

Freshwater algae associated with high elevation bogs in the Hawaiian Islands¹

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As part of the Hawaiian Freshwater Algae Biodiversity Survey (2009–2012) we have been documenting algae (with a focus on macroalgae) associated with numerous habitats, including high elevation bogs on the main Hawaiian Islands. Bogs represent a very different environment from streams, where most of our collections originated, in that they have much lower (or absent) water flow, lower temperatures due to high elevation, and usually acidic pH conditions. This paper provides an updated taxonomic checklist for high elevation bog-associated algae in Hawai'i and compares our identifications to historical literature records.

Hawaiian bog ecosystems are characterized as small, isolated and permanently wet areas, which tend to be scarce (only 1–2 present on each large island), consisting of hummocks of native sedges and dwarf individuals of native plant species (Ziegler 2002). In general, bogs represent acidic, dystrophic environments that have a very characteristic littoral flora (Wetzel 2001). It has long been recognized that bogs host a diverse and interesting biota. The microflora of this habitat is typically characterized by a great diversity of algal species, although few of these are ubiquitous. Amongst the algae, desmids are typically species-rich in bog habitats (often several hundred species), while cyanobacteria, chrysomonads, dinoflagellates and diatoms are typically present though less diverse (Wetzel 2001).

The algal flora of Hawaiian bogs has not been studied in great detail. As far back as the early 1900s it was recognized that high elevation bogs likely harbored interesting species, and that further taxonomic attention was due:

“It is to be regretted that the algal flora of the summit bogs has not received careful investigation.” (MacCaughey 1918a, p. 55)

Since that time, very few algal collections have been made from these habitats in the Hawaiian Islands. Filkin *et al.* (2003) reported a survey of stream macroalgae from Hawai'i and included four sites from the Alaka'i Swamp on Kaua'i; seven species in total were recorded, including the green alga *Microspora pachyderma* (Wille) Lagerheim,

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which was a new record for the Hawaiian Islands and was common to three of the four sites from the Alaka'i Swamp. Likewise, Main (2004) documented the diatoms of a stream draining the Alaka'i Swamp and described three new taxa (*Eunotia abbottiae* Main, *E. smithiae* Main and *Actinella punctata* var. *alakaiensis* Main). Aside from these few reports, however, very little has been published recently.

Specimens examined for this study were collected by the authors and other members of the Freshwater Algal Biodiversity group (Dr. Rex Lowe, Bowling Green State University; Dr. Pat Kociolek and Carrie Graeff, University of Colorado; Dr. Jeff Johansen and Melissa Vaccarino, John Carroll University) between July 2009 and November 2010. Samples of microalgae from the sediment surface as well as visible macroalgae (free floating or attached) were collected from high elevation bogs on the islands of Kaua'i, O'ahu, Moloka'i and Hawai'i. Samples were collected using either long-handled forceps or a turkey baster. Although macroalgae were targeted in the survey, microalgae were identified when collected in quantity. Identifications were made using taxonomic literature most pertinent for each lineage (see Sherwood 2006 for a list of taxonomic references). Sherwood Lab accession numbers (ARS) are given in Table 1 to enable data for each sample to be accessed *via* the Hawaiian Freshwater Algae Database (<http://algae.manoa.hawaii.edu/hfwadb/>). Microscope slides have been accessioned at the Bernice P. Bishop Museum (BISH) for representative specimens from our own survey collections, and those accession numbers are also included in Table 1. Algal taxonomy was updated following AlgaeBase (Guiry & Guiry 2012).

Some trends were observed from our checklist of freshwater algal flora of Hawaiian bogs, which was assembled from both literature records and our own identifications (Table 1). Species richness was dominated by the green algae (especially the desmids) and cyanobacteria, but a few other groups were also encountered. Thirteen cyanobacteria, 86 green algae, one yellow-green alga, one euglenoid and four diatoms were reported in total (Table 1); these total 105 taxonomic records. Records from the literature only comprised 58.1% of the total, while 37.1% were from our collections only and 4.8% were shared.

Given the isolation of these unique habitats and the native or endemic vascular plants that characterize Hawaiian bogs, it is likely that endemic species of algae are present as well. Many of the macroalgal species are being studied in greater detail using molecular methods as part of the ongoing research of the Hawaiian Freshwater Algae Biodiversity Survey, and this comparative work will allow further insight into the origins and degree of genetic isolation of the Hawaiian high elevation bog algal flora. In addition, many microalgae were encountered that could not be confidently identified and were not included in the checklist. The total diversity of algae occurring in these habitats probably exceeds the list provided below.

