

Freshwater algae associated with taro cultivation 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 taro fields on the accessible main Hawaiian Islands. Taro fields provide a very different environment from streams, where most of our other collections originate, in that they have much lower (or absent) water flow and temperatures that can be substantially higher (measured as high as 37.0 °C in our field sites). This paper provides an updated taxonomic checklist for taro field-associated algae in Hawaii 'i and compares our identifications to historical literature records for this interesting habitat.

Although several past authors have recorded collections of freshwater algae from taro fields, the only researchers to explicitly discuss algae collecting in these fields were Tilden (1901, 1902) and MacCaughey (1917, 1918a, b). Josephine E. Tilden spent several months collecting algae from almost every conceivable habitat in Hawaii 'i in the year 1900. In an informal account of her expedition to the islands of O'ahu, Hawaii 'i and Kaua'i (Tilden 1901) she mentions the following collections from Hawaii 'i: "In a taro patch was found *Anabaena variabilis*, some *Chara* and diatoms" (Tilden 1901: 168). MacCaughey made extensive collections from taro fields on a number of islands and compiled these records in his summary manuscripts (MacCaughey 1917, 1918a, b). Abbott (1992) noted that *limu* were sometimes gathered from upland *lo 'i*, and Aiona (2003) documented names of *limu* from taro fields along with their Latin names (*limu kala wai* – *Spirogyra* spp.; *lī pālāwai* – *Pithophora* sp., *Stigeoclonium amoenum*, *Hydrodictyon reticulatum* and *Spirogyra* spp.; *hulu 'ilio* – *S. amoenum*; *limu nehe* – *Spirogyra* spp.) based on ethnobotanical interviews with native Hawaiian peoples. Given that Hawaiian names exist for some species of freshwater algae and the recorded history of these algae being collected from taro fields, the freshwater algae of taro fields must have also played a role in the diet of some native Hawaiians, either directly or indirectly.

Collections for this study were made by the authors and other members of the Freshwater Algal Biodiversity group (Dr. Rex Lowe, Bowling Green State University; Dr. Pat Kocielek and Carrie Graeff, University of Colorado; Dr. Jeff Johansen and Melissa Vaccarino, John Carroll University) between July 2009 and January 2011, with several additional collections made by the senior author dating back to 2001. Samples were collected from the sediment surface, free-floating, or attached in taro fields on the islands of Kaua'i, O'ahu, Moloka'i, Maui and Hawaii 'i. Identifications were made using taxonomic literature sources most pertinent for each lineage (see Sherwood 2006 for taxonomic references). Catalog numbers are Bishop Museum (BISH) *Herbarium Pacificum* numbers for representative microscope slides deposited of each taxon. Sherwood Lab accession numbers (ARS) are also given to enable supplementary data for each sample to be accessed via the Hawaiian Freshwater Algae Database (<http://algae.manoa.hawaii.edu/hfwadb/>).

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Table 1. Checklist of freshwater algae associated with taro fields in the Hawaiian Islands.

