocarpus fagifer)
Envelopes with genes
Reference Key

Advanced Preparation: Create PowerPoint presentation, design gene activity

Time: Lesson planned for 50 minutes for a 60 minute lesson

Groups: 7 groups of 3-4

Procedure:
1. Introduction (5 min)

The question of the week this week is: What is the difference between an introduced and an indigenous species? Remind the kids of their deadline for next week's Fete des Plantes, and then introduce the lesson by saying that we are going to learn about a research project happening at the Gump Station and about genes.

2. Lecture and Presentation (15 min)

There's a lot to get through today, so try to keep the discussions short and succinct. Open with a PowerPoint presentation introducing the Moorea Biocode Project. Tell them that scientists from all over the world are coming to Moorea to work on this project (ask them again if there is such a thing as a Tahitian scientist to see if they have changed their perception in the previous weeks). Explain that just like them, these scientists are studying biodiversity, particularly the biodiversity of Moorea. The goal of the project is to find and document every species on the island and in the waters surrounding the island. Show them a slide that shows the kind of data we are entering for each species. Tell them that after Xmas, they too are going to be scientists working on Biocode, and that the plant and insect specimens they collect on their field trips will become part of the project.

Ask them if they know what a gene or DNA is. See what kinds of responses they give to gauge their baseline knowledge (likely very little). Using PowerPoint slides, show them that genes are little bits of information stored inside their cells that determine what they look like, how their bodies function, and how they behave. Explain that plants and other species also have genes just like them. Tell them that genes are inherited from parents, and ask them how we know this. Show pictures of human families to emphasize the similarity in parents and offspring. Explain that every species has a unique set of genes whose DNA sequence is used to distinguish it (this will require explaining that genes and DNA are basically the same thing). In the Biocode project, we will determine the DNA sequence of each species using equipment in the laboratory. Tell them that today we are going to play a game to teach them more about genes.

3. Activity (25 min)

Divide the class into their Adopt A Plant groups. Give each group an envelope that contains six genes, represented by six slips of paper. On each gene (numbered 1-6) there will be a sequence of six letters (A,T,C,G) representing DNA (no need to explain what the A,T,C, and G stand for, just say that they are DNA molecules and the order in which they are arranged determines some trait of the species). Also hand each group a reference key, which will have all six genes listed. For each gene on the reference key, there will be 2 DNA sequences listed, each corresponding to a particular value for that trait (i.e. for gene 1, sequence ATTCGG=opposite leaves; ATCGGA=alternate leaves). They will match each gene with its corresponding trait value for all six genes, until they have a plant with six characteristics (i.e. a tree with simple, opposite, elongate leaves with white flowers and purple fruit). Tell the groups that their task is to figure out the identity of the mystery plant (in the mystery box) by figuring out what their plant looks like for the 6 genes included.

4. Wrap-Up (5 min)

To wrap up, we will ask them what a gene is to see what they have comprehended. We will ask where genes are found and how the sequence of DNA can affect what a species looks like. We'll ask them questions that require them to apply what they've learned in a new way. We will ask if they have any questions, and remind them about their presentations next week.

Lesson Recap

DATE TAUGHT: December 4, 2008
DATE OF REFLECTION: December 8, 2008

Learning goals: what were the goals of this lesson?

This lesson was the last one before La Fête Des Plantes, which is the final lesson before Christmas. La Fête Des Plantes will also serve as the launch for a new program based at the Gump Station called Ethnocode, whose goal is to incorporate all of the Gump programs in stimulating research and education on the cultural and scientific knowledge of Moorea's biodiversity. Since the students will be hearing more about Biocode at La Fête Des Plantes (and eventually contributing specimens to the project), we felt it important to introduce them to the Biocode project in this lesson. Our goal was for them to understand the enormity and importance of Biocode, and to take pride in the fact that their island is the staging ground for a project that draws scientists from all over the world. We also took the opportunity to remind them that they too are becoming scientists and that they are going to be a part of Biocode as much as the other researchers. In order for them to truly appreciate Biocode, we also felt it necessary to provide a simple introduction to genetics, since DNA barcoding is a big part of Biocode. This was a very tricky challenge, as it is very difficult to teach genetics to kids at this level. I tried to keep it simple—the main concepts we wanted them to understand were that genes are very small bits of information inside of cells, that they are heritable, and that they determine what organisms look like.

Do you feel these goals were successfully achieved? How could you tell?

Overall, I was pleased with the outcome of this lesson. I knew I was being ambitious in trying to teach genetics at this level, but I think the kids grasped the 3 main concepts. The exercise that we did was a game in which the kids tried to identify the plant inside a "Mystery

Box," using genes as clues. Each gene coded for a particular plant trait (i.e. alternate vs. opposite leaves) and was represented by a strip of paper with a sequence of nucleotides (we didn't teach them the word nucleotides, we just told them that A,C,T and G are the letters in the "DNA code"). For each gene, there were two possible DNA sequences (and corresponding phenotypes); using a reference sheet, the students matched their genes' sequences with the appropriate phenotypes. Once they had "decoded" their plant, they then had to figure out which plant had all of their traits, which they did by discussing among themselves, drawing on past knowledge, looking in reference books, and looking at specimens. The kids "got" the activity pretty quickly; the hardest part for them was cobbling together all of their clues to guess the identity of the mystery plant. I was pleased with the way the activity pushed them to collaborate and use reference materials, and the way it reinforced the material from past lessons. The kids actually took the initiative several times; for example, I did not immediately hand out the plant specimens or books that were in the room, but some of them approached me to ask if they could use those materials to help them. I don't think they fully grasped the concept of the DNA barcode, but I was pleased enough with their progress. I spontaneously had the idea to have each group come up with a guess for the plant's identity, and turned it into a bit of a competition (complete with announcing each group's guess one at a time, having a drumroll kind of suspense, and having one lucky student open up the mystery box and pull out its contents). Only one group in the two classes came up with the right answer, and they celebrated in grand fashion when they were announced as the winners.

How did you wrap up the lesson (assessment, discussion, etc)?

In the first class (Caroline's class), I wrapped up by explaining why a project like Biocode is important (during the activity Caroline had approached me and asked me to address this). To do so, I told a hypothetical story about a student wandering around in the woods one day looking at plants. This student had no scientific background, but was naturally curious about biodiversity. He/she saw a plant they particularly liked and wanted to know what it was. With the data generated through Biocode, that student could take a sample from the plant, bring it into the lab, and in very little time figure out its identity by looking at its genes (and referring to the database). Thus Biocode will be a vastly important tool for identifying species, especially for non-experts. While this may have been a nice explanation in theory, it was a bit hard to pull off in French, and I'm afraid they may have zoned out a little (they were all pretty tired by the end of the lesson).

In Patrick's class, I wrapped up by asking one of the groups what a gene was. They had no answer, which was discouraging. So I called on another student, who said that genes are little bits of information inside our cells. I then pointed out a student with blonde hair, and asked him why his hair is blonde (the idea here was for them to apply the concepts of the lesson to humans, after having been thinking about them in the context of plants). One student said, "Because of his parents." So I asked how his parents contribute to his hair being blonde. And one of the students explained that the parents passed their genes on to their kids.

What worked well?

As I explained above, I think the presentation and activity both went well.

What did the students like about the lesson? What did they dislike? (How could you tell?)

I have been trying to directly incorporate the students into my presentations as much as possible. In my PowerPoint, I included photos of them in the slides explaining the scope of the project and who is participating. On the slide explaining DNA barcodes, I included a photo of a student next to a photo of a Hibiscus tree and said that both organisms had the same basic genetic code, but different barcodes. The kids seem to like when they are included in the presentations; plus it is a reminder to them that they are a species too. The kids also liked the video I showed them about Biocode and got very excited when they saw students from their school collecting insects in the field.

What was most difficult for the students? (How could you tell?)

The hardest part for them was guessing the identity of the plant in the mystery box. Once they figured out the clues, it was hard to figure out exactly which of their adopted plants had all the traits they were looking for (many of the plants might have the right color flowers, for example, but not the right color fruit). Since each group has only been focusing on one plant species, they did not know the traits for all the other plants, which required them to ask people in other groups. Of course, when you have kids of this age moving all over the classroom, things inevitably get a little chaotic.

What was most difficult for you?

The hardest part for me was getting across the idea of a DNA barcode without explaining nucleotides, proteins, or the rest of the genetic vocabulary. I tried to provide the metaphor of the grocery store barcode, but it is still a difficult concept.

If you were to do this activity again, or were designing a similar one, what would you do differently?

There were a few minor things I would change, but in general I think the core lesson was effective.

Further comments about the logistics of running this lesson?

Further comments about the materials (worksheet, specimens)?

Other comments?

I don't know how full-time elementary ed teachers do it. After teaching back-to-back classes, I am so drained I can barely see straight. What's your secret?

Lesson 5

Title: The Visualization of Data in Science

Author: Brad Balukjian

Overview: After a several-week break, the GK-12: Moorea project begins again. Because of scheduling issues and various delays last fall, the Plants unit was interrupted by the break, and so we will pick up where we left off. I want to ease the students back into the program by reviewing the meaning of biodiversity, and also to recap the seed germination experiment that they completed before the break. The main goal of this lesson is to teach them how scientists transform raw data into pictures or graphs to maximize comprehension. While they have probably seen graphs before in the media, they probably do not know much about how to construct or interpret them. The skills they learn in this lesson will also enhance their understanding of the process of science; one of the goals for the year is for the kids to grasp the entire scope of scientific inquiry (observation, hypotheses, procedure, results, discussion, conclusion) and how we summarize the whole process in scientific reports (as specified in the French Polynesian educational standards). The seed germination project was our first group experiment; in the second one, on insect behavior, the students will be expected to incorporate knowledge from this lesson in their assigned task of writing a complete scientific report.

Learning how to visualize data is an abstract and difficult task, especially for those who are not visual thinkers. We will start with a familiar example involving their birthdays, and then ask them to try and imagine how we could similarly visualize the results of their seed germination experiment. The tangible product of the lesson will be for each of the groups to create a graph showing the data that they collected. They will then be asked to interpret the overall results.

Concepts:
-Data can be represented in many different ways, such as raw numbers, words, tables, lists, and graphs.
-In order to more easily communicate their findings, scientists represent their data graphically.
-There is no one set way to visually represent data; the challenge is finding the most effective way.
-In an experiment, we measure and compare some quantity in order to test for an effect.

Vocabulary:
Graph
Data
Experiment

French Polynesian Education Standards Addressed:
Parler:
1. Utiliser le lexique spécifique des sciences dans les différentes situations didactiques mises en jeu (Use scientific lexicon in different teaching contexts and environments)
2. Formuler des questions pertinentes (Formulate pertinent questions)

3. Utiliser à bon escient les connecteurs logiques dans le cadre d'un raisonnement rigoureux (Use logical connections in order to achieve rigorous reasoning)

Lire:
1. Traiter une information complexe comprenant du texte, des images, des schemas, des tableaux, etc. (Work with complex information comprised of text, images, tables, etc.)

Ecrire:
1. Produire, créer, modifier et exploiter un document à l'aide d'un logiciel de traitement de texte. (Produce, create, modify, or improve a document using the logical treatment of text).

Grade Span: CM2 (roughly 5^{th} grade)

Materials:
Laptop with projector
PowerPoint presentation
Results table from seed germination experiment
Individual sheets of large paper for drawing graphs
Markers and large rulers for drawing graphs

Advanced Preparation: Create PowerPoint presentation

Time: Lesson planned for 50 minutes for a 60-minute lesson

Groups: 7 groups of 3-4

Outline
1. Introduction (5 min)

We will start with some logistics, since it will have been awhile since I have seen them. I will explain that we have two more lessons on plants (including today), and will then tell them that they will have a short test (to be handed out at the end of next week) on the material they've learned in the plants unit. They will then be given a grade based on their exam score, their field notebooks, their oral presentations at La Fete Des Plantes, and their posters for La Fete Des Plantes. In two weeks, we will start the next unit, on insects.

I will then give them the question of the week, which will be a refresher and is central to the program overall: What is biodiversity?

2. Lecture and Presentation (15 min)

Start by reminding them of our seed germination experiment. Ask them what the purpose of the experiment was (testing the effect of polluted water on plants) and how we did it. Reiterate that the purpose of an experiment is to answer a question about nature by measuring and comparing things. Once we have finished the experiment, we need to show our data, which are the results of our experiment. We can show the data in many ways, such as in words, but we can also show them in pictures, or graphs, which makes it easier for people to understand.

Start the PowerPoint presentation and show them the slide of the bar graph, which has a blue bar and a purple bar of different heights, but without any labels. Ask them if they have seen

pictures like that before, and if so, where? Ask them what the graph means. They will likely have no idea (as they shouldn't). Then show them the same data in words (Blue=2 Purple=26). Tell them that this is the same information, but just represented in words instead of a picture. Explain to them that without more information on our graph, it doesn't make any sense. Then show them slides in which the graph is properly labeled (it shows the dates of their birthdays). Even though there are no exact numbers on the graph, it is very easy to see that there are a lot fewer students with birthdays in February then all the other months combined. Transition by showing them the data they collected in the germination experiment (which is in the form of a table), and ask them how we can represent this data in a picture, or graph, much like we did with their birthdays. Ask for a volunteer to come to the board to try and draw the graph.

3. Activity (25 min)

Once they have arrived at a reasonable solution, tell them that the activity for the day is for each of their groups to draw a graph of the data for the seeds that they monitored. When we are done, we will hang their graphs on the walls of the classroom. Hand out large sheets of paper, rulers, and markers, and put the master data table in the front of the class for their reference. Walk around the room assisting as needed. When finished, ask a representative from each group to hold up their graph, and then ask the rest of the class what the trend is? What is the overall result? Is it easy to see on our graphs?

4. Wrap-Up (5 min)

To conclude, ask them, after all that we've done today, what we did in our seed germination experiment, and what the result was. Ask them how we can represent our data after we have finished an experiment. Tell them that for homework (pass out sheet here) they are to choose from five other environmental problems in Moorea, and they are to write a paragraph explaining the problem and why they think it's important. They also have the option of choosing their own environmental issue.

Lesson Recap

DATE TAUGHT: January 29, 2009
DATE OF REFLECTION: January 30, 2009

Learning goals: what were the goals of this lesson?
After a long layoff, one of the main goals of the lesson was to get the students back into the swing of things, thinking about science. To do so, I led off with the question of the week, which was simply, "What is biodiversity?" I was pleasantly surprised to hear the answers; while it took awhile to get a precise definition, they grasped the essence of the concept, that of variation and quantity of living things. The other goals were to show them how scientists use graphs to present their data, and how graphs present the same information as words and numbers, but in a way that is more quickly understood. I also wanted to reiterate the importance of experiments, specifically why we do them (to answer questions about the natural world) and how (by comparing different things and looking for an effect). And I wanted them to be able to draw conclusions from the data and graphs that we assembled for the seed germination experiment.

Do you feel these goals were successfully achieved? How could you tell?