Acknowledgments

We thank our freshwater algal colleagues for their field assistance, intellectual stimulation and algal expertise. This research was supported by a grant from the National Science Foundation (DEB-0841734). Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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Table 1. Checklist of freshwater algae associated with high elevation bogs in the Hawaiian Islands.

Algal taxon	Collecting location	Source	Representative accession
Cyanobacteria			
<i>Chroococcus macrococcus</i> (Kützing) Rabenhorst	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878)	
<i>C. turgidus</i> (Kützing) Nägeli	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878)	
<i>Hapalosiphon fontinalis</i> (C. Agardh) Borner (as <i>H. braunii</i> Nägeli and <i>H. pumilis</i> (Kützing) Kirchner)	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878)	
<i>Phormidium retzii</i> C. Agardh ex Gomont	Stream exiting Alaka'i Swamp, Kaua'i	Filkin <i>et al.</i> (2003)	
<i>Schizothrix</i> sp.	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878)	
<i>Scytonema calothrichoides</i> Kützing	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878)	
<i>S. chiastum</i> Geitler	Stream exiting Alaka'i Swamp, Kaua'i	Filkin <i>et al.</i> (2003)	
<i>S. coactile</i> Montagne ex Kützing	Stream exiting Alaka'i Swamp, Kaua'i	Filkin <i>et al.</i> (2003)	
<i>S. mirabile</i> (Dillwyn) Borner (as <i>S. figuratum</i> C. Agardh)	Swamp on Mauna Kea, Hawai'i	Lemmermann (1905)	
<i>S. tolypothricoides</i> Kützing	Stream exiting Alaka'i Swamp, Kaua'i	Filkin <i>et al.</i> (2003)	
<i>Sirosiphon ocellatum</i> (Dillwyn) Kützing	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878)	
<i>Stigonema ocellatum</i> Thuret ex Borner & Flahault	Swamp on Mauna Kea, Hawai'i	Lemmermann (1905)	
<i>Tolypothrix muscicola</i> var. <i>hawaiiensis</i> Nordstedt	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905)	
<i>Actinotaenium cruciferum</i> (De Bary) Teiling	Stream draining bog in Kohala State Forest Reserve, Hawai'i		BISH 754175 (ARS 07050-00005)

Table 1. (Continued)

Algal taxon	Collecting location	Source	Representative accession
Chlorophyta			
<i>A. cucurbita</i> (Brébisson ex Ralfs) Teiling	Kohala Bog, Kohala State Forest Reserve, Hawai'i		BISH 754176 (ARS 07041-00001)
<i>A. disporum</i> var. <i>americanum</i> (WWest & G.S.West) Teiling	Stream draining bog in Kohala State Forest Reserve, Hawai'i		BISH 754177 (ARS 07056-00004)
<i>A. palangula</i> (Brébisson ex Ralfs) Teiling (as <i>Cosmarium palangula</i> Brébisson ex Ralfs)	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905)	
<i>A. subglobosum</i> (Nordstedt) Teiling (as <i>Cosmarium subglobosum</i> Nordstedt)	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905)	
<i>Aphanochaete repens</i> A.Braun	Swamp on O'ahu	Lemmermann (1905)	
<i>Closterium acutum</i> Brébisson ex Ralfs	Kohala Bog, Kohala State Forest Reserve, Hawai'i		BISH 754178 (ARS 07050-00006)
<i>C. bailyanum</i> var. <i>multinucleatum</i> (Nordstedt) Grönblad (as <i>C. didymotocum</i> Corda var. <i>multinucleatum</i> Nordstedt)	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905)	
<i>C. diana</i> Ehrenberg ex Ralfs	Swamp on Mauna Kea, Hawai'i	Lemmermann (1905)	
<i>C. gracile</i> Brébisson ex Ralfs	Kohala Bog, Kohala State Forest Reserve, Hawai'i		BISH 754179 (ARS 07042-00010)
<i>C. lineatum</i> var. <i>sandvicense</i> Nordstedt	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905)	
<i>C. moniliferum</i> Ehrenberg ex Ralfs	Mt. Ka'ala Rd., Mt. Ka'ala, O'ahu		BISH 754180 (ARS 07122-00003)
<i>C. navicula</i> (Brébisson) Lütkemüller (as <i>Penium navicula</i> Brébisson)	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905)	
<i>Closterium parvulum</i> Nägeli	Swamp on Mauna Kea, Hawai'i	Lemmermann (1905)	
<i>C. parvulum</i> f. <i>minor</i> Nägeli	Swamp on Mauna Kea, Hawai'i Nordstedt (1878)		
<i>C. setaceum</i> Ehrenberg ex Ralfs	Swamp on Mauna Kea, Hawai'i, and Kohala State Forest Reserve, Hawai'i	Lemmermann (1905)	BISH 754181 (ARS 07057-00004)