Algal taxon	Source	Representative accession
Cyanobacteria		
<i>Anabaena confervoides</i> Reinsch	Tilden (1902), MacCaughey (1918b)	
<i>Anabaena</i> sp.	MacCaughey (1918a), this study	BISH 749534; (ARS 07431-00002)
<i>Aphanothece stagnina</i> (Sprengel)		
A. Braun	MacCaughey (1918b)	
<i>Aphanothece</i> sp.	MacCaughey (1918a)	
<i>Calothrix fusca</i> (Kützing) Bornet & Flahault		
<i>Calothrix</i> sp.	MacCaughey (1918b)	
	MacCaughey (1918a), this study	BISH 749535; (ARS 04236-00001)
<i>Chamaesiphon confervicola</i>		
A. Braun	MacCaughey (1918b)	
<i>C. elongatus</i> (Nordstedt) Kann	MacCaughey (1918b)	
<i>Chamaesiphon</i> sp.	MacCaughey (1918a)	
<i>Chroococcus</i> sp.	MacCaughey (1918a)	
<i>Cylindrospermum muscicola</i>		
Kützing ex Bornet & Flahault	this study	BISH 749536; (ARS 04236-00002)
<i>Cylindrospermum</i> sp.	this study	BISH 749668; (ARS 07513-00005)
<i>Gloeocapsa</i> sp.	MacCaughey (1918a)	
<i>Gloeotheca fusco-lutea</i> Nägeli	MacCaughey (1918b)	
<i>Gloeotheca</i> sp.	MacCaughey (1918a)	
<i>Gloetrichia natans</i> (Hedwig)		
Rabenhorst ex Bornet & Flahault	MacCaughey (1918b)	
<i>Leptolyngbya rivulariarum</i>		
(Gomont) Anagnostidis & Komárek	MacCaughey (1918b)	
<i>Lyngbya aestuarii</i> (Mertens)		
Liebman ex Gomont	MacCaughey (1918b)	
<i>L. aestuarii</i> f. <i>natans</i> Gomont	MacCaughey (1918b)	
<i>Lyngbya</i> sp.	MacCaughey (1918a), this study	BISH 749669; (ARS 07032-00001)
<i>Merismopedia glauca</i> (Ehrenberg)		
Kützing	MacCaughey (1918b)	
<i>Merismopedia</i> sp.	MacCaughey (1918a)	
<i>Nostoc linckia</i> (Roth) Bornet ex Bornet & Flahault	MacCaughey (1918b)	
<i>N. piscinale</i> Kützing ex Bornet & Flahault	MacCaughey (1918b)	
<i>N. punctiforme</i> (Kützing) Hariot	MacCaughey (1918b)	
<i>N. spongiaeforme</i> C. Agardh ex Bornet & Flahault	MacCaughey (1918b)	
<i>Nostoc</i> sp.	MacCaughey (1918a)	
<i>Nostochopsis</i> sp.	this study	BISH 749670; (ARS 04320-00003)
<i>Oscillatoria aeruginosa</i> C. Agardh ex Gomont	MacCaughey (1918b)	
<i>O. princeps</i> Vaucher ex Gomont	this study	BISH 749671; (ARS 07509-00002)
<i>Oscillatoria</i> sp.	this study	BISH 749672; (ARS 06981-00001)
<i>Phormidium retzii</i> (C. Agardh) Kützing ex Gomont	this study	BISH 749673; (ARS 04149-00001)
<i>Rivularia</i> sp.	MacCaughey (1918a)	
<i>Scytonema crispum</i> (C. Agardh) Bornet	MacCaughey (1918b)	
<i>Scytonema</i> sp.	MacCaughey (1918a), this study	BISH 749674; (ARS 04320-00004)
<i>Stigonema</i> sp.	MacCaughey (1918a)	
<i>Trichormus catenula</i> (Kützing ex Bornet & Flahault) Komárek & Anagnostidis	MacCaughey (1918b)	
<i>T. variabilis</i> (Kützing ex Bornet & Flahault) Komárek & Anagnostidis	Tilden (1901), MacCaughey (1918b)	

Table 1. (continued)