As has been the case several times this year, the lesson was the story of two classes: Caroline's class went much smoother; Patrick's was rough. As I've explained before, Patrick's class is now essentially taught by a glorified sub named Uramoe, who despite being quite knowledgeable and effective one-on-one, is too timorous to have much control over the whole class. Not only that, but due to the strike last year (Caroline crossed the picket lines a week before the strike ended, so her class ended up having one more lesson than Patrick's) Caroline's class had done the seed germination experiment and collected all the corresponding data, while Patrick's class had not. Since this lesson dealt specifically with the data from that experiment, I faced the additional challenge of explaining the experiment to Patrick's class. (As an aside, I spoke with Uramoe after class about his role, as suggested at our GK-12 meeting before Christmas. I asked him to try and be more vocal during the lecture part of the lesson, to help me if he sensed that the kids were not understanding something. I also got his contact information so I can send him lesson plans ahead of time. He seemed responsive.) In Patrick's class, the students seemed lost. I struggled to explain the experiment, let alone the concept of graphs. I kind of felt like a stand-up comedian who is bombing in front of a live audience—I could sense the kids weren't really with me. Plus, in Patrick's class, there is a group of 4 very precocious and vocal boys who tend to dominate the classroom. They can be disruptive, but the thing is, they are very, very smart, enthusiastic and helpful. I really like them. But I think the other kids get intimidated by them, because they are so extroverted. But I slogged through it, and ground it out, and through sheer effort alone averted abject failure. I could tell that a couple of the groups got it, that they understood how to use and read graphs, but many of the other groups had a hard time even with the basics of drawing the x- and y-axes. By contrast, in Caroline's class things went really well. I was further bolstered by the fact that Caroline had introduced them to graphs earlier in the day (not sure if this was a coincidence or that she did it because I had sent her the lesson plan), and so they were already familiar with the concept. What most impressed me was when I asked them how we could represent the seed germination data with a graph, they came up with multiple ways to do it, which was one of the lesson concepts, that there is not just one way to graph data.

How did you wrap up the lesson (assessment, discussion, etc)?
I had planned on wrapping up by asking each group to hold up their graphs, and then to have the class say what the graphs told us. Also, I wanted to ask them again why it is we do experiments, and why we graph data. I made a command decision in the moment to sacrifice the wrap-up, since they were in the middle of drawing the graphs and making good progress. I continue to struggle with the wrap-up; I know it is very important to reiterate the objectives and concepts, but in this case I didn't want to break the flow that they had established. I did hand out a review sheet for their test next week and a homework assignment.

What worked well?
To introduce them to graphs, I showed them a PowerPoint graph of their birthdays. I started by showing them the graph without any labels, legends, or titles, and then showed a slide that included them to emphasize the importance of proper labeling. I showed them the data depicted by the graph in words, and then showed them how the graph and words represented the same thing. I then transitioned into working with the data from the germination experiment, and asked for a volunteer to see if they could draw a similar graph on the board representing these data. I was impressed that in both classes, students correctly drew the graphs, albeit without all the proper labels, etc. Once they got going, the students got in a good groove working on the graphs.

It's neat to see them work as a team, discussing how to approach a problem, even arguing about how to do it. In some cases, however, there are 1-2 students in the group that assume the bulk of the responsibility, and the other students unfortunately seem content to coast.

What did the students like about the lesson? What did they dislike? (How could you tell?)
As usual, the students liked being personally included in the example graph during lecture. Kids of that age always love their birthday, so it was a good example to use to teach them about graphs. I also included pictures of them in the presentation, which they seemed to like. I started the lesson by briefly recounting my adventures being stuck on Mehetia, where we ate wild goats and pigs. They dug that. I think Patrick's class in particular did not like working with the other class' data.

What was most difficult for the students? (How could you tell?)
I think the students continue to struggle with articulating some of the more abstract concepts. For example, when I ask them what we did in the seed germination experiment, they can tell me. When I ask them why we did it, they say, "To see which seeds grew or germinated more." But they aren't necessarily making the next jump in logic to "To test the effect of pollution on plants." I will continue working on this with them, to help them make the connection between a question that interests us and the experiment we can design to answer that question.

What was most difficult for you?
The hardest part for me by far was the lecture portion of Patrick's class. They are a harder group to connect with, and I had the task of explaining the seed germination experiment and the concept of graphing data.

If you were to do this activity again, or were designing a similar one, what would you do differently?
I would probably teach Patrick's class using some other data that they could more easily relate to. I'm not sure exactly what, but it was tough for them to work with Caroline's class' data. They also may have felt a little cheated, as in, why didn't we get to do the experiment? I saw firsthand what a difference it makes in comprehension if you actually do an experiment versus just hearing or reading about one. Doing is everything…I'm sure someone wise has said that before, most likely Mark Twain (since he seems to have said 75% of all great quotes).

Further comments about the logistics of running this lesson?

Further comments about the materials (worksheet, specimens)?

Other comments?
It was really cute how the kids were so proud of their prizes from La Fete Des Plantes. They made sure to point out the posters of plants that were hanging on the walls and the location of the grand prize, the globe/book.

Lesson 6

Title: Creating Herbarium Specimens

Author: Brad Balukjian

Overview:

Biodiversity is the central theme of this program. In our study of plants so far, we have gone from the large-scale (collecting whole organisms) to the microscopic (discussing genes), from observation (drawing and describing plants) to hypothesis testing (the seed germination experiment). But we have not yet covered an essential component to any biodiversity course—the preservation of actual specimens. The biological sciences in general have drifted away from an emphasis on basic taxonomic and natural history education and knowledge, which provides the foundation of all the integrative disciplines that are so in vogue. The main goal of this lesson is to teach the kids the importance of properly preserving plant specimens so that they can be used for future studies. Museum specimens not only allow for closer and more detailed study than is possible in the field (taxonomy, genetics, morphology) but also provide a historical record of the biota of a particular locality. I will use this opportunity to introduce the concept of extinction, albeit tangentially (extinction and the dynamic nature of biodiversity will be explored in detail in the evolution unit).

In order to give the students a sense of ownership over their work and to teach them about museums at the same time, the main activity of this lesson is preparing an herbarium specimen using the plants they collected earlier in the week. They will be allowed to keep their mounted specimens, which we may also display at the Fete de la Nature later in the semester. Time permitting, I would like them to have the chance to examine their specimens under the microscope.

Concepts:

-An herbarium is a museum for plants, where specimens are stored and displayed.
-Scientists put plants in herbaria in order to study them further and to create a historical record of the plants that existed in a particular region at a particular point in time.
-Plant specimens are prepared for deposit in herbaria following a standard procedure involving pressing plants and then mounting them with labels on special paper.
-Species sometimes go extinct, either because of human interference or because of natural causes.

Vocabulary:

Herbarium
Museum
Extinction

French Polynesian Education Standards Addressed:

Parler:

1. Utiliser le lexique spécifique des sciences dans les différentes situations didactiques mises en jeu (Use scientific lexicon in different teaching contexts and environments)
2. Formuler des questions pertinentes (Formulate pertinent questions)

3. Utiliser à bon escient les connecteurs logiques dans le cadre d'un raisonnement rigoureux (Use logical connections in order to achieve rigorous reasoning)

Lire:
1. Traiter une information complexe comprenant du texte, des images, des schemas, des tableaux, etc. (Work with complex information comprised of text, images, tables, etc.)

Ecrire:
1. Produire, créer, modifier et exploiter un document à l'aide d'un logiciel de traitement de texte. (Produce, create, modify, or improve a document using the logical treatment of text).
2. Rédiger, avec l'aide du maître, un compte rendu d'expérience ou d'observation (Write or edit, with the help of the teacher, a report on an experiment or observations)

Grade Span: CM2 (roughly 5^{th} grade)

Materials:
Laptop with projector
PowerPoint presentation
Plant samples from field trip in plant press
Herbarium paper
Glue
Paper for label information
Paintbrushes for spreading glue
Herbarium specimen example

Advanced Preparation: Create PowerPoint presentation, pressed plants

Time: Lesson planned for 50 minutes for a 60-minute lesson

Groups: Students will work individually

Outline
1. Introduction (5 min)

To recap last week, I will lead off with the question of the week, which will involve some writing for a change. I will draw an unlabeled bar graph on the board, explaining that it shows the results of an experiment testing the effect of light on seed germination. I will then ask a student to provide a title and three labels for the graph: 1 for each of the bars on the x-axis, and one for the y-axis.

I will then tell them that we are going to work with the specimens they collected earlier in the week.

2. Video (5 min)

Before we get into the details of the lesson, I want to take a few minutes to show them the video that we produced from La Fête Des Plantes. I think they will enjoy seeing themselves on film.

3. Lecture and Presentation (10 min)

I will base today's lecture on a PowerPoint presentation that covers the reasons for why we deposit specimens in museums. The lecture will be question-driven, as usual, and will try to get the students to come up with the answers themselves before I give them anything. I will ask them if they have heard of an herbarium, or if they have been to a science museum before (specifically Le Musée de Tahiti et Ses Iles, which is the country's natural history museum). I will ask them why we have museums and herbaria. I will also introduce them to the concept of extinction by pointing out that many extinct species are only known from museum specimens (I will use the Raiatea parakeet as a case study, which was captured on Capt. Cook's second voyage to French Polynesia and deposited in two museums, never to be seen again). But before that, I will get a sense of their baseline knowledge of extinction by asking them if they know of any extinct species and why species go extinct. I will finish with a recap of the biodiversity they collected on their field trip earlier in the week, with a list of all the plant species they found.

4. Activity (25 min)

The main activity today is for each student to create an herbarium specimen using the specimen they collected on the field trip. I will provide paper and glue to each student, and will show them an example of a properly mounted herbarium specimen. Once they have mounted their plant on the paper, I will give them a sheet of paper on which they will write all the information to go on the label. Identifications have been provided by Biocode botanist Ravahere Taputuarai; the students' main task will be to transfer their field observations from their field notebooks to the label. Since it is too logistically difficult to have them type up and print out their labels, I will have them handwrite the information and I will type them up later. When everything is done, they will have the chance to keep their specimen or to send it to the herbarium in Tahiti for display (this is pending approval from the herbarium director, who I have contacted).

If we have some time left over, I will then give them a chance to look at their specimens under the GK-12 dissecting microscopes.

5. Wrap-Up (5 min)

To wrap up, I will remind them that this is the last lesson on plants, and that they will have a test shortly on the whole unit. We will begin the insect unit next week. I will then ask them what their favorite lesson was in the plants unit and why. No homework—yipee!

Lesson Recap

DATE TAUGHT: February 5, 2009
DATE OF REFLECTION: February 5, 2009

Learning goals: what were the goals of this lesson?

The main goal of this lesson was to teach the students about the importance of museums and herbaria, and to then give them the chance to prepare specimens that could actually go in an herbarium. I also wanted to introduce the concept of extinction, as it is an essential part of any course on biodiversity (in the evolution unit, we will discuss how the addition of new species—speciation—and the deletion of species—extinction—affects biodiversity (the number and variety of species)). I also wanted to emphasize continuity with past lessons, as usual. The

students worked with the specimens that they collected on the field trip earlier in the week, and the field notes they took provided the data for their specimen labels.

Do you feel these goals were successfully achieved? How could you tell?

I do think the goals were successfully achieved. I told them how impressed I was that they collected so many different species (a good cross-section of biodiversity) and that they avoided collecting the most accessible and well-known plants. They had a good baseline understanding of why we put organisms in museums, and also of the concept of extinction. I was surprised by how few of them had been to museums before, although when I think about it, I shouldn't have been, as there are only a couple of museums in French Polynesia. Caroline was very excited by the idea of taking a field trip to Papeete to visit Le Musée de Tahiti et Ses Iles (the country's natural history museum). The activity was straightforward and the students enjoyed seeing their pressed plants and mounting them on the herbarium paper.

How did you wrap up the lesson (assessment, discussion, etc)?

In the first class (Caroline), I wrapped up by telling them that we will begin working with insects next week, and then asked them what their favorite lesson or activity was from the plants unit. Everyone responded with "Tout," which means "everything." It made me feel really good to hear them say that on their own accord. In Patrick's class, I just let them finish working on their plants, as I was emotionally drained and a bit out of sorts (see below for an explanation). Perhaps I need to be a little less ambitious with the lesson plans to have enough time to wrap up effectively.

What worked well?

For the question of the week, which leads off every lesson, I tried something different. Instead of asking a question orally, I drew an unlabeled graph on the board, and explained that it showed the results of an experiment on the effect of light on plants. I then asked someone to come to the board to label the graph and to provide a legend. This took some time (probably more time than the question of the week should take up, which put us behind for the rest of the lesson), but in Caroline's class, one student did it successfully. The exercise with mounting the plants and writing the content of the labels went smoothly.

What did the students like about the lesson? What did they dislike? (How could you tell?)

In between classes (I have 15 minutes between classes), I saw a bunch of students huddled together looking at something. Naturally, I figured it was a gossipy note or a video game, but it turned out to be the list of plants they had collected with their names. They were so excited to find their names and to see the scientific names (which don't exactly roll off the tongue) of the plants (our resident Biocode botanist, Rava, had identified all the plants). That was so cool to see.

The students also really liked the video that I showed them of La Fete Des Plantes from last December. The Biocode team had taped the whole day, and then edited the footage down to a crisp 6-minute clip. The students laughed seeing themselves on-screen, and although the audio was not loud enough, they seemed entertained. They did not seem to dislike anything; in fact, I think they liked working individually for a change, as each of them had their own plant.

What was most difficult for the students? (How could you tell?)

The only time that I saw them struggle today was when Patrick's class had to answer the question of the week. Again, because they had not done the seed germination experiment themselves, they had a hard time grasping the concept of an experiment, data, graphs, results, etc. They were unable to label the graph properly, and in the interest of time, I decided to end the activity without awarding the prizes to anyone (I think it's important to teach them that if there is no one deserving, then no one wins. We don't give out accolades for charity).

What was most difficult for you?

This was the first time since I began this program that I felt truly upset/frustrated. Caroline's class went well. Knowing that Patrick's class (now led his replacement, the feeble Uramoe) is harder to teach, I tried to take the necessary precautions. I asked Uramoe to stand in front of the class with me (he usually stays in the back corner) and to help me clarify and elaborate on points. He is with them all day long, and has a better sense of the pulse of the class than I do. I also asked the most disruptive student, Michel, to trade places with another student even before the class began (he was sitting next to another student who he tends to feed off of). He refused for awhile, until finally he moved. We then got off to a slow start, as the class did not understand the question I was posing for the question of the week. While one of the students came forward to attempt a response, several of the others (all boys) were being so rude, raising their hands asking to replace the kid at the board, shouting out things, just being disruptive. Uramoe is completely and utterly useless when it comes to disciplining the students. In fact, he becomes part of the problem. More than one person remarked to me that he was talking as much as the other students while I was trying to give my presentation on the field trip on Tuesday. He hardly even tries to discipline the students, and they walk all over him. At the onset of the program, Patrick had told us that he had asked to have the more troublesome kids in his class, because he welcomed the challenge of disciplining them. That worked fine until he was promoted to principal, and now Uramoe is saddled with a hard group of kids.

I had to get stern with the kids and tell them very clearly that they were being rude and should not talk while others are talking. I told them to respect their classmates. As I explained the activity for the day, I heard Michel laugh/snicker, and then I lost it. I asked him what was so funny, and he said nothing, just sitting there with a smug grin. Which, of course, made me even more mad. I walked over to him and lost my temper, shouting at him that I do not put all of this work into the class to be laughed at. He finally got the point, and the entire class fell dead silent. I hate when I lose my temper like that, and it affected my performance for the rest of the class. Towards the end of class, I went over to him (he worked quietly for the rest of the class) and asked him if he understood why I was mad at him. He claimed that he wasn't even the one laughing, that it was someone else, and would refuse to answer my questions. What made me feel even worse was that it is possible he was right. While there was no doubt he was being obnoxious and disruptive in general, it may have been someone else who laughed, and I may have misheard. This is where the language barrier gets really frustrating; there is a greater chance that I will misunderstand something. Overall, I felt frustrated with the whole class, as I feel like my job should be to teach them about science, not to waste time with discipline issues.

Afterwards, I explained what had happened to Patrick, and he was very supportive and helpful. He immediately called Michel's parents and told them in no uncertain terms that if Michel did not improve his behavior, he could find another school. He also told me that it was a hard situation, because although he recognizes Uramoe's weaknesses, his hands are tied, as he

needs Uramoe right now (and admitted to needing to be especially deferential to Uramoe these days).

If you were to do this activity again, or were designing a similar one, what would you do differently?

Further comments about the logistics of running this lesson?

Further comments about the materials (worksheet, specimens)?

Other comments?