Table 1. (Continued).

Algal taxon	Collecting location	Source	Representative accession
Chlorophyta			
<i>C. striolatum</i> Ehrenberg ex Ralfs	Mt. Ka'ala, O'ahu		BISH 754182 (ARS 07112-00002)
<i>Closterium</i> sp.	Mt. Ka'ala, O'ahu		BISH 754183 (ARS 07112-00001)
<i>Cosmarium anceps</i> P. Lundell	Kohala State Forest Reserve, Hawai'i		BISH 754184 (ARS 07053-00004)
<i>C. anisochondrum</i> Nordstedt	Swamp on Mauna Kea, Hawai'i	Lemmermann (1905)	
<i>C. annulatum</i> (Nägeli) De Bary (as <i>Dysphinctium</i> <i>annulatum</i> Nägeli)	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905)	
<i>C. botrytis</i> Ralfs	Kohala State Forest Reserve, Hawai'i		BISH 754185 (ARS 07053-00005)
<i>C. caelatum</i> Ralfs	Kohala State Forest Reserve, Hawai'i		BISH 754186 (ARS 07053-00006)
<i>C. connatum</i> (Brébisson) Ralfs (as <i>Dysphinctium</i> <i>connatum</i> (Brébisson) De Bary)	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905)	
<i>C. depauperatum</i> Nordstedt	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905)	
<i>C. obliquum</i> Nordstedt	Kohala Bog, Kohala State Forest Reserve, Hawai'i		BISH 754187 (ARS 07047-00009)
<i>C. pachydermum</i> P. Lundell	Mt. Ka'ala Rd., Mt. Ka'ala, O'ahu		BISH 754188 (ARS 07124-00007)
<i>Cosmarium pseudoprotuberans</i> var. <i>sulcatum</i> (Nordstedt) Coesel (as <i>C. sulcatum</i> Nordstedt)	Swamp on Mauna Kea, Hawai'i	Lemmermann (1905)	
<i>C. pyramidatum</i> Brébisson ex Ralfs	Kohala State Forest Reserve, Hawai'i		BISH 754189 (ARS 07053-00003)
<i>C. regnelli</i> Wille	Pepe'opae Bog, Moloka'i		BISH 754190 (ARS 06679-00004)
<i>C. subcucumis</i> Schmidle	Kohala Bog, Kohala State Forest Reserve, Hawai'i		BISH 754191 (ARS 07043-00004)

Table 1. (Continued).