Lesson 7

Title: Build-A-Bug: An Introduction to Insects

Author: Brad Balukjian

Overview:

This lesson begins the second of this year's four units, on the biodiversity of insects. The program for this unit is similar to the plants unit—there will be a couple of long-term projects, we will emphasize the collection and preservation of specimens (as this is a Berkeley Natural History Museums project), and lessons will center on basic biology with inquiry-based activities.

In this lesson and the next, the principal goal is to convey an appreciation for the vast diversity of insects in the world. Insects are an ideal taxon for studying biodiversity, as the sheer quantity of species and variety of form underscore the very meaning of the word. By the end of this lesson, students should be able to name the traits that all insects have in common, and should be able to identify some basic ways that insects have adapted to specific environments. In order to build local context into the lesson, my presentation will include photos and information on the insects of French Polynesia and Moorea. The activity, in which students build their own imaginary bug following the basic body plan of an insect, will enable them to use their imagination and reasoning skills as they envision how their bug would be morphologically adapted to its environment. While science is undoubtedly a field built on concrete facts and laws, activities such as this one teach kids that there is also a great deal of creativity involved with doing science.

Concepts:

-Insects are the most diverse group of organisms on the planet, with more species than any other group.
-Insects are invertebrates, meaning that they do not have a backbone.
-All insects have a pair of eyes and a pair of antennae on their heads, as well as six legs and three body sections (head, thorax, and abdomen).
-Insects have been on Earth for a long time, much longer than mammals, allowing them to evolve into many different species.
-Many insects have developed special adaptations to live successfully in their environment.

Vocabulary:

Invertebrate
Insect
Head
Thorax
Abdomen
Compound Eye

French Polynesian Education Standards Addressed:

Parler:

1. Utiliser le lexique spécifique des sciences dans les différentes situations didactiques mises en jeu (Use scientific lexicon in different teaching contexts and environments)

2. Formuler des questions pertinentes (Formulate pertinent questions)
3. Utiliser à bon escient les connecteurs logiques dans le cadre d'un raisonnement rigoureux (Use logical connections in order to achieve rigorous reasoning)

Lire:
1. Traiter une information complexe comprenant du texte, des images, des schemas, des tableaux, etc. (Work with complex information comprised of text, images, tables, etc.)

Ecrire:
1. Produire, créer, modifier et exploiter un document à l'aide d'un logiciel de traitement de texte. (Produce, create, modify, or improve a document using the logical treatment of text).

Grade Span: CM2 (roughly 5^{th} grade)

Materials:
Laptop with projector
PowerPoint presentation
Pipe cleaners
Styrofoam balls (for body segments)
Colored balls
Markers
Colored Paper
Toothpicks
Glue
Yarn or string
Fly models
Straws
Sponges

Advanced Preparation: Create PowerPoint presentation

Time: Lesson planned for 50 minutes for a 60-minute lesson

Groups: Students will work in groups of 4-5

Outline
1. Introduction (5 min)

Before class starts, write the lesson vocabulary on the board, along with an outline for the lesson with the amount of time each activity will take. Tell the kids that we are going to follow this outline strictly, and that they can help me by watching the clock and telling me if I am going on too long. Start by asking the question of the week: Why do scientists put specimens in museums? Try to get answers from some kids that haven't said much in recent classes. Award the winner with the selected prize. Transition into the lesson by telling them that we are starting the insects unit today, and ask them if they like insects. If so, why, and if not, why not? Tell them that the lesson will allow them to combine science with art.

2. Lecture and Presentation (10 min)

The lecture portion of the past several lessons has gone too long, leaving little or no time in the end for a proper wrap-up. I believe the lessons have suffered a little as a result. I have allotted only 10 minutes for this lecture, and so will be extra conservative in putting together a concise presentation. The presentation starts with a slide showing several examples of showy and bizarre insects in order to give them a sense of the incredible diversity in this group. In order to introduce them to the concept of deep time (without using that term) and as a precursor to the evolution unit, show them how much longer insects have been around than humans (350 million years vs. 200,000 years) with a slide that includes a timeline. Include pictures of many of the insects of French Polynesia to provide local context. Then pose the question: How do we know an insect is an insect? What do all insects have in common? Are spiders insects? Go through the basic insect body plan with them, using two large rubber house flies as a visual aid. Then show a few slides explaining the ways that insects are adapted for survival in their environment, such as having specific kinds of mouths and legs.

3. Activity (30 min)

Once the slide show is over, tell them that they will now have the chance to make up their own insect species and built it themselves. Hand out a variety of art materials, including pipe cleaners, foam balls, colored balls, colored paper, straws, sponges, toothpicks, yarn, and markers, and tell them they can be as creative as they want, as long as their insect follows the body plan of 3 segments, six legs, and a pair of antennae and a pair of eyes on the head. Also, the insect must make functional sense (i.e. function follows form; a giant man-eating beetle with laser cannons for legs isn't going to cut it). Have them work in their plant team groups, with each group building one insect. Tell them that they need to choose a type of mouth (sucking, chewing, or sopping), a type of leg (jumping, digging, walking, aquatic), and any protection adaptations they wish, such as camouflage. After 25 minutes of work, ask each group to present their insect to the class and to explain why it looks the way it does and how it is adapted to its environment. I vow to end the activity on time in order to leave time for the wrap-up (Note: Patrick's class has an extra 10 minutes—it's 70 minutes rather than 60—so that gives me a little more freedom).

4. Wrap-Up (5 min)

To wrap up, hand out a couple of worksheets for homework, and for a quick activity that will preview next week's lesson, show them some small rubber insects and ask them if they know their names. Then tell them that next week we will learn how to identify the names of insects, much like we did with plants.

Lesson Recap

DATE TAUGHT: February 12, 2009
DATE OF REFLECTION: February 13, 2009

Learning goals: what were the goals of this lesson?

The main goals of the lesson were to teach the defining characteristics of insects and to give the kids an appreciation for the incredible diversity of form and function that exists in the insect world. Insects, while not as charismatic in the public eye as other groups (such as mammals and birds), are ideal organisms for young kids, as they are easily accessible and

ubiquitous. Given the close interactions between insects and plants, they also provide a natural transition from the plants unit. The lesson was designed to indulge the kids' creativity, as they were asked to construct an imaginary insect species using various arts and crafts. Too often, science is mislabeled as being "uncreative," when in fact it requires a great deal of creative thought and reasoning. The kids were given freedom to let their imaginations roam while still conforming to the basic body plan of an insect; thus, their species had to have all of the group's defining characteristics (such as six legs, three body segments, etc.) and the link between form and function had to be considered (i.e. how does the species' morphology correspond to its use of the environment?) I also wanted to continue honing their oral skills, as they were to present their bugs to the rest of the class and explain the choices they made in constructing them. I also had the opportunity to foreshadow the evolution unit by including one slide that showed a timeline of the past 400 million years, in which I plotted the evolution of insects in comparison to the evolution of humans. Having a basic understanding of Deep Time will be very important for the evolution unit.

Do you feel these goals were successfully achieved? How could you tell?

I was impressed with the students' baseline knowledge of insects. In both classes, most of the students knew already that spiders were not insects, and a few kids even knew why. They had no problem grasping the terminology of the basic insect body plan (head, thorax, abdoment, etc.). And although they weren't familiar with the term invertebrate, once I explained it, they clearly understood (I quizzed them by asking if various animals were invertebrates). They eagerly dove into the bug-building activity (not surprising, as this lesson seems to be one of the "classics;" I only wish I had such enthusiasm for arts and crafts, but was a very linear thinker even at that age). They started with the most obvious and simple parts—making a head with a styrofoam ball, adding eyes, and antennae, etc. While most kids chose the most obvious building materials for the head, thorax, and abdomen, a few were creative and used things like sponges stacked on top of each other to represent the thorax. I was actually impressed with Uramoe's class, as they seemed to be more creative in producing their bugs. And yet, the age-related limit on their creativity was obvious as well. At this age, kids seem to be exploring their creative side while still wanting to follow convention and making sure they are observing the rules. With the bugs, I had to remind them to think about how their bug would live and interact in its environment. Their tendency was to jump in and start building the prototypical bug, but I told them to think first about their bug's natural history. I was encouraged to hear one kid remind one of his teammates to think before he acted. While they weren't able to completely finish building their bugs in the time allotted, they made good progress. That is another thing I have noticed about kids this age—many of them are very attentive to detail, and so have little experience with time management and pacing themselves. They will spend excessive time just drawing a line or measuring something, and will lose sight of the big picture and how much time there is. I took Nicole's advice this week and led off with an outline of the class and how long each activity would take. I don't know how much it helped, but I don't think it hurt. There may be a few kids in the class who are particularly conscientious who could use that information to help pace themselves, but I think they're at an age where they are largely indifferent to time. I had originally planned on telling the kids in the beginning of the class to help me keep track of the time and to hold me accountable if I was going too long, but at the last minute decided against it. It just did not seem necessary, and I went with my gut feeling, which usually serves me well.

How did you wrap up the lesson (assessment, discussion, etc)?

You'll be happy to know, Judy, that in at least one of the classes, I did a wrap up! Although they had not finished constructing their bugs, I stopped them and told them they could finish later. I then went with the planned wrap-up activity, which was to excite them for the next lesson, on insect taxonomy and identification. I held up several rubber insects, and asked if they knew their names. They could identify the common names of everything, but when I asked for their scientific names, they were stumped. It was good, because just when they were feeling good about themselves and knowing it all, I brought up a twist (the scientific names) and they were left thinking, "Oh, I guess I do have a lot more to learn." Hopefully it piqued their interest for the next lesson.

In the other class, my plans were railroaded when I was called out of the classroom to pay the transportation bill from the last field trip right when I was ready to start the wrap-up. I tried, Judy, I tried!

What worked well?

The bug-building was a natural hit, and the presentation contained sufficient information without overloading them. One example of how a good teacher can enhance our work comes from Caroline's class. When showing the timeline slide of the past 400 million years, she asked them where the age of the dinosaurs fell on the chart. It was the perfect question, as kids love dinosaurs and they are the greatest example of extinction and Deep Time. When the kids saw that the insects appeared before even the dinosaurs, they really understood how "old" insects are.

I tried out another technique in class. My general strategy is to design the lesson and all of its materials, write out a script for myself in French, and then practice it at least once (this process takes a long time). In the earlier classes, I relied a lot more heavily on my script, which interfered somewhat with my ability to interact fluidly with the class. Now, while writing out the script is still very helpful for me, I use it very little in the actual lesson. But this time, I chose kids that usually don't talk and who tend to get lost in the shuffle, and scripted that I would ask them to read phrases from the PowerPoint out loud. I think it is important for their voices to be heard, and for them to feel involved. In general, it has been nice to see my French improve to the point where that no longer occupies too much of my brain while teaching, leaving more time for me to experiment with different pedagogical techniques.

Behavior-wise, this week was so much better than last. As usual, Caroline ran a tight ship. Before Uramoe's class started, Patrick came into the classroom and had all of the students sign a contract of conduct, in which they agreed to behave. He then posted the contract in the classroom, and said that whenever the kids acted up, I could just point to the contract. I rarely had to raise my voice this week, and I noticed that the kids did a much better job of policing each other when things started to get rowdy. Uramoe was his usual ham-fisted self, sitting by idly and actually talking to other students when I was talking.

I was impressed during the question of the week, when I asked "Why do scientists put specimens in museums?" and one student said "For display for the public," which I had totally forgotten about.

What did the students like about the lesson? What did they dislike? (How could you tell?)

It seems that some of the students would have preferred to make their own insect rather than having to work in teams to create one species for the whole group. I understand the feelings of pride and accomplishment that working individually can generate, but practical considerations

(having enough building materials) dictated this decision. The students always like the question of the week (it's so nice when they get excited about something as simple as a sticker. Why do kids love stickers so much?) It appears that incentive-based competition works well, as long as it's not done excessively. Before class, every week without fail, kids approach me and ask me what the prize is, and then what the question is. It amazes me that they actually think I would tell them the question ahead of time, but they keep asking!

Another thing I've noticed with this age group is how important positive affirmation is to them. I usually show up a good 45 minutes before class starts (during their lunch) to set things up, get my bearings, and interact with them. They are extremely helpful, always offering to help me set up my stuff. And they are always saying stuff to me. It took me awhile (partially due to the language) to realize that most of what they were saying merited no real response; they just like to tell me about stuff they have done or are interested in, and to get a nod from me. Sometimes they ask questions, but mostly they just want to tell me things. They have not yet reached that age where they start being self-conscious about what they're saying and how I will react. They are also very resilient; if they get something wrong, they don't seem to dwell on it. One student asked me before the lesson if I had ever heard of an 8 cm-long red wasp that someone had told him about. He talked about it with such enthusiasm and conviction.

What was most difficult for the students? (How could you tell?)

Before class started, I decided to ask several of them if they could understand me when I spoke in class. Sometimes I get so wrapped up in planning the content that I forget to check in with my audience to make sure they can understand me (my language, not the content). I was reassured that while I might talk funny, they understand me.

I think the biggest challenge for the students was presenting their bug. In Caroline's class, they did not have enough time to finish their bugs, let alone present them. But in Uramoe's class, where they have an extra 10 minutes, they had time to go in front of the class to explain their bugs. It's funny how when they're sitting down, everyone's a rock star, joking and playing around. But when they get up in front of the class, even the most confident kids get shell-shocked and tongue-tied. I improvised a bit in Uramoe's group; I had 2 groups present at a time, and then would survey the class about which bug they though was "fitter" based on their adaptations, and how the two bugs would interact if they encountered each other in nature. This turned out to be very entertaining and something the students enjoyed.

What was most difficult for you?

The hardest part for me was making sure the kids were getting the most out of the bug-building activity. It was very important that they remembered what they were working on—a biologically feasible, thoughtfully designed insect, not a comic book monster or a doll. I had to remind them to think about how their insect would actually live in the wild and to be realistic.

If you were to do this activity again, or were designing a similar one, what would you do differently?

Further comments about the logistics of running this lesson?

Further comments about the materials (worksheet, specimens)?

Other comments?

Before class starts, the kids love to doodle on the board. One of them, Terika, has a lot of natural artistic talent, and she drew a very nice butterfly complete with a prominent proboscis, which fit perfectly into the lesson. I already had a slide showing a close-up of a butterfly's mouth, but decided to leave her picture on the board as a perfect example.

Another helpful thing is that the kids will correct my French in a very respectful way. They have reached a comfort level with me (finally I know all 55 of their names) in which they are eager to help me improve.

While waiting for class, I hung out in the admin office for awhile chatting with one of the assistants, who taught in the schools here for 30 years and his nearing retirement. She told me how great she thought the program was and how much the students love it, and said that they need more programs like this to broaden their education. I guess it's not very common to have scholars and specialists come in from the outside here (probably because there's so much damn red tape involved).

Lesson 8

Title: Insect Identification: Learning the Orders

Author: Brad Balukjian

Overview:

To follow up on last week's insect anatomy and biodiversity lesson, this lesson will give the students a foundation in insect taxonomy by focusing on seven of the most common and accessible insect orders. Keeping the emphasis on collections and museums, this lesson gives the students the tools necessary to identify their own specimens that they will collect shortly. While they are already familiar with many of the common names for orders, they know little to nothing about the scientific taxonomy or the characteristics that define certain groups.

The main goal of the lesson is for the students to be able to identify the seven orders that I have selected for study, and to know the characteristics defining each order. I hope that they will also appreciate the diversity within orders as they examine numerous specimens of different species (for example, several different beetles in the order Coleoptera). A number of questions given throughout the lesson will push the students to link form and function, as emphasized in the previous lesson. From the pedagogical perspective, another goal is to test the efficacy of a different learning system, as the students will spend more time teaching themselves the material and less time listening to me lecture.

Concepts:

-Insects, like all other organisms, can be classified into orders. An order consists of several similar species which are closely related to each other and which share certain defining characteristics.

-Although all the species in an order are similar in many ways, there is also a great deal of variation between them in behavior, appearance, and ecology.

Vocabulary:

Order
Coleoptera
Hymenoptera
Dermaptera
Blattaria
Diptera
Lepidoptera
Orthoptera
Elytra
Scales

French Polynesian Education Standards Addressed:

Parler:

1. Utiliser le lexique spécifique des sciences dans les différentes situations didactiques mises en jeu (Use scientific lexicon in different teaching contexts and environments)
2. Formuler des questions pertinentes (Formulate pertinent questions)

3. Utiliser à bon escient les connecteurs logiques dans le cadre d'un raisonnement rigoureux (Use logical connections in order to achieve rigorous reasoning)

Lire:
1. Traiter une information complexe comprenant du texte, des images, des schemas, des tableaux, etc. (Work with complex information comprised of text, images, tables, etc.)

Ecrire:
1. Produire, créer, modifier et exploiter un document à l'aide d'un logiciel de traitement de texte. (Produce, create, modify, or improve a document using the logical treatment of text).
2. Prendre des notes lors d'une observation, d'une expérience, d'une enquête, d'une visite (take notes on an observation, experiment, survey, or visit)

Grade Span: CM2 (roughly 5^{th} grade)

Materials:
Fact sheet for each of the 7 orders
Laptop with connecting cable to microscope
Dissecting microscope
Display cases with specimens for each of the 7 orders
Rubber flies
Photocopies showing insect anatomy
Alcohol for Petri dishes
Petri dishes for microscopic specimens
Microscopic specimens (Diptera and Coleoptera)
Extension cord
110V/220V adapter
Paintbrush and tweezers (for handling specimens)
Signs for each station
Cards showing pictures of insects

Advanced Preparation: Prepare content for each of the 7 stations, collect insect specimens

Time: Lesson planned for 55 minutes for a 60-minute lesson

Groups: Students will work in groups of 4-5

Outline
1. Introduction (5 min)
Welcome the students back from vacation, and ask them whose birthday it is today (one of their classmates, Kahaia, turns 11 today). Ask them who remembers what we did in the last lesson. Then ask the question of the week: What are the three segments of the insect body named?

2. Lecture (10 min)

Tell them that the lecture will be brief today because they have a lot to do themselves. Define an order (in the taxonomic sense) on the board, and have one of the students read the definition aloud. Tell them that this is the key vocabulary word for this lesson. It will undoubtedly be a weird and new word to them (in this context), so tell them that you will elaborate. Hold up a photo of a butterfly, and ask them what it is. Then hold up a photo of a different butterfly that looks much different. Ask them if they are the same species. When they say no, ask them if they are in the same order. Refer them back to the definition on the board, and walk them through the process of understanding that an order is a more inclusive group than a species (without getting into all the difficult jargon of "hierarchy" or "nested subset").

Explain very clearly that the objective of this lesson is for them to learn how to identify common insects so that when they collect their own specimens, they will be able to ID them.

Explain the protocol for the activity, which will take some getting used to. There are seven stations set up around the classroom, with each representing a different order. Tell them that they are to bring their field notebooks with them and to write all of their answers and drawings in their notebooks. Remind them of the importance of a neat and well-organized notebook, with all the proper labels (they struggle with this, as I saw when grading their notebooks recently).

Finally, take a minute or two to emphasize that the specimens are fragile and do not belong to them, and that there are dangerous chemicals involved in the activity (alcohol). They need to be extremely careful and cautious at all times while examining specimens.

3. Activity (35 min)

The students will spend approximately five minutes working at each station. For each order, there is a fact sheet explaining how to identify members of that order, followed by some natural history information. At the bottom of each fact sheet is a task, usually involving drawing or answering a conceptual question. These questions are supposed to be challenging, some with many possible answers, and ask the kids to form hypotheses about the insects' form and function. Depending on the accessibility of each order, there will be varying numbers of real specimens to examine. The two dissecting microscopes will be employed at two stations, along with the laptop hookup. Students are to work together by reading the fact sheets aloud and collaborating on their answers. They will rotate after each five-minute window into each group has visited all seven stations.

4. Wrap-Up (5 min)

In the last five minutes, ask the students to share their answers to some of the more difficult conceptual questions (such as: What is the projection on the rear of Orthopterans used for?) Try to get a feel for the range of their thought process. Tell them that we're not concerned if they got the questions right or not, that this is more an exercise in thinking than in evaluation.

Lesson Recap

DATE TAUGHT: February 26, 2009
DATE OF REFLECTION: February 26, 2009

Learning goals: what were the goals of this lesson?

Insects are so overwhelmingly diverse that you need to break them down into manageable chunks in order to teach their biodiversity. Like plants, insects are ideal organisms for teaching biodiversity because they are abundant, easily accessible, and everywhere. Even in a biologically depauperate place like French Polynesia, there are plenty of insects. The goal of this lesson was for the students to learn seven of the most common and accessible insect orders, and how to identify them, and also for them to understand the meaning of a taxonomic order. While we taught the plants at the species-level, insects are more easily taught as orders given the more clearly defined and well-known taxonomy at higher levels in the insects. The other goal was for the students to have the experience of working with actual specimens and to see biodiversity itself in the classroom.

Do you feel these goals were successfully achieved? How could you tell?

A number of challenges cropped up during the planning for this lesson. Sometimes knowledge can be a blessing and a curse, especially when PhD students with little teaching experience are trying to speak a common scientific language with fifth-graders. I've come to accept that I need to sacrifice some scientific precision when teaching concepts at this level. And that's OK. At this point, it's more important for them to be exposed to the natural world, and the specific content is not as crucial. For example, in planning this lesson, I tied myself in knots trying to work out how to teach the concept of a taxonomic order. It's an abstruse and clunky term for the layman (a good baseline reference point, as evidenced by the recent hit TV show "Are you smarter than a fifth grader?), and yet it is important when teaching insect identification, as the most popular terms ("butterflies," "flies") correspond with orders. At first, I was thinking too complex, trying to figure out how I could explain a species as a subset of an order. But had these kids even been exposed to the concept of hierarchy yet? Probably not. Then I got more complex, worrying that my definition of an order was not scientifically accurate enough because it relied too much on "similarity" and not enough on "homology." But homology is such a bugaboo of a concept itself. I ended up taking a step back, accepting that my definition of an order would probably get slashed by a GRE official, let alone the merciless fangs of a Berkeley professor, and phrased the definition in a way that my kids could understand and that remained true to the essence of the actual meaning.

In my continuing attempt to flout complacency and to experiment on my kids and myself, I twisted the lesson protocol a bit. In recent weeks, my teaching style has been to lecture with a PowerPoint, covering the lesson concepts and then trying to reinforce those concepts through the activity. The kids have responded well to this format—they seem to like the gee-whiz gadgetry of a computer and PowerPoint (computers are pretty common here, PowerPoint teaching not so much)—but it also crams the activity for time, at the expense of the wrap-up (yes, it is unfortunate, Judy). So I decided to scrap PowerPoint, blasting us back to 1998, and to lecture on only one concept, that of the taxonomic order. After that, I wanted to see how the students would do with teaching themselves much of the content. The fact sheets I had written for each order were chock full of natural history info and how to identify a given order. At the bottom of each sheet was a task for the students to complete in their field notebooks. I gave them minimal direction with this, and set them loose. I found that they had a very hard time working independently. Perhaps it is through habit, perhaps it is part of their normal developmental trajectory, but they did not do well at following the simple directions of reading the fact sheets and answering the questions. When presented with a slate of materials—a fact sheet, some specimens, some reference diagrams, some toy figures, a microscope—they preferred to jump

for the “shiny objects,” looking under the microscope, doodling in their notebooks, etc. The inquisitiveness that defines childhood has not yet given way to the sense of structure and obligation that we develop later on, at least when the kids are left to their own devices. I ended up playing the most active role I have played in the activity portion of a class thus far, herding them from task to task, explaining clearly (and repeatedly) exactly what they should do when they get to a new station: write down the name of the station, read the fact sheet together, read the question together, etc. At this age, they are very concerned with academic propriety as well, which may also be why they revert to their natural curiosity when left without firm guidance. For example, they bombard me with little nitpicky questions like, “Should I start a new line for this question, or can I write on the same line where I left off?”

Once I explained exactly how they should organize themselves at each station, they did a lot better. They provided thoughtful answers to the questions and took great pride in their drawings. But they still needed me to tell them what the important concepts were. For example, if I had lectured about what defines a beetle, that would have stuck with them better than it did here, when that concept was included in a fact sheet with a bunch of other information.

How did you wrap up the lesson (assessment, discussion, etc)?
Two weeks in a row with a wrap-up Judy! I quickly realized in teaching this lesson that I would not have nearly enough time to do the activity justice, even with the brief lecture. So I made the command decision early on to split this lesson into 2 class periods. That bought us more breathing room. I took the last five minutes of each class to ask them to share some of their answers with me to the tougher questions.

What worked well?
The students did an excellent job of working responsibly with the specimens. I don’t think a single antenna or leg got snapped, which is incredible considering how young these kids are. Once they grasped the general protocol, they did well at managing their time. It was a real privilege to have such cool equipment as the microscope camera connected to the laptop, which the kids really dug. Many of them still don’t seem to work naturally in groups, and so in some cases, kids will work individually unless asked to collaborate.

What did the students like about the lesson? What did they dislike? (How could you tell?)
The kids loved the microscopes. And they liked having real specimens to work with and handle. They got a thrill out of being able to open the insect boxes and to take the specimens out. They seemed to enjoy drawing as well.

What was most difficult for the students? (How could you tell?)
I think I covered this pretty well above.

What was most difficult for you?
Right from the start of Caroline’s class, I could sense that the energy was excessive today. The kids seemed hyperactive and restless, like the oppressive heat had worn down their last threads of self-control. I knew I was in for a tough one. I decided to take the situation head-on. I started by telling them that they seemed to have a lot of energy today, but that they needed to be extra calm and careful because they were dealing with fragile specimens on loan and that they would be using dangerous chemicals. Nonetheless, in a surprising turn of events, Caroline’s class ended

up being more difficult today. They were much rowdier than Uramoe's class; you can imagine that by the end of Caroline's class, I thought I'd be totally spent by the time Uramoe's kids chewed me up and spat me out. I was pleasantly surprised. Uramoe's kids were the best-behaved I've seen all year. Michel, he that caused so much strife a few weeks back, was excellent. He contributed, he had a good attitude, and he was polite. It turns out that Uramoe was sick today, so we had a sub for the sub. She was a non-factor, chipping in here and there. After class, Patrick called me into his office and asked me how his class went. I told them they were great. He asked me because he is getting the sense that the kids are actually more obedient when Uramoe is not there. He said that Uramoe has become his problem, that the kids make no progress with him, that he hits students when they act up, etc. So we will see about that.

If you were to do this activity again, or were designing a similar one, what would you do differently?

I would keep the same format, except I would spent a little more time explaining exactly what the students should do when they got to each station. Also, I would improve the layout of the fact sheets to make them clearer. I would somehow off-set or boldface the task at each station, so the students could more quickly recognize what they had to do.

Further comments about the logistics of running this lesson?

Further comments about the materials (worksheet, specimens)?

Other comments?

Some of the kids have taken to making little presents for me, which is quite touching. Terika, who is very needy and very artisitic, makes little sculptures of various animals for me. Today, it was a bird out of what appeared to be chewing gum foil. Another student, Tamatea, who is very smart and hard-working, presented me with a dichotomous key of the vertebrates that he had copied (and gussied up) out of a textbook. The kids also like to try and impress me with their knowledge. One girl, Wendy, told me before class that they knew all the parts of an insect and what distinguishes an insect from other animals.

One of the most stupefying things I have discovered, and it happens time and again, is the way that the kids expect me to give them answers. We start every class with the question of the week recapping the previous week's lesson, and every class they ask me beforehand what the question is. When they are answering questions during the activity, they ask me directly what the answer is. There's no coy rephrasing of the question or attempt to dupe me into giving away the answer, they just look at me with a sincere expression and want the answer handed to them. It's so bizarre to me.

In between classes, while shuttling back and forth to set things up, I could plainly see the students from Caroline's class telling kids in Uramoe's class what the question of the week was as well as the answer. I usually ask the same question, which they clearly have caught on to by now. Determined to thwart their little strategy, I threw a head fake and instead of starting as usual, I asked them who already knew the question of the week because they had talked to kids in the other class? A few of them looked guilty, a few of them ratted others out, and one, Michel, actually raised his hand. He then proceeded to tell me exactly what the question was. I told him

that was wrong, and on the fly I changed the question to something else without further explanation, hopefully leaving them befuddled and perhaps feeling a little betrayed by their George Tenet-quality intelligence sources.

Lesson 9

Title: Cricket Jumping Experiment

Author: Brad Balukjian

Overview:

While the process of science is a complex and interconnected web of activities (see the Understanding Science website for a graphical representation), it can be broken down into two main components: descriptive science and experimental science. The goal of GK-12: Moorea is to introduce both to primary school students in order to (1) get them excited about continuing in science and (2) help them believe that they can actually become scientists, the latter being particularly important in French Polynesia. The direct link with the Berkeley Natural History Museums ensures that the students get a solid foundation in descriptive science and an appreciation for the importance of museums in preserving biodiversity. The GK-12: Moorea project includes lessons focused on collecting and cataloguing biodiversity (insect and plant field trips) and lessons on the process of designing and performing experiments in science.

Back in November, we introduced the students to experimental science with an experiment testing for the effect of water pollution on seed germination. The students were told from the outset what the question was and how to perform the experiment. We also did not introduce the concept of a hypothesis at that time. This time around, we would like the students to do more of the planning themselves, given that they are already familiar with the concept of an experiment. The goal of this lesson is for the students to form questions and hypotheses based on observations, and to then perform an experiment to test their hypotheses. Since we are in the midst of the insects unit, the lesson will give us an opportunity to also teach them about insect behavior and to reinforce the link between form and function that we covered in the insect identification lessons.

Concepts:

-Science starts with the observation of organisms in the natural world, and based on those observations, we come up with questions we would like to answer.
-In an experiment, scientists measure and compare different data in order to answer a question about the natural world.
-Before doing an experiment, scientists develop a hypothesis, which is a prediction of the outcome of the experiment based on observations and prior knowledge.
-The size and shape of the parts of an insect's body is often related to the way in which it interacts with its environment.
-Science is collaborative; working together, scientists can accomplish much more than they could alone.

Vocabulary:
Experiment
Hypothesis

French Polynesian Education Standards Addressed:
Parler:

1. Utiliser le lexique spécifique des sciences dans les différentes situations didactiques mises en jeu. (Use scientific lexicon in different teaching contexts and environments.)
2. Formuler des questions pertinentes. (Formulate pertinent questions.)
3. Utiliser à bon escient les connecteurs logiques dans le cadre d'un raisonnement rigoureux. (Use logical connections in order to achieve rigorous reasoning.)

Lire:
1. Traiter une information complexe comprenant du texte, des images, des schemas, des tableaux, etc. (Work with complex information comprised of text, images, tables, etc.)

Ecrire:
1. Produire, créer, modifier et exploiter un document à l'aide d'un logiciel de traitement de texte. (Produce, create, modify, or improve a document using the logical treatment of text.)
2. Prendre des notes lors d'une observation, d'une expérience, d'une enquête, d'une visite. (Take notes on an observation, experiment, survey, or visit.)
3. Rédiger, avec l'aide du maître, un compte rendu d'expérience ou d'observation. (Write up, with the help of the teacher, a report based on an experiment or set of observations.)

Grade Span: CM2 (roughly 5^{th} grade)

Materials:
Handout explaining experimental design
Review sheet from insect identification lesson
Worksheet on insect identification for homework
Data collection sheets for each group
Rulers or tape measures
Cricket specimens
Glass jars for holding crickets
Field Notebooks
Nets

Advanced Preparation: Prepare worksheets, collect crickets, test their relative jumping abilities and feasibility of measuring the distances that they jump. Before class, write the steps of experimental design on the board (to go with the handout to be distributed in class), along with the date and title of the lesson for them to write in their field notebooks. Also write the vocabulary word "hypothesis."