Algal taxon	Collecting location	Source	Representative accession
Chlorophyta			
<i>C. subgranatum</i> (Nordstedt) Lütke Müller (as <i>C. granatum</i> var. <i>subgranatum</i> Nordstedt)	Swamp on Mauna Kea, Hawai'i	Lemmermann (1905)	
<i>Cosmarium</i> sp.	Kohala State Forest Reserve, Hawai'i		BISH 754192 (ARS 07057-00003)
<i>Cylindrocystis</i> cf. <i>brebissonii</i> De Bary*	Kohala Bog, Kohala State Forest Reserve, Hawai'i		BISH 754193 (ARS 07041-00003)
<i>C. gracilis</i> Him	Kohala Bog, Kohala State Forest Reserve, Hawai'i		BISH 754194 (ARS 07043-00002)
<i>Cylindrocystis</i> sp.	Ka'ala Bog, Mt. Ka'ala, O'ahu and Kohala Bog, Kohala State Forest Reserve, Hawai'i		BISH 754195 (ARS 07090-00002)
<i>Euastrum ansatum</i> Ehrenberg ex Ralfs	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905)	
<i>E. binale</i> (Turpin) Ralfs	Swamp on Mauna Kea, Hawai'i, and Kohala State Forest Reserve, Hawai'i	Nordstedt (1878), Lemmermann (1905)	BISH 754196 (ARS 07050-00007)
<i>E. sinuosum</i> Lenormand	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905)	
<i>Euastrum</i> sp.	Mt. Ka'ala, O'ahu		BISH 754197 (ARS 07118-00003)
<i>Geminella minor</i> (Nägeli) Heering	Kohala Bog, Kohala State Forest Reserve, Hawai'i		BISH 754198 (ARS 07048-00007)
<i>Gloeocystis gigas</i> (Kützing) Lagerheim (also as <i>G. ampla</i> (Kützing) Rabenhorst)	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905), MacCaughey (1918b)	
<i>Gonatozygon kinahani</i> (WArcher) Rabenhorst	Mt. Ka'ala Rd., Mt. Ka'ala, O'ahu		BISH 754199 (ARS 07120-00005)
<i>Haplotaenium minutum</i> (Ralfs) T.Bando	Kohala Bog, Kohala State Forest Reserve, Hawai'i		BISH 754200 (ARS 07042-00002)
<i>Klebsormidium</i> sp.	Alaka'i Swamp, Kaua'i		BISH 754201 (ARS 04445-00001)
<i>Mesotaenium</i> sp.	Kohala Bog, Kohala State Forest Reserve, Hawai'i		BISH 754202 (ARS 07041-00012)

* Species of *Cylindrocystis* can only be confidently identified when spores are present. Spores were absent for this collection.

Table 1. (Continued).

Algal taxon	Collecting location	Source	Representative accession
Chlorophyta			
<i>Micrasterias adscendens</i> Nordstedt	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905)	
<i>M. truncata</i> (Corda) Brébisson ex Ralfs	Swamp on Mauna Kea, Hawai'i, and Alaka'i Swamp, Kaua'i	Nordstedt (1878), Lemmermann (1905)	BISH 754203 (ARS 04449-00001)
<i>Microspora pachyderma</i> (Wille) Lagerheim	Stream exiting Alaka'i Swamp, Kaua'i	Filkin <i>et al.</i> (2003)	
<i>Microspora</i> sp.	Kohala State Forest Reserve, Hawai'i, Alaka'i Swamp, Kaua'i and Pepe'opae Bog, Moloka'i		BISH 754204 (ARS 07055-00001)
<i>Microthamnion kuetzingianum</i> Nägeli ex Kützing	Alaka'i Swamp, Kaua'i		BISH 754205 (ARS 04445-00002)
<i>Mougeotia capucina</i> (Bory) Nordstedt	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905)	
<i>Mougeotia</i> sp.	Stream exiting Alaka'i Swamp, Kaua'i, Pepe'opae Bog, Moloka'i and Kohala Bog, Kohala State Forest Reserve, Hawai'i	Filkin <i>et al.</i> (2003)	BISH 754206 (ARS 06665-00002)
<i>Mucidosphaerium pulchellum</i> (H.C.Wood) C.Bock, Proschold & Krienitz	Kohala Bog, Kohala State Forest Reserve, Hawai'i		BISH 754207 (ARS 07047-00006)
<i>Netrium digitus</i> Itzigsohn & Rothe	Pepe'opae Bog, Moloka'i		BISH 754208 (ARS 06665-00003)
<i>Nitella havaiensis</i> Nordstedt	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905)	
<i>Oocystis naegeli</i> A.Braun	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905), MacCaughey (1918b)	
<i>Oedogonium acrosporium</i> var. <i>majusculum</i> Nordstedt	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905), MacCaughey (1918b)	
<i>O. crispum</i> var. <i>havaense</i> Nordstedt	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905)	

Table 1. (Continued).