Time: 60 minutes

Groups: Students will work in groups of 4-5

Outline
1. Introduction (5 min)
Start out with logistics announcements and birthdays. For the Question of the Week, ask "How many legs does an insect have?" in order to reinforce one of the fundamental concepts of this unit. Try to solicit an answer from one of the underachieving students (this is an easy

question, so everyone in the class should know the answer). Maybe even call on a student this time.

2. Discussion (15 min)

Tell them that today we are going to learn more about experiments in science. Ask who remembers what an experiment is and why we do them. Ask them to take out the sheet explaining the steps of an experiment (the teacher should have already distributed this) and direct their attention to the board, where the same steps are written. Pass out live cricket specimens in a glass jar, so that each group has their own specimen. Tell them that before we do an experiment, we have to have a question to answer, and before we have a question, we have to observe our organism. Give them five minutes to observe their cricket in the container (put some soil and leaves in the container as well) and have them take notes in their field notebook. What do the crickets look like? How do they move? Ask them to think about the questions they are interested in answering. What do they want to know about the cricket? Write their ideas on the board as they brainstorm. See if any of them come up with something about jumping behavior or body size on their own. If so, it will make it very convenient; from here you can just say, "OK, we are going to study how far crickets can jump and the effect of body size on jumping distance." If not, encourage their ideas, and say that we are going to do an experiment to see if large crickets can jump farther than small crickets (have them write the question in their field notebooks: Do large crickets jump farther than small crickets?)

Introduce them to the concept of a hypothesis. Ask them: If we do an experiment to see how far crickets can jump, do you think large crickets can jump farther or not as far as small crickets? Ask each group to come up with a hypothesis and to write it in their field notebooks.

3. Activity (30 min)

Students will work in their usual insect groups for the activity. Each group will be given 1 cricket in a glass jar, a ruler or tape measure, a net, and a data collection sheet. Tell each group to divide their tasks so that each person is responsible for some aspect of the experiment—one person to remove the cricket and to release it, another to mark and measure the distance of the jump, another to record the data on the data collection sheet, and another to make sure the cricket gets back into the container. There is a lot of potential for things to get out of control, as the students might have a hard time getting their crickets in and out of the containers, so don't be surprised if you have some moments of chaos where students are chasing loose crickets around. All that you can do is to emphasize to the kids that they are to handle the specimens carefully and to do their best not to let them escape.

Take the students outside together, and ask them to spread out so that each group has enough space for their crickets (and you don't want them getting their crickets confused). Tell them that they are to record five separate jumps, one at a time (i.e. not five jumps consecutively once the cricket is released). Let the cricket go, measure the distance of its first jump, capture it, and reset. Each group will have a net to use to catch the cricket after it has jumped.

4. Wrap-Up (10 min)

Back in the classroom, remind the students that we have only done the first part of the experiment. We now know how far the crickets can jump, but how do we know how big they are? We can't just guess at their size, so we must measure them. Since there won't be enough time, tell them that tomorrow we will measure their body length (from head to the end of the

hind leg when pressed flat) and the length of their hind legs. Tell them that you will put the crickets in the freezer overnight to kill them so that we can measure them tomorrow. If it comes up, explain that as long as we are using them for scientific purposes, killing organisms is OK.

Ask them to recap what we learned today and what we did. Hand out the insect identification review sheet and worksheet for homework.

Lesson Recap

DATE TAUGHT: March 19-20, 2009
DATE OF REFLECTION: March 20, 2009

Learning goals: what were the goals of this lesson?

The main goal of this lesson was to provide experience with the experimental side of science, to complement the recent work on descriptive science. The idea of an experiment is very conceptual and somewhat abstract, and is not easily grasped at this young age. However, it is essential that students learn early that science is a process and is driven by asking questions and testing hypotheses. We hoped that the students would be able to do more of the thinking and planning themselves on this experiment, whereas in our last experiment the project was fed directly to them. We wanted them to see a project through from conception to completion, beginning with observations and ending with some conclusions and thoughts on future work.

Given that this lesson deals with crickets, a second goal was for the students to discover how body form links with function. We wanted them to see how the size and shape of an organism's anatomy can be (but is not necessarily) related to some adaptive function. For example, crickets have evolved large legs (relative to their body) to allow them to jump high and far, which is an adaptation for evading predators. This led to an obvious question: Do crickets with larger bodies and longer legs jump further than smaller ones? This question was the goal of our experiment.

A third goal was for the students to learn how to work together, and to understand the importance of collaboration in science.

Do you feel these goals were successfully achieved? How could you tell?

I was satisfied with our modest amount of success. I had never tried this lesson before, more or less came up with it from scratch, and was generally pleased with how well it went. Crickets are a great study organism for kids this age. They continue to struggle with understanding the concept of an experiment (see more below), but they grasp the mechanics of the experiment well (making observations, forming a hypothesis, measuring data, graphing results, etc.). It is the big picture that they have a hard time with, which I imagine has as much to do with their intellectual development as anything else (i.e. fact-based, concrete information is easier to grasp at a younger age than abstract, conceptual thinking). They did a great job of coming up with questions based on their observations of the crickets in captivity. Here are some examples: How old is the cricket? What month was it born in? Why are the hind legs so much bigger than the other legs? How long ago did the species evolve? (i.e. appear for the first time). Why does it jump so high? Why are the antennae so long? Why is there a brown streak running down the thorax and abdomen? I was very impressed with the range of their questions, and told them that we could design an experiment for every one of them. Since they came up with questions pertaining to the size of the legs and jumping ability on their own, I used that to segue

into the introduction to our question: Can large crickets jump further than small crickets? (I struggled with how to phrase the question for awhile beforehand. At this age, is it better to pose the question in the simplest terms, as I ultimately decided to do? Or should I have posed it in a more scientific way, such as "What is the effect of body size on jumping ability?" Thoughts?)

How did you wrap up the lesson (assessment, discussion, etc)?

I wrapped up by reconvening the class inside after the data collection was over, and asking them what more we still had to do in our experiment. One class had no idea, so I told them. The other class got it—we still need to know the size of the crickets. All we had done is measure how far they had jumped, but to answer our question, we needed to measure the other variable. I should note that in this lesson, I introduced the concept of a hypothesis for the first time. The word seems very foreign to them, and they are not yet comfortable with it, but they get the concept of making a prediction based on prior knowledge. In fact, when I asked one class what a hypothesis was, a boy named Zacharie said, "It's what we think when we're not sure of something, like the idea of aliens," which I thought wasn't bad. Other than hypothesis, experiment, and observation, however, I have avoided introducing too much technical vocabulary, such as control, variable, etc. The wrap-up was a bit rushed, but at least I got it in. I also gave them a review sheet and sheet of questions for homework.

What worked well?

On the whole, the actual data collection part went a lot more smoothly than I anticipated. I was fearing the worst—crickets escaping everywhere, students ripping legs off by accident (or on purpose), complete chaos. But the kids were great. They did an amazing job of collecting the data despite some very uncooperative crickets (many jumped in unanticipated directions, and other refused to jump at all). Only one group lost their cricket, and it was my fault that they didn't have a backup (I had collected some backups, but forgot them in my office). The crickets that wouldn't jump provided a very fortuitous opportunity to teach an important lesson in science. In one group, their cricket jumped one centimeter and then refused to jump again, despite extensive prodding (literally). The kids were disappointed, and started marking down the distances that it had walked, because they wanted to have data. I told them to erase what they had written and to put all zeroes for the jumps. They were not happy about that, but I told them that part of science is not getting the results you necessarily want or expect. Things go wrong. Things break. Crickets don't jump. But it is our duty as ethical scientists to report exactly what we find, regardless of the outcome.

In general, the discussion before the activity went better too, as I've come a long way in my ability to understand them. Admittedly, in the beginning of the year, there were times when they would say something and I would just nod and smile, but now that rarely happens. It helps that they're a very forgiving audience; if I don't understand something, they are very patient with me.

The Question of the Week went well. I took Judy's advice, and went with an easy question (how many legs does an insect have?). I stood right next to Flaminia (the girl who last week said she was unaware of even having a Question of the Week). When I asked the question, about a dozen hands shot up. I watched Flaminia in particular, and saw her initial reaction, almost like she was resigned to the fact that she would not know the answer, followed by her realization that, wait, I do know the answer, and then her hand went up. Sure enough, she got it right. I could sense that Caroline felt like I had rigged the question for Flaminia, which I had, but

Caroline seemed a bit disgusted (Flaminia is one of her "problem kids" who drives her up the wall. No doubt she can be difficult, but sometimes I think Caroline gets in these ruts where she writes certain students off and plays the favorites.) I made sure to congratulate Flaminia after class on getting the question right, and she seemed really happy, which was nice to see.

About Caroline, I must say yet again that it makes all the difference having a teacher who is truly invested in this project at my side. I have been tempted at various times to just quit Patrick/Uramoe/Vaihiria's class because it feels sometimes like it is not serving one of the objectives of this project, which is to directly benefit me in my professional development (the NSF is very emphatic about the program's benefits to me as the grad fellow). But when it comes down to it, despite the challenges with that class, the kids are great, and I know they would be very disappointed if I stopped working with them. It's not their fault that they've been treated like the foster child of the Paopao School. Anyway, Caroline enhanced this lesson by reviewing the experimental process with the students before class, and then when I returned to the school to do the second part of the lesson today, she had already had the students graph their results, all on her own accord. Uramoe's replacement, Vaihiria, is very nice and more assertive than her hapless predecessor, but she still doesn't have it. She teaches like a sub, which is what she is—she doesn't show the passion or investment in the class that you want in a teacher to make the program that much better.

I was also pleasantly surprised by our discussion on hypotheses. I asked the class what their hypotheses were for our experiment, and much to my surprise, several said they expected the smaller crickets to jump further, because they are lighter. I hadn't even thought of that.

What did the students like about the lesson? What did they dislike? (How could you tell?)

The students liked it when I brought the endemic Raiatean cicada into the classroom for them to see. I brought their crickets into the classroom today so they could measure them (post-mortem), and brought in a cicada that I had collected on a recent trip to the island of Raiatea. Cicadas are only found on that one island in the whole region, and they are a remarkable biogeographic story. They are large and bright turquoise, very easy on the eyes.

I think the students really liked working with live specimens. They treated them with a lot of respect, and after having looked at dead specimens the past couple of weeks, this was a nice change. Of course, then I went and killed all of their crickets so they could measure them, but that's science.

What was most difficult for the students? (How could you tell?)

Easily, the hardest thing about this lesson was getting them to understand the concept of an experiment. In Caroline's class, when I asked them what an experiment was, there was no shortage of answers. Just a shortage of quality answers. They kept saying things like, "it's when we study insects." They kept defining an experiment as involving insects until I finally said, "Why do you guys keep talking about insects? Can we only do experiments with insects?" When I refreshed their memories about the seed germination experiment and asked them what we did, they started regurgitating our methods. This is the biggest challenge—they have a hard time seeing the big picture and understanding what an experiment is and why we do it. When I ask them what we did, they focused on the specific details, not the main point. In the other class, we didn't even get that far. There was one group in particular that just wasn't getting anything. It was as if they were hearing the words, but nothing was sinking in. I got a little frustrated because it seemed they just weren't trying.

What was most difficult for you?
Aside from trying to explain the concept of an experiment, I'd say the hardest part was the logistics of preparing this lesson. Not having done it before, I didn't know quite what to expect. I still don't know what the results are going to look like. It was a pain in the ass to catch all those crickets too.

If you were to do this activity again, or were designing a similar one, what would you do differently?
I would definitely not leave the extra crickets behind! I also wish I had spent more time in the discussion seeing if the kids could come up with the experimental design themselves. We were pressed for time, so rather than asking the kids what kind of experiment we could do to study the effect of body size on jumping ability, I told them what we were going to do. Bad boy. Not inquiry-based.

Further comments about the logistics of running this lesson?

Further comments about the materials (worksheet, specimens)?

Other comments?
It's funny that Betsy was just asking me how my GK-12 activities relate directly to my research, and just today when I got to the school, Terika (one of the students) brought me an insect she had just caught. It was the species that I study for my dissertation! So sure enough, I now have her listed on the label as the official collector of a specimen in my collection.

Lesson 10

Title: Insect Curation

Author: Brad Balukjian

Overview:

One of the most exciting things about Berkeley's GK-12 program is the access we have to the campus's system of natural history museums. In an age when genomics and integrative biology are all the rage, it is increasingly important that we maintain our expertise in the organisms themselves, and this is where museums become critically important. Unfortunately, French Polynesia has little in the way of natural history museums; there is the Museum of Tahiti and Her Islands, where there is a nice herbarium and a set of displays, but there is no formally maintained entomological collection anywhere in the islands. Hopefully this will change in the future, and the goal of this lesson is to teach the upcoming generation (which will hopefully include some scientists) about the need for museums and the proper way to care for specimens.

The students have already had some hands-on experience with specimen curation through the herbarium lesson. Now, having taken a field trip to collect insects, we will show them the proper mounting and preservation techniques for insects. This lesson provides an introductory demonstration, followed by time for them to work with their own specimens. They will also be given the assignment of creating their own collection over the next several weeks, which must include at least one specimen from the seven orders we have studied, properly mounted, labeled, and identified. These collections will all be displayed as part of our culminating event, the Science Expo 2009 in June. In this lesson we will also emphasize the reasons why we preserve specimens and deposit them in museums.

Concepts:

-Scientists curate and deposit specimens in museums so that they can study them, to create a historical record of biodiversity in a given place, and to create visual displays for the public.
-There is a set of standards that scientists follow in the curation of insects to ensure the proper preservation of specimens.

Vocabulary:

Museum
Entomologist
Point Mount
Pinning Block
Spreading Board

French Polynesian Education Standards Addressed:

Dire:

1. Utiliser le lexique spécifique des sciences dans les différentes situations didactiques mises en jeu. (Use scientific lexicon in different teaching contexts and environments.)
2. Formuler des questions pertinentes. (Formulate pertinent questions.)
3. Utiliser à bon escient les connecteurs logiques dans le cadre d'un raisonnement rigoureux. (Use logical connections in order to achieve rigorous reasoning.)

Lire:
1. Traiter une information complexe comprenant du texte, des images, des schemas, des tableaux, etc. (Work with complex information comprised of text, images, tables, etc.)

Ecrire:
1. Produire, créer, modifier et exploiter un document à l'aide d'un logiciel de traitement de texte. (Produce, create, modify, or improve a document using the logical treatment of text.)

Grade Span: CM2 (roughly 5^{th} grade)

Materials:
Point Mounts (30 for each group)
Pins (50 for each group)
Paintbrushes (for handling specimens)
Forceps (as many as are available)
White glue
Pinning blocks (one for each group)
Aerial nets (one for each group)
Hand lenses (one for each group)
Collecting trays (one for each student)
Extra Styrofoam
Laptop with presentation
Laptop projector
Extension cords/plug adaptors
Specimen for pinning demonstration
Spreading boards
Label paper
Curated specimens (for reference)
Review sheet
Insect Collection Assignment

Advanced Preparation: Prepare all the materials and specimens for class. Before class, draw diagrams showing proper pinning and point mounting techniques on the board, along with the vocabulary word "entomologiste." Prepare review sheet for the exam next week, as well as a handout explaining the insect collection assignment.

Time: 50 minutes (planned for 50 minutes for a 60-minute class)

Groups: Students will work in groups of 4-5

Outline
1. Introduction (5 min)
Start out with logistics announcements (insect exam next week, next week is the last lesson in the insect unit) and birthdays. For the Question of the Week, ask "What is a hypothesis?" to return to the cricket jumping lesson of a few weeks ago.

2. Lecture and Discussion (15 min)

Why do we put specimens in museums? Where do we put plants? Should we put insects in museums too? Start out with these questions for discussion. Go over the concept listed above regarding the importance of museums. Tell them that today we are going to learn how to mount and preserve insects for storage in museums. Mention that it is important for all scientists follow the same procedure in mounting insects so that we ensure that specimens are properly preserved.

Start out by holding up forceps, a pin, a collecting tray, and a pinning block, and explain that these are the tools of an entomologist. Ask them what an entomologist is (refer to the blackboard), and then tell them that today they are all going to be entomologists. Go through a demonstration of pinning a large beetle, using the blackboard and the specimen itself (might be hard to see). Then explain that when specimens are particularly small and fragile, we use a different technique, using what we call a point mount. Show how to point mount on the board, and tell them that you will go around to each group to do a demonstration (this would definitely be too difficult to see in front of the whole class). For butterflies and moths, we use a special tool called a spreading board. Hold one up with an example of a properly spread moth. They will have spreading boards available for use.

Finish the lecture with an explanation of the importance of labels. Ask them why labeling is important. Using the laptop and projector, show them the proper format of a label, and tell them to look at the labels on the reference specimens when they are passed around. Tell them that they are going to create labels for their own specimens.

3. Activity (25 min)

Announce that each student has the assignment of creating their own insect collection (they will get the handout explaining this after class, so as not to distract them now). They will each get their own collecting tray, and each group will have a set of collecting and curating tools that they are to share. Each student must collect one specimen from each of the 7 orders we studied (ask if anyone can name all 7 orders), and then mount, identify, and label it properly. The due date is June 9, which is the day we are having the Science Expo. They will have the opportunity to use the laptop to make their labels in the future. Today they can start mounting their specimens and looking at them under the microscope. Ask if they have any questions.

4. Wrap-Up (5 min)

For a wrap-up and a little change of pace, ask the students to share any stories they have about the insects they've collected. What insects do they like the most and why? Which do they enjoy studying more, insects or plants? Finish by handing out the review sheet and the collection assignment.

Lesson Recap

DATE TAUGHT: April 16, 2009
DATE OF REFLECTION: April 16, 2009

Learning goals: what were the goals of this lesson?

In keeping with our emphasis on the study and preservation of organisms, this lesson was designed to teach the kids the practical skills involved in creating a collection of insects. Any study of biodiversity needs to be begin with a well-curated collection of organisms that serve as a reference point for all future studies. One of the main goals of our program in general is to literally bring the outdoors inside; rather than just read about biodiversity in books, we go outside and collect it, and then learn how to properly preserve it. The goal of this lesson was to reinforce the importance of museums for biodiversity by creating a mini-museum ourselves. Between this lesson and the herbarium lesson, I think they have a good understanding of why we collect and preserve biodiversity. Another practical goal was for them to understand why we need to follow a set protocol for the curation of organisms. While the objectives of this lesson may be more concrete and practical than one of the experimental lessons (which may involve more critical thinking), it is just as important to learn the skills acquired here.

Do you feel these goals were successfully achieved? How could you tell?

While I was pleased overall, this was one of those lessons where I'm reaching for a cold beer as soon as I'm out of sight of the students. It was by no means a disaster, but rather a slow grind. I think I was rusty from not having taught a traditional lesson in awhile (they were on vacation the past 2 weeks, and before that we went on a field trip), and so I got a little tripped up with the cumbersome explanations of how we pin insects (in French, of course). There was a ton of material to bring in for this lesson (nets, pins, pinning blocks, specimens, microscopes, computers, spreading boards, etc.), so it was hard enough just to keep all of that straight. By the time I started Vaihiria's class, I was already a little fatigued. But, again, the students quickly grasped the mechanics of pinning insects and got most of their specimens done. As I told them, they still have the hard part, which is identifying them (only to order, not so bad) and making the labels. Making the labels will give them a chance to use the computer, which is good, because the national educational standards have a lot in them about information technology. They did seem very engaged; unlike some lessons, where kids start zoning out, they were involved with their specimens and took great pride in having mounted them (always shoving them in my face for approval). I had brought in a drawer of curated specimens (the new Gump reference collection that I created), and when one girl, Homai, finished early, I told her she could look at the specimens, which she was very excited about. It was nice to see her (and others') enthusiasm for just looking at all the specimens lined up on pins, properly labeled. I think they will get a lot of satisfaction out of seeing their finished collections on display at the Science Expo in June.

How did you wrap up the lesson (assessment, discussion, etc)?

In Caroline's class, I wrapped up by asking the students to describe some of their specimens to me. This was OK, as they happily obliged, but I think I could have come up with a more stimulating way to finish. That being said, I did an impromptu wrap-up in Vaihiria's class. That class always has an extra 10 minutes, so I can go at a more relaxed pace (it's also the last class period before school ends, so it's hard to keep their attention at the very end). Instead of repeating what I did with Caroline's class, I asked them a series of questions, starting with what they prefer to study, insects or plants? At first, everyone said insects. Then, one of the most studious and thoughtful kids, Raianu, spoke up and said both are good. The class does seem more enthusiastic about insects, although this could also be because it is what we are doing now, and I find that at least for fifth-graders, the present is always a little more glamorous than the past. I continued by asking them if they wanted to study mammals (a resounding yes was the

answer). I then asked if there were any native mammals in French Polynesia, and they accurately said no. I went on to ask if there were native frogs (no), lizards (yes, we think), snakes (no), or birds (yes). This ended up being a fun discussion, and a bit of a free-for-all, BUT…even though they were kind of all talking at once, I decided to just let it go this time. It was the end of the day, we were all tired, we were having fun, and I think it's OK now and then to let loose a little bit and let them just run with it.

What worked well?

The actual activity of pinning the insects went smoothly. It didn't take them long once they got the hang of it, and I think everyone has their specimens pinned now. The teachers are going to allot time outside of our class to work on the labels and identification. They have the assignment of creating their own collection for the Science Expo in June. Each student has to collect at least 7 specimens, one from each of the orders that we studied.

What was most difficult for the students? (How could you tell?)

They struggled with the same things that we struggle with as professional scientists, which should not be surprising. Getting older and more experienced doesn't make some of these problems go away. For example, they were often not sure whether to use a pin or a point mount for an insect, which is a decision made based on the insect's size. I told them that that was a judgment call and a decision they had to make on their own, but if they chose poorly, they would see the consequences (either the insect gets destroyed or is too big to fit on a point mount and keeps falling off). They also continue to struggle with identifications. Teaching a unit on insect biodiversity, at least here, is much more challenging than the plants because the plants are so much better known. There many be a couple of plant species still out there in French Polynesia awaiting discovery, but the flora is pretty complete, whereas maybe half of the insects have not yet been formally described. Unlike in the plants, where they were able to focus on one species, with the insects I am content if they can identify 7 of the most common orders.

It's becoming increasingly clear to me that there is a small set of students who really excel, a set who are interested and do well enough, and then a set (maybe 6-8 in each class) who just seem hopeless. They are not disruptive or difficult, but they also never participate voluntarily. I tried calling on several of them today during the discussion, but they won't even venture a guess. I think what astounds me most is the sheer apathy. This is probably more alarming to me because I went to junior high/high school at a prep school where even the most remedial students made an effort to appear interested, but here there are a bunch of students who just don't care. For example, one girl, Milada, did not do her homework. When I told her she would get a zero (after having given her ample opportunity to turn it in), she shrugged. Then, perhaps most disturbingly, Vaihiria (the teacher), who was nearby, said "It's not a big deal." I looked at her, shocked, and asked, "Why not?" and she shrugged and said, "I don't know." Do you believe that?

What was most difficult for you?

Definitely explaining how to pin and point-mount insects in French. It's not the most colloquial of things to explain, as you can imagine. But I got through it. I had originally not planned on teaching them this skill, but when they ended up collecting mostly tiny insects, it became a necessity. Again, having an invested teacher like Caroline is so important. When I was struggling with how to say "upside down" in my explanation, I told her what I was trying to say,

and she clarified for the students which was perfect. Vaihiria, on the other hand, seems to react to my lectures with more incredulity and naivete than the students. Sure, she might be learning this stuff for the first time too, but shouldn't she at least project an aura of authority to the students? This is one thing that she and Uramoe both lack, that understanding of the teacher's job as a leader in the classroom, even when we don't really know what we're talking about.

It's actually a good thing that I start with Caroline's class, because she can help me make adjustments for the second time around. I admit, the disparity in the teacher participation is so great that in planning, I sometimes forget I have a second class. And it's admittedly hard to get as psyched up for Vaihiria's class when I know I'm not going to have the support I need.

If you were to do this activity again, or were designing a similar one, what would you do differently?

I am thinking that it may have been useful to incorporate a dichotomous key into this lesson for the identification part. I worry that the kids still have not learned the key characters for identifying orders well enough. This is partially my fault—while we have reviewed identifications during the insect orders lesson (there were two of them) and homework, I could have taught identification in a more inquiry-based way. Although this would be harder to figure out how to do, I think concepts stick with them more when they are inquiry-based. A dichotomous key is the perfect example of an inquiry-based exercise, and if I had a partner teacher, I may have been able to pull this off. This is one of those times when working all alone out here has its drawbacks—I've only got so much time as one person.

Further comments about the logistics of running this lesson?

Further comments about the materials (worksheet, specimens)?

I gave out two handouts today—one was a review sheet for the insects unit exam they have next week, and the other reviews the insect collection assignment.

Other comments?

Lesson 11

Title: Cricket Jumping II

Author: Brad Balukjian

Overview:

In this lesson, we return to the experimental side of science to complete our experiment on cricket jumping, testing the connection between form (anatomy) and function (behavior). We've already done the fun part, which is to go outside and watch the crickets jump and collect the data. Now comes the harder part, where we analyze the data and then synthesize everything in a document. The goal of this lesson (which will have to be finished outside of class) is to create a poster that summarizes the entire experiment, including an introduction, hypothesis, methods, results (graph), and discussion/conclusion. This will give the kids their first exposure to the process of science as it is done professionally. During the class, I hope to (a) work collectively to create a rough draft of the finished graph and (b) work in small groups on the text that will go on the poster. The poster will be one of the exhibits at our culminating Science Expo on June 9.

This lesson requires a lot of concentration and critical thinking. It is not a hands-on lesson in the way that many other recent lessons have been (catching insects, studying specimens, curating specimens). The work itself is not glamorous (mostly writing text). I plan on being very firm and explicit at the start of this lesson that I expect the students to think hard and to work hard during this lesson. I don't want them goofing off and forgetting what it is that they are supposed to be doing. I plan on being very strict during this lesson.

Concepts:

-In many organisms, anatomy is related to behavior. The goal of our experiment was to examine the relationship between body and leg size and jumping ability.
-Scientists complete their work by writing reports or creating posters that summarize their hypotheses, methods, results, and conclusions.

Vocabulary:

Anatomy
Behavior

French Polynesian Education Standards Addressed:

Dire:

1. Utiliser le lexique spécifique des sciences dans les différentes situations didactiques mises en jeu. (Use scientific lexicon in different teaching contexts and environments.)
2. Formuler des questions pertinentes. (Formulate pertinent questions.)
3. Utiliser à bon escient les connecteurs logiques dans le cadre d'un raisonnement rigoureux. (Use logical connections in order to achieve rigorous reasoning.)

Lire:

1. Traiter une information complexe comprenant du texte, des images, des schemas, des tableaux, etc. (Work with complex information comprised of text, images, tables, etc.)

Ecrire:
1. Produire, créer, modifier et exploiter un document à l'aide d'un logiciel de traitement de texte. (Produce, create, modify, or improve a document using the logical treatment of text.)
2. Rédiger, avec l'aide du maître, un compte rendu d'expérience ou d'observation (texte à statut scientifique). (Write, with the help of the teacher, a report of an experiment or observation in scientific prose.)

Grade Span: CM2 (roughly 5th grade)

Materials:
Large graph paper
Rulers (for drawing graphs)
Colored pencils or markers (for graphs)
Plain white paper
Handout on the process of science

Advanced Preparation: Revise the handout on the process of science. Make sure students bring their data sheets. On the board before class begins, write the vocabulary terms "anatomy" and "behavior."

Time: 50 minutes (planned for 50 minutes for a 60-minute class)

Groups: Students will work in groups of 4-5

Outline
1. Introduction (5 min)

Birthdays this week: Kealoha on Friday. Tell them that their homework for next week is to write a Question of the Week, and I will choose one of them to ask at the end of class next week. This week's questions (1 for each class, since they have taken to collaborating) are: What is an entomologist? (Caroline's class) and What is a hypothesis? (Vaihiria's class). Go over some logistics concerning the insect collection assignment, such as the need to keep labels on their specimens and that they don't have to identify everything, only the 7 orders that we studied. Distribute extra vials for collecting.

Tell them that today is a challenging lesson that will require them to do a lot of thinking, and that I have high expectations of them. If they start to goof off, I am going to get upset, and they will know it.

2. Group Graphing Activity (15 min)

Start by saying that we are returning to our cricket jumping experiment. Ask them what the objective of the experiment was (they always struggle with questions like this. They will probably get as far as saying that we wanted to see if large crickets jump further than small crickets). If they don't get their on their own, tell them that the reason why we are interested in knowing if large crickets jump further is because we want to know the effect of anatomy on behavior. Refer them to the vocabulary words on the board (anatomy and behavior). Explain that anatomy refers to the appearance, size, and shape of an organism, and that behavior is how the

organism acts in its environment. Ask them what part of the anatomy we studied in the experiment, and how we measured behavior. As much as is possible, try to get them to make the link between what we literally did and the bigger picture of why we did what we did. Take a poll of how many students have the hypothesis that the large crickets jumped further and how many thought the smaller crickets jumped further (for use when writing up the experiment).

Ask them to take out their data collection sheets, where they have calculated the average jumping distance, the crickets' body size, and the length of their hind legs. Tell them we are going to make a graph together on the board to summarize our data. Ask them what should go on the two axes (jumping distance on the y-axis, body size on the x-axis). We will make a graph together for body size only. Ask for a representative from the first group, and have them try and place their data point on the graph. Then ask the other groups to call out their data and plot it. Draw a line connecting all of the dots to see the trend. Explain that this is a different type of graph from the one we made previously—this is a line graph, rather than a bar graph. Ask them what the overall trend is (if there is one), and what it means.

3. Activity (25 min)

Have them take out their process of science worksheet for reference. Break them into four groups: introduction/hypotheses, methods, results (graph), and discussion/conclusion. Go through a quick explanation of each, and tell them that their goal is to write a rough draft for their respective section of the report, which will later go on a poster for the Science Expo.
1) Introduction/Question/Hypotheses: What was the main question we were interested in addressing? What was our study system (location, organism, etc.)? What were our hypotheses and how did we justify them?
2) Materials and Methods: What exactly did we do in the experiment? Create a step-by-step list of what we did.
3) Results: Using large graph paper, draw two graphs: one for the relationship between jumping distance and body length, and one for jumping distance and hing leg length.
4) Discussion/Conclusions: What did our results tell us, and what conclusions can we draw from them? What further studies could we do in the future to further our knowledge?

4. Wrap-Up (5 min)

Ask them what more we could do in a future experiment to further their study? What other experiments might they be interested in doing in general? For homework, they are to continue working on their experiment poster and insect collection.

Lesson Recap

DATE TAUGHT: April 23, 2009
DATE OF REFLECTION: April 23, 2009

Learning goals: what were the goals of this lesson?

The goal of this lesson was two-fold: One, to impart the importance of writing up our results in a scientific document, and two, for the students to understand the bigger significance of the cricket jumping experiment. In the course of the year, I have seen that kids at this age (10-11) are effective when given a lot of structure, but have a hard time making the cognitive leap to

more abstract thinking. That is why they struggle with grasping the scientific process, because the process is by definition more reticulate than linear. The descriptive part of science is much easier for them to handle; go out, collect organisms, observe them, draw them, measure them. But the experimental side, in which we are testing hypotheses and examining processes and mechanisms, is harder. It's hard for me, and I'm working on my PhD, let alone for fifth graders with basically no scientific background in a country that has not historically valued science, trying to learn from a heavily-accented foreigner. But, we set our sights high, and hope that some of our concepts trickle down to them in some way. In this particular instance, our question was whether or not large crickets can jump further than small crickets, but the larger objective was to examine the relationship between anatomy and behavior.