Algal taxon	Collecting location	Source	Representative accession
Chlorophyta			
<i>O. pringsheimii</i> f. <i>pachydermatosporum</i> (Nordstedt) Hirn	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905), MacCaughey (1918b)	
<i>Oedogonium</i> sp.	Swamp on Mauna Kea, Hawai'i and Ka'ala Bog, Mt. Ka'ala, O'ahu	Nordstedt (1878)	
<i>Pediastrum bidentulum</i> var. <i>ornatum</i> Nordstedt	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905)	
<i>Pleurotaenium indicum</i> (Grunow) Lundell	Swamp on Mauna Kea, Hawai'i	Lemmermann (1905)	
<i>P. nodulosum</i> (Brébisson ex Ralfs) Rabenhorst	Swamp on Mauna Kea, Hawai'i	Lemmermann (1905)	
<i>P. trabecula</i> (Ehrenberg) Nägeli	Swamp on Mauna Kea, Hawai'i, and Mt. Ka'ala, O'ahu	Lemmermann (1905)	BISH 754209 (ARS 07120-00006)
<i>Scenedesmus quadricauda</i> (Turpin) Brébisson	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905)	
<i>Spirogyra</i> sp.	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878)	
<i>Spirotaenia kirchneri</i> Lütkemüller	Kohala Bog, Kohala State Forest Reserve, Hawai'i		BISH 754210 (ARS 07049-00004)
<i>Stauastrum scabrum</i> Brébisson (as <i>S. subscabrum</i> Nordstedt)	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905)	
<i>S. margaritaceum</i> (Ehrenberg) Meneghini	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905)	
<i>S. monticulosum</i> var. <i>duplex</i> Nordstedt	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905)	
<i>S. muricatum</i> Brébisson ex Ralfs	Kohala Bog, Kohala State Forest Reserve, Hawai'i		BISH 754211 (ARS 07041-00010)
<i>S. muticum</i> Brébisson ex Ralfs	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905)	
<i>S. spongiosum</i> var. <i>griffithianum</i> (Nägeli) Lagerheim	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905)	

Table 1. (Continued).

Algal taxon	Collecting location	Source	Representative accession
Chlorophyta			
<i>S. subtile</i> Nordstedt	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905)	
<i>S. trihedrale</i> Wolle	Kohala Bog, Kohala State Forest Reserve, Hawai'i		BISH 754212 (ARS 07041-00006)
<i>Staurastrum</i> sp.	Kohala State Forest Reserve, Hawai'i		BISH 754213 (ARS 07057-00006)
<i>Stigeoclonium subsecundum</i> (Kützing) Kützing	Stream exiting Alaka'i Swamp, Kaua'i	Filkin <i>et al.</i> (2003)	
<i>Tetmemorus brebissonii</i> Ralfs	Pepe'opae Bog, Moloka'i		BISH 754214 (ARS 06671-00002)
<i>T. granulatus</i> f. <i>minor</i> Nordstedt	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905)	
<i>T. laevis</i> var. <i>continuus</i> Nordstedt	Swamp on Mauna Kea, Hawai'i	Lemmermann (1905)	
<i>Tetraspora</i> sp.	Alaka'i Swamp, Kaua'i and Kohala Bog, Kohala State Forest Reserve, Hawai'i		BISH 754215 (ARS 04440-00001)
<i>Xanthidium armatum</i> var. <i>fissum</i> Nordstedt	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878), Lemmermann (1905)	
<i>X. octocorne</i> var. <i>majus</i> f. <i>hawaiensis</i> Nordstedt	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878)	
<i>Zygnema spontaneum</i> Nordstedt	Swamp on Mauna Kea, Hawai'i	Nordstedt (1878)	
<i>Zygnema</i> sp.	Kohala Bog, Kohala State Forest Reserve, Hawai'i		BISH 754216 (ARS 07112-00003)
Ochrophyta – Bacillariophyceae (diatoms)			
<i>Actinella punctata</i> var. <i>alakaiensis</i> Main	Alaka'i Swamp, Kaua'i	Main (2004)	
<i>Eunotia abbottiae</i> Main	Alaka'i Swamp, Kaua'i	Main (2004)	
<i>E. smithiae</i> Main	Alaka'i Swamp, Kaua'i	Main (2004)	
<i>Tabellaria flocculosa</i> (Roth) Kützing	Stream exiting Alaka'i Swamp, Kauai, and Kohala State Forest Reserve, Hawai'i	Filkin <i>et al.</i> (2003)	BISH 754217 (ARS 07054-00005)

Table 1. (Continued).

Algal taxon	Collecting location	Source	Representative accession
Ochrophyta – Xanthophyceae (yellow-green algae)			
<i>Tribonema</i> sp.	Kohala State Forest Reserve, Hawai'i and Hanalei Trail exiting Pepe'opae Bog, Moloka'i		BISH 754218 (ARS 07052-00003)
Euglenozoa			
<i>Euglena</i> sp.	Alaka'i Swamp, Kaua'i		BISH 754219 (ARS 04456-00006)