Do you feel these goals were successfully achieved? How could you tell?

I think the kids easily grasped the importance of writing up a scientific report. I told them from the outset that this would be a difficult and sometimes boring lesson, but that science cannot be glamorous and exciting all the time. Perhaps this was the wrong way to approach it. I split the class into four groups, with each taking one part of the report (introduction, methods, results, and conclusions). They were to write a rough draft of each part, which we would then rewrite and paste onto a large poster for display at the Science Expo.

As for the bigger goal, I do not think I succeeded. In fact, after the first class, it was so obvious to me that the concept was over their heads that I didn't even try with the second class. Making the leap from cricket jumping to the relationship between behavior and anatomy was just too hard. Perhaps if I had been speaking in my native language and could have really gone into detail I would have made more progress, but it is more likely that this was just asking too much. Again, there are a handful of kids that would probably get it, but I don't know if it's a good idea to teach to the top handful. I learned an important lesson today; it's possible to be too ambitious, and that's OK. As enthusiastic and idealistic as I can be about this program, I need to recognize its limits in order to maximize its efficacy.

How did you wrap up the lesson (assessment, discussion, etc)?

I didn't. The time went by very quickly, and we didn't even come close to finishing. My wrap-up, which was to have them think of further studies we could do or other experiments they were interested in, would have been inappropriate given our lack of progress. Here I'd like to pause to ask you a question—at this age, given the limits in intellectual development and comprehension that I described above, what makes for a good wrap-up? It seems by definition that the wrap-up is a way to encourage the kids to stretch mentally, to take what they've learned and apply it in another context. But given what I've seen this year, is this really a feasible approach for this age group?

What worked well?

The graph we made together on the board went well. I wanted them to see how a graph is constructed data point by data point, especially since we made a type of graph (line graph) that we hadn't covered before. So I had them tell me what to put on the axes, and then one at a time, had them plot their data points on our graph. At the end, I asked them what our general trend was; interestingly, in one class the large crickets jumped further, while in the other class, the small crickets jumped further.

The Question of the Week also went well; both classes got the questions quickly. As Judy had previously suggested, I asked the kids to come up with a Question of the Week for homework, which I will choose and ask at the end of next week's lesson.

What was most difficult for the students? (How could you tell?)

There was just a bad vibe in the air today. Right from the start, things weren't going well. The school didn't have any electricity, as the local building officials recently declared the school unsafe; for awhile it looked like the school might shut down completely mid-semester. The kids were rambunctious, I was frazzled, and the always steady Caroline was not herself. Maybe she wasn't feeling well, or maybe she was just worn down, but for a good part of the lesson she did little to support me, which is unusual. In the other class, Vaihiria was her usual ineffective self. She lacks any leadership, and can actually be a distraction as she talks with kids in small groups while I am trying to talk to the whole class.

Even little things today were difficult. I took a poll in each class of how many kids had the hypothesis that the small crickets would jump further and how many favored the large crickets, and in both classes, we wasted precious time because kids weren't voting or changing their votes, and we had to repeat the process. The kids were generally lazy and disruptive today, which made it especially difficult.

What was most difficult for you?

It was tough for me to try and explain the different parts of the scientific report, especially the introduction and conclusion. That shouldn't be surprising, as it's something I still struggle with. I realize now that one thing to have them think about in the conclusion would be other things that could have affected the crickets' ability to jump, like how rough they were with handling them, or perhaps some other variable affecting jumping ability, like cricket age.

Caroline also told me before the class started that she thinks we need to slow down a little with all the projects we have going on. She presented the problems (it's too hard to share one computer among 57 students, they don't have a printer at the school for labels, lizards and ants in the classroom are eating the kids' specimens, etc.) and we found solutions, one of which is to slow down the introduction of new material and to dedicate more time to working on these long-term projects. So, next week will be a catch-up lesson. I've decided not to teach evolution after all, as it would be asking too much of the kids.

If you were to do this activity again, or were designing a similar one, what would you do differently?

I would not try to make the connection to anatomy and behavior.

Further comments about the logistics of running this lesson?

Further comments about the materials (worksheet, specimens)?

Other comments?

I think that I should put more emphasis on individual work. I realized today that we've done an awful lot of group work, which is good (to teach the importance of collaboration) and sometimes necessary, given the limited materials we have. However, group work can also slow things down, and lazier, underachieving students are able to ride the coat-tails of the trail-blazers.

I can remember as a K-12 student not liking group work, because I was at the mercy of other people and not able to control my own destiny. Plus I tended to be one of the more conscientious students that the others leaned on. Group work can also create a more disruptive atmosphere, as students start goofing off together. I intend to steer the class in a more individualistic direction in the coming lessons.

I left the class feeling very frustrated today, particularly with the behavior of some of the students. I am amazed at their insouciance, just getting up in the middle of the lesson to walk around or to walk outside to call to one of their friends. This is where I need the support of a good teacher, who can provide the discipline we need. It's hard enough for me to communicate the lesson in a foreign language, let alone worrying about disciplining in French too.

Lesson 12

Title: Rimatara Pen Pals

Author: Brad Balukjian

Overview:

Several weeks ago, I had the opportunity to work with the fifth-grade (CM2) class in Rimatara, a tiny island in the Austral archipelago of French Polynesia. I found many traits in common with the students here in Moorea, as well as some differences. I led a lesson on insect morphology and went out in the field to collect insects with several students. I then had them each write a letter to a student in my class here, describing the natural history and culture of their island and introducing themselves.

We now have the chance to respond to those letters. The objective of this lesson is to show the students how each island has its own distinct biodiversity and culture, and that while many things are similar between islands, there are just as many differences. With 118 islands in French Polynesia, there are plenty to choose from, but Rimatara offers a nice contrast with Moorea. While Moorea is big and cosmopolitan (by French Polynesian standards), Rimatara is tiny and much more traditional. I doubt that any of the students in my classes have been there or know anything about it. Creating pen pal correspondence between the two classes will give my students the chance to meet other students who share much of their heritage and national identity, but who have grown up in a very different place. While this lesson strays a bit from the traditional curriculum of the sciences, I think it is invaluable as a way of teaching the kids the importance of communication, diplomacy, and establishing a good rapport, which are essential not only in science, but in all walks of life.

Concepts:
-Each island in the world has its own distinct biodiversity and culture
-Oceanic islands form through a variety of geological processes, such as hot-spot volcanism and secondary uplift
-An endemic species is one found only in a given locality and nowhere else
-Communication and collaboration are essential to make science effective

Vocabulary:
Endemism
Subsidence
Hot spot
Secondary uplift

French Polynesian Education Standards Addressed:
Dire:
1. Utiliser le lexique spécifique des sciences dans les différentes situations didactiques mises en jeu. (Use scientific lexicon in different teaching contexts and environments.)
2. Formuler des questions pertinentes. (Formulate pertinent questions.)
3. Utiliser à bon escient les connecteurs logiques dans le cadre d’un raisonnement rigoureux. (Use logical connections in order to achieve rigorous reasoning.)

Lire:
1. Traiter une information complexe comprenant du texte, des images, des schemas, des tableaux, etc. (Work with complex information comprised of text, images, tables, etc.)

Ecrire:
1. Produire, créer, modifier et exploiter un document à l'aide d'un logiciel de traitement de texte. (Produce, create, modify, or improve a document using the logical treatment of text.)

Grade Span: CM2 (roughly 5th grade)

Materials:
Letters from Rimatara
White paper for writing letters
Powerpoint presentation
Pictures and maps of Rimatara
Worksheet from museum field trip

Advanced Preparation: Before class, write on the board all of the topics they should address in their letters, along with the vocabulary words. Also photocopy article on island formation for them to read as homework

Time: 50 minutes (planned for 50 minutes for a 60-minute class)

Groups: No groups; individual work

Outline
1. Introduction (5 min)

Tell them that there will be no Question of the Week this week, but that for homework they are to come up with their own question. Ask them if there is such thing as a Tahitian scientist to see if there is a difference in their response now versus the start of the year (let's hope there is). Then ask them how they liked the museum field trip, and then ask for examples of things they learned at the museum. Ask if they have any questions. Have them take out the worksheet.

2. Presentation/Discussion (15 min)

Referring to the worksheet, ask them how many archipelagoes and islands there are in French Polynesia. Ask them why we should study other islands. Why not just study Moorea? Ask them if they know where the island of Rimatara is, and see if they can point it out on the map. Explain that I went to Rimatara last month for my research and also worked with the CM2 class there. Show them the map of the island and the poster that the students made. Turn on the Powerpoint, and have them read the slides aloud. For the slide about Rimatara's geology, ask them to explain the formation of oceanic islands using their museum worksheet. Ask them what stage Moorea is at, and see if they can guess Rimatara's stage. Ask for a definition of a hot spot and of subsidence, then define secondary uplift in the explanation of Rimatara's formation.

Show them the slide of the ‘ura, the endemic lorikeet bird of Rimatara. See if anyone knows what endemic means. Once you’ve defined it, ask if there are any endemic species in Moorea, and see if they can figure out why there aren’t any (the proximity to Tahiti).

3. Activity (25 min)

Hand out the letters and blank white paper for the responses. Direct their attention to the board, where you will have written the structure for the letters. They will write 3-paragraph letters; the first paragraph is a personal introduction, the second covers the natural history of Moorea and what we’ve learned this year, and the third is about what they like to do for fun. Giving them concrete structure is important, but it’s just as important to give them some freedom in what they choose to write about within that structure. At the end of class, have them hand in their letters, and tell them that you will add their picture before sending them off.

4. Wrap-Up (5 min)

Ask for some volunteers to introduce their pen pals to everyone else, and then to recap what they wrote in their letters. Hand out the reading on island formation in Tonga as homework for the next lesson. Remind them that for homework they are to each come up with a Question of the Week, and the winner will get the Rimatara t-shirt.

Lesson Recap

DATE TAUGHT: May 14, 2009
DATE OF REFLECTION: May 14, 2009

Learning goals: what were the goals of this lesson?

After another unexpected and prolonged hiatus from school (due to repairs on the building), the main goal of today was to get the kids back on track with a pen-pal lesson, which is always fun. We lost much of our momentum with the school closing, and now I am trying to stabilize us for one final sprint to the end of the year when we have our culminating Science Expo. Today’s Rimatara correspondence lesson involved several concepts from different disciplines. I wanted to build on the museum activity on Tuesday by having a discussion about island geology; the stark differences in the geology of Moorea (a high, young volcanic island) and Rimatara (an old, mostly flat, secondarily uplifted island) provided a nice case study. I also wanted to introduce the concept of endemism, which is very important to studies of the island environment. After introducing endemism, it would be nice to be able to spend a couple of lessons on evolution, but we don’t have the time. I have tried to incorporate bits of evolution throughout the year, but I will be happy if they leave this class simply with the sense that life on earth is very dynamic, old, and has changed considerably through time. I have realized over the course of the year that trying to teach evolution with genetics is a bit too ambitious at this level. Finally, I wanted them to understand the importance of communication in science and of the humanity of science. Too often, science is practiced without regard for the scientists themselves. While objectivity and logic are essential to good science, I believe that a dose of compassion is good too. We are not machines programmed to do science, after all. We are real people with real feelings, and if we establish a good rapport with each other, we will all be happier and better off

in the long run. Writing correspondence is a perfect way to make new contacts, share knowledge, and expand our view of the world.

Do you feel these goals were successfully achieved? How could you tell?

I think this ended up being just the right lesson to transition back into our curriculum. It had a fun, light feel to it but included some key concepts. And it was a nice prelude to our next lesson on island formation. I was very pleased with the students' responses when I posed the question, "Why do we study other islands? We have 118 islands in French Polynesia, but why not just study Moorea?" They responded that there are some species that live here that don't live on other islands, and vice versa. This may sound obvious, but it is the very essence of the field of biogeography. It also indicates that they have an appreciation for the importance of comparison, which is one of the most fundamental concepts of science. Their response provided a nice segue into my explanation of the concept of endemism. I then asked a very challenging question: Why aren't there any endemic species in Moorea? I was shocked in the best way to get a correct answer, from my erstwhile ne'er-do-well friend Michel. He said, "because Tahiti is so close." Ding-ding-ding! I was so proud. In fact, Michel has turned out to be one of the year's most pleasant surprises. He got so many questions right today that I told him "good work today" at the end of class.

The hardest content to explain was the geological history of Rimatara and Moorea. I don't understand all the complexities, but the basic story is pretty fascinating—in the case of Rimatara, the island actually eroded down to nothing, completely disappearing below the ocean, before being secondarily uplifted by further volcanic activity. Pretty cool stuff. The island sunk, and then was born again. I got tripped up trying to come up with the right vocabulary to explain this, but I think they got the point. The key concept I wanted to get across was simply that islands form through a variety of processes, and that islands are dynamic through time.

How did you wrap up the lesson (assessment, discussion, etc)?

I wrapped up by having one of the students read an excerpt from his letter, and then by explaining the homework assignment.

What worked well?

Overall, the lesson went smoothly. The presentation part went a little long, as it took awhile to explain the geology and the concept of endemism, but they clearly enjoyed reading and responding to their letters. I had included pictures of their pen pals, which they were particularly excited about. One thing that I often forget to think about in planning the lessons is how meticulous and methodical most of the students are in writing anything. They always write with their rulers to make sure their lines are evenly spaced, and are very punctilious about any types of mistakes. They are clearly well trained, which is a good thing, but this slows us down considerably. Thankfully, the teachers have been very understanding about having them finish their science work during other periods.

I think they also enjoyed the presentation I gave on Rimatara, which covered some of the history and culture of the island as well as the biodiversity. There are some neat anecdotes about that place, such as having to walk through a cloud of ceremonial smoke when you arrive at the airport in order to cleanse outsiders of any diseases. In general, we had a lot of fun with this lesson. My French has developed to the point where I can almost always understand their questions and feel very comfortable joking around with them.

I was also thrilled to hear their answers when I asked them if there are Tahitian scientists. I didn't hear a single negative response in either class. What a contrast from the beginning of the year.

What was most difficult for the students? (How could you tell?)

As I mentioned above, the geology was hard for many of them to grasp. It's become clear to me that they do not have a sense of Deep Time, and it would be fun and worthwhile to dedicate an entire unit to geology/archaeology/evolution. There are so many potential "kid-friendly" lessons in this area, involving fossils and dinosaurs, and it would be good to consider developing some lessons in these areas for future classes.

What was most difficult for you?

The hardest part for me was Vaihiria's class. I had asked them on Tuesday to bring in their insects so that we could dedicate the entire period to curation (I didn't have enough letters from Rimatara for both classes, and Vaihiria's class is always further behind). Out of the 27 students, only 5 brought their insects. The rest were just negligent. I was disgusted by their carelessness and apparent lack of concern. I asked Patrick to come in to yell at them (he is particularly effective at this), and he went so far as to tell them that science will be cancelled for the rest of the year, excepting the five students who brought their insects. (He later told me that it was a hollow threat, but he wanted them to get the message.) His tirade cleared the way, however, for the most pleasant, calm class session we've had all year. I debated about what to do during the hour, as I had planned an entire lesson that I could no longer do. I considered just giving up and going home and telling them that we would have no class today. I decided instead to play it by ear, and engaged them in a casual conversation about the museum field trip and what they learned. This actually felt refreshing, to not have to follow the rigid minute-by-minute protocol of a traditional lesson plan. I then showed them my Powerpoint on Rimatara, and with half an hour remaining, I gave them the choice of what to do. I said we could just talk about science and I could answer their questions, or we could write letters to the kids in Rimatara, or we could just end the class. They said they wanted to write the letters, which is what we ended up doing.

If you were to do this activity again, or were designing a similar one, what would you do differently?

I would do a better job of pointing out the vocabulary words written on the board.

Further comments about the logistics of running this lesson?

Further comments about the materials (worksheet, specimens)?

Other comments?

Lesson 13

Title: Island Biogeography

Author: Brad Balukjian

Overview:

This will be the last lesson with new content for the year. After today, we will focus exclusively on preparing for the Exposition des Sciences, our culminating end-of-year exhibition. This lesson gives us a chance to explore the intersection between geography and biology, known as biogeography. We have dabbled in this field throughout the year, such as learning the concepts of introduced vs. indigenous species and the term "endemism." In this lesson, we introduce the students to the concept of Deep Time by showing them how old the island of Moorea is and how it formed, as well as how the plant and animal communities came to be. In doing so, we will also reinforce the concepts they learned on the museum field trip, where there was an entire exhibit devoted to the geology of French Polynesia.

The activity simulates the colonization process of a remote oceanic island like Moorea and shows how difficult it is for organisms to get there, and once there, to establish a successful population. The students will also see that the flora and fauna of islands is non-random; that is, many species are better than others at colonizing islands because of their ability to fly, float, or be carried by other organisms. I designed this activity specifically for this lesson, and I hope that it is a fun way to explain some of the basics of island biogeography.

Concepts:

-Many oceanic islands like Moorea formed through the activity of hot-spots on the ocean floor, where volcanic eruptions produce new islands.
-The islands of French Polynesia are very old compared to the history of humans on the islands; while the first Polynesians arrived around 1500 or 1000 years ago, the island of Moorea is approximately 1.5 million years old.
-Some species are better than others at getting to ("colonizing") remote islands like Moorea because of their ability to fly, float, or be carried across long distances.
-It takes a long time before an island builds up a community of plants and animals because of the difficulty of colonization.
-Many organisms may reach an island but then fail to establish a permanent population because they cannot reproduce without a member of the opposite sex.

Vocabulary:

Introduced Species
Indigenous Species
Hot spot
Colonization

French Polynesian Education Standards Addressed:

Dire:

1. Utiliser le lexique spécifique des sciences dans les différentes situations didactiques mises en jeu. (Use scientific lexicon in different teaching contexts and environments.)

2. Formuler des questions pertinentes. (Formulate pertinent questions.)
3. Utiliser à bon escient les connecteurs logiques dans le cadre d'un raisonnement rigoureux. (Use logical connections in order to achieve rigorous reasoning.)

Lire:
1. Lire et comprendre un ouvrage documentaire, de niveau adapté, portant sur l'un des thèmes au programme (Read and understand an article or book, adapted to the appropriate level, concerning one of the themes of the program).

Ecrire:
1. Produire, créer, modifier et exploiter un document à l'aide d'un logiciel de traitement de texte. (Produce, create, modify, or improve a document using the logical treatment of text.)

Grade Span: CM2 (roughly 5^{th} grade)

Materials:
Topographic map of Moorea
Coins covered in blue or pink construction paper
Article from Internet (homework)

Advanced Preparation: To prepare the activity, cut out circles from pink and blue construction paper and paste them onto one side of the coins (I used the 2 franc pieces, although quarters would also work well). Make an even number of males and females, and choose only 3 species so that there is a good enough chance that males and females will reproduce. Divide the coins up into groups so that each group represents a given period of time of potential colonization. Before class, students should read the article on a recent eruption in Tonga where a new island formed. On board before class, write the vocabulary words and sketch a rough map of Oceania, Australia, the Americas, and Southeast Asia.

Time: 50 minutes (planned for 50 minutes for a 60-minute class)

Groups: Everyone will do the activity together

Outline
1. Introduction (5 min)

Tell them you will collect their field notebooks and their Questions of the Week at the end of class, and that you will select one question to ask next week. The person who wrote the question will get a prize, as will the person who correctly answers the question. Ask this week's Question of the Week: What is an endemic species? For the other class, what is the vocabulary word to describe the kind of volcano that forms islands like Moorea? For the prize, give them the Rimatara t-shirt.

2. Presentation/Discussion (15 min)

Ask who read the article for homework and what it was about. See if they know why I had them read an article about Tonga if we are in Moorea. See if they can figure out on their own that Moorea's origins are similar to the Tongan island's. Refer them to the vocabulary word hot

spot (on the board) and ask someone what it means. Ask when the island of Moorea formed, and follow up by asking how long ago Polynesians arrived here (try to impress upon them the huge difference in time scale).

Ask what Moorea looked like after it formed. Explain that gradually, there were more and more species in Moorea as things arrived (introduce the vocabulary word "colonization"). Ask what kinds of plants and animals colonized Moorea a long time ago, and what word we use to describe these things ("indigenous"). Ask why there aren't any tigers in Moorea or any frogs. Discuss what features are good for colonization (ability to fly or float or be carried).

Refer to the map on the board and ask where most of the animals and plants came from. Mention the arrival of humans, and ask what kinds of species humans brought with them. What do we call these kinds of species ("introduced")?

3. Activity (25 min)

Tell them that today we are going to play a game to see how hard it was for animals and plants to colonize Moorea. Go outside to the courtyard. Show them the coins covered in blue paper, and tell them that each student will get one coin. The coins represent plants and animals that were living in Asia 1.5 million years ago (there is a species name and a number written on each coin). Position everyone so they are standing in a circle around a map of Moorea. The space between us and Moorea represents the Pacific Ocean. Pass out one coin to each student, and have them sort themselves into the six groups, with each group representing a period of 250,000 years (there is a number, 1-6, on each coin). One at a time, the groups will try to either throw (representing aerial dispersal) or roll (representing the ocean) their coin so it lands on the map of Moorea, representing a successful colonization. For example, all the members of group 1 throw/roll their coins, representing the first 250,000 years after Moorea. Then all the members of group 2 will throw/roll, representing the next 250,000 years, up until the present. Now explain why there are some coins that are blue and some that are pink. The blues represent males, and the pinks females. If a male gets to Moorea, that's great, but what does he need in order to create a permanent population? A female of course. In order for a species to successfully establish on Moorea, the male and female of the same species need to land next to each other. At the end, see what species ended up successfully establishing on Moorea and review the species composition of the community.

4. Wrap-Up (5 min)

While still outside, show them a couple more coins representing a dog (male and female), and ask who can represent how they got to Moorea. This will be critical in showing them how much easier it was for introduced species to get here versus indigenous species.

Back in the classroom, remind them to bring all of their insect specimens in for next week's lesson.

Lesson Recap

DATE TAUGHT: May 28, 2009
DATE OF REFLECTION: June 3, 2009

Learning goals: what were the goals of this lesson?

Originally, I had planned a more extensive unit on the island environment, encompassing ecology, geology, and conservation. But due to the closure of the school and the need to prepare for the Science Expo, we were left with only one lesson for this unit. I felt it was essential to devote this one lesson to island biogeography, which unites several disciplines and ties together many of the concepts we've learned throughout the year, such as Deep Time, introduced vs. indigenous species, and hot spot volcanism.

The goal of this lesson was to use a game to teach the basic concept of island colonization, and how the biota of Moorea came to be. I wanted them to appreciate how difficult it is to colonize an island, and also that it is largely a non-random process, with some species more likely than others to succeed because of their superior dispersal abilities. I also wanted them to understand how much time it takes to build an island community, especially when compared to the duration of human civilization.

Do you feel these goals were successfully achieved? How could you tell?

Yes, in fact, I think this was my favorite lesson of the year, both in terms of personal satisfaction and effectiveness for the kids. This lesson was very experimental, as it was an activity I designed on my own, and I had never had the chance to practice it. What made the result so satisfying was the way in which we improvised together as a class and the possibilities we thought of for further improvements. Also, I think this was the best I've ever done at accomplishing all of the goals of the lesson. I could tell that the kids got it based on their responses to my questions and the suggestions they made.

The game involved simulating the colonization of Moorea by having the kids throw or roll coins wrapped in colored paper onto a topographic map of Moorea that we laid on the ground outside. Each coin represented one of three species that is indigenous to Moorea, the miki-miki (a shore plant), a bird, and a beetle. Each coin was either male (blue paper) or female (pink paper). The kids were divided into groups, with each group representing 250,000 years, starting from the time of Moorea's formation (1.5 million years ago) to the present. Each student tried to land their coin on the island, using either aerial dispersal (throwing the coin) or sea dispersal (rolling it). If a male and female of the same species landed close enough to each other, it was considered a successful colonization.

The kids quickly grasped the point of the game, and had a lot of fun in playing. Each colonization attempt was watched with great anticipation, and it was fun when a coin would roll around for a little while before finally settling. But the real success of this lesson came with the kids' ability to think critically and to help me improvise. For example, when a bird coin landed next to a miki-miki coin, one of the students pointed out that the bird would eat the plant. Brilliant, I thought. The kids had just expanded the scope of the game on their own by adding ecological interactions to the potential outcomes. I then thought of different ways to introduce ecology; for example, when two male beetles landed next to a female, I asked what would happen. They guessed that one of the males would win and copulate with the female; I agreed, but added the possibility that the female could mate with both males, since insects often have multiple matings. Another example of improvisation is when one of the kids landed their miki-miki coin on the very edge of the island. Rather than having it scored as a "death," I said that it would successfully colonize because miki-miki is a coastal plant, and it landed in its habitat.

In the first class (Caroline's class), I quickly realized that we were going to finish the activity too fast, so I improvised. Instead of doing just one round of the game, I decided to turn it into an experiment with hypotheses by doing multiple games. In the first round, we simulated

dispersal from Southeast Asia. But the second time around, I had them start their "dispersal" from a closer distance, (they physically moved closer to the map), which represented dispersal from Hawaii, which is closer to Moorea than Southeast Asia. I asked them what their hypothesis was before we began; would they have fewer or more successful colonizations starting from Hawaii than from Asia? They predicted Hawaii, because it would be easier to land the coins on the map from the closer distance. For the third round, I had them start even further away than they had for Asia, and said that that represented dispersal from the Americas. I again asked them for their hypotheses. In the end, their data confirmed their hypotheses, which worked out very conveniently. We had the most colonizations when the source area was closest, and the fewest for the most distant source area.

How did you wrap up the lesson (assessment, discussion, etc)?

I wrapped up by introducing two more coins to the game—a male and female dog. They quickly pointed out that dogs were introduced to the islands, demonstrating a firm understanding of the concept of introduced vs. indigenous species. But then I asked them how they would physically represent the arrival of the dogs. They were confused by this, Caroline's class especially. But in Vaihiria's class, Michel (once again!) figured it out. He took the two coins, and walked them over to the map, dropping them in place next to each other, thus representing the ease of a successful colonization for introduced species. I was very impressed.

What worked well?

A lot worked well in this lesson, from beginning to end. I was pleased with the kids' responses during our opening discussion. I was able to incorporate a little geography, as I sketched a map of the Pacific on the board, and they were able to identify New Zealand and the location of Rimatara, which was a review of last week's lesson. Their recall of hot-spot island formation, and introduced vs. indigenous species was also very good. They also had good answers when I asked them what Moorea looked like when it first formed, and how animals and plants came to colonize the island. I tried to use the assigned reading, an article on the eruption of a volcano and formation of a new island in Tonga, as the introduction to this lesson. I also wanted them to understand why we would read something about Tonga if we are here in Moorea (the value of comparison).

More good news is that Vaihiria is clearly trying to make more of an effort to assert her authority and to keep the kids on task. She is now writing down the homework on the board, a simple yet very important act to keep the kids organized.

What was most difficult for the students? (How could you tell?)

The students had a hard time understanding the time context of the game. My goal was for each group of students to represent 250,000 years of time, but they didn't seem to grasp this idea. Perhaps I should have spent more time in the pre-activity discussion spelling this out. In the end, I kind of scrapped the time dimension in the second class, as it was clear it was lost on the first class. 250,000 years is kind of an awkward time interval, and when dealing with numbers that big at this level, the significance can be easily lost.

What was most difficult for you?

For me, the hardest part was explaining the time context, as mentioned above. Also, it was hard to control Caroline's class, which was a little rowdy. Not having done this activity

before, my explanation of the game was clunky the first time around; by the second class, I had learned what to emphasize and how to better explain the activity, and it went smoother.

If you were to do this activity again, or were designing a similar one, what would you do differently?

The objective of the kids either rolling (sea dispersal) or throwing (aerial dispersal) their coins wasn't fulfilled because we ended up playing on sand, which is not good for rolling. In the future I would try to play on pavement. There were also several small details I would tweak, such as having them throw their coins one at a time from the same location.

The most exciting thing about this lesson is the prospect for improvement. You could really get a lot of mileage out of this basic activity depending on the concepts you wanted to cover. The opportunities for incorporating ecology, natural history, and even natural selection abound. For example, instead if just arbitrarily defining "close" in saying whether or not a male and female landed close enough to each other to reproduce, you could incorporate knowledge of the home range and dispersal ability of that species, and then have the students use rulers to measure the actual distance apart that they landed on the island to determine the likelihood of reproduction.

Further comments about the logistics of running this lesson?

Further comments about the materials (worksheet, specimens)?

Other comments?

I am in the process of correcting their exams from the insects unit, and was thrilled to see that the only student who scored a perfect score was a mediocre-performing, quiet boy named Josua who up until now had not shown this kind of breakout performance. Also, Vaihiria's class is showing steady improvement in work ethic and discipline. The story of their class is quickly turning to one of redemption, and for those cynics who are too quick to give up on a seemingly lost cause, their story and that of Josua are telling reminders of the virtues of patience and optimism.

The students also continue to surprise me. When I asked why there weren't any frogs or toads in French Polynesia, one of them pointed out that a large toad had recently been spotted on Tahiti (this made the news, as the arrival of toads could be an ecological disaster). Another student showed me a tiny insect he had collected, which was encouraging because it means that they are interested in more than just the large, charismatic eye-candy insects. And still another student brought in a beautiful longhorn beetle that he had captured at home and was keeping in a jar to show the other students.

Appendix B: Full qualitative codes for 8-question scientific knowledge evaluation

1. What does the word biodiversity mean?
Codes:
1A: Limits biodiversity to plants
1B: Limits biodiversity to insects
1C: Limits biodiversity to animals
1D: Defines biodiversity as being limited to a specific place (i.e. the sea)
1E: Considers insects as separate from animals

2. Come up with an experiment to test the hypothesis that plants need light. Briefly describe the experiment. What materials would you use?
Codes:
2A: Specifically uses watermelon seeds in the study design

3. Explain the geological origin of Moorea. How did the island form?
Codes:
3A: Mentions God
3B: Attributes island formation to something relating to a lizard or a yellow lizard
3C: Incorrectly asserts that an atoll existed before the volcano that formed the island

4. Why do we collect organisms and put them in museums?
Codes:
4A: Explanation implies that mostly rare or old (or ancient) things go in museums
4B: Limits organisms to plants
4C: Limits organisms to insects
4D: Limits organisms to animals
4E: Considers insects separate from animals

5. What characteristics do all insects have in common?
Codes:
5A: Mentions wings as a defining characteristic of insects (or says that they fly)
5B: Mentions small size as a defining characteristic
5C: Says that insects are mean

6. Give an example of an environmental problem in French Polynesia. Who is it a problem for? How can we resolve it?
Codes:
6A: Gives some form of pollution/littering as their example of an environmental problem
6B: Gives Miconia as their example

7. How old is the island of Moorea?
Codes:
7A: Says Moorea is 500 million years old or older
7B: Says Moorea is 1000 years old or younger

8. What is the difference between an indigenous species and an introduced species? Give an example of an indigenous plant species and an introduced plant species.
Codes:
8A: For the indigenous plant example, mentions a plant that was introduced by the Polynesians
8B: Defines an indigenous species as a specific kind of taxon rather than being inclusive of all biodiversity (*i.e.*, an indigenous plant is…)
8C: Gives a complete scientific name for a plant (genus and species)