Algal taxon	Source	Representative accession
Cyanobacteria (continued)		
<i>Xenotholos kernerii</i> (Hansgirg) M.Gold-Morgan, G.Montejano & J.Komárek	MacCaughey (1918b)	
<i>Xenococcus</i> sp.	MacCaughey (1918a)	
Chlorophyta		
<i>Ankistrodesmus</i> sp.	this study	BISH 749675; (ARS 06762-00002)
<i>Bulbochaete</i> sp.	MacCaughey (1918a)	
<i>Chara braunii</i> C.C.Gmelin	this study	BISH 749677; (ARS 07513-00001)
<i>Chara</i> sp.	Tilden (1901), MacCaughey (1918a)	
<i>Cladophora glomerata</i> (Linnaeus) Kützing	this study	BISH 749678; (ARS 04135-00001)
<i>C. lehmanniana</i> (Lindenberg) Kützing	MacCaughey (1918b)	
<i>Cloniophora spicata</i> (Schmidle) Islam	this study	BISH 749676, 749679; (ARS 06769-00001)
<i>Coleochaete</i> sp.	MacCaughey (1918a)	
<i>Conferva</i> sp.	MacCaughey (1918a)	
<i>Cosmarium</i> sp.	this study	BISH 749680; (ARS 06764-00008)
<i>Desmidiium</i> sp.	this study	BISH 749681; (ARS 06756-00001)
<i>Draparnaldia</i> sp.	MacCaughey (1918a)	
<i>Gonium</i> sp.	MacCaughey (1918a)	
<i>Hyalotheca dissiliens</i> Brébisson ex Ralfs	this study	BISH749682; (ARS 07514-00003)
<i>Hydrodictyon reticulatum</i> (Linnaeus) Bory de Saint-Vincent	MacCaughey (1918b), this study	BISH 749683; (ARS 07444-00001)
<i>Hydrodictyon</i> sp.	MacCaughey (1918a)	
<i>Klebsormidium subtile</i> (Kützing) Tracanna ex Tell	MacCaughey (1918b)	
<i>Mougeotia</i> sp.	MacCaughey (1918a), this study	BISH 749684; (ARS 06652-00002)
<i>Netrium</i> sp.	this study	BISH 749685; (ARS 06733-00002)
<i>Nitella</i> sp.	MacCaughey (1918a), this study	BISH 749686; (ARS 07510-00001)
<i>Oedogonium</i> sp.	MacCaughey (1918a), this study	BISH 749687; (ARS 07028-00005)
<i>Pithophora</i> sp.	this study	BISH 749688; (ARS 07024-00001)
<i>Raphidium</i> sp.	MacCaughey (1918a)	
<i>Rhizoclonium hieroglyphicum</i> (C.Agardh) Kützing	this study	BISH 749689; (ARS 07511-00004)
<i>Rhizoclonium</i> sp.	this study	BISH 749690; (ARS 07025-00002)
<i>Scenedesmus</i> sp.	MacCaughey (1918a), this study	BISH 749691; (ARS 06733-00004)
<i>Sirogonium</i> sp.	this study	BISH 749692; (ARS 07516-00001)
<i>Spirogyra</i> spp.	MacCaughey (1918a), this study	BISH 749693; (ARS 06988-00001)
<i>Stigeoclonium</i> sp.	this study	BISH 749694; (ARS 06753-00011)
<i>Tetraabaena socialis</i> (Dujardin) H.Nozaki & M.Itoh	MacCaughey (1918b)	
<i>Ulothrix minulata</i> Kützing	MacCaughey (1918b)	
<i>Ulothrix</i> sp.	MacCaughey (1918a)	
<i>Zygnema spontaneum</i> Nordstedt	MacCaughey (1918b)	
<i>Zygnema</i> sp.	MacCaughey (1918a), this study	BISH 749695; (ARS 06760-00002)
Rhodophyta		
<i>Chantransia</i> sp.	this study	BISH 749696; (ARS 06986-00001)
<i>Compsopogon caeruleus</i> (Balbis ex C. Agardh) Montagne	this study	BISH 749697; (ARS 06757-00001)

Table 1. (continued)

Algal taxon	Source	Representative accession
Chrysophyceae		
<i>Dinobryon sertularia</i> Ehrenberg	MacCaughey (1918b)	
Tribophyceae		
<i>Vaucheria</i> sp.	this study	BISH 749698; (ARS 06760-00004)
Bacillariophyceae		
<i>Hydrosera</i> sp.	this study	BISH 749699; (ARS 07449-00003)
<i>Pleurosira laevis</i> (Ehrenberg) Compère	this study	BISH 749700; (ARS 07443-00002)
Euglenophyta		
<i>Euglena</i> sp.	this study	BISH 749701; (ARS 04141-00002)
<i>Lepocinclis spirogyroides</i> Marin & Melkonian	MacCaughey (1918b)	
<i>Monomorphina pyrum</i> (Ehrenberg) Mereschkowski	MacCaughey (1918b)	
<i>Phacus pleuronectes</i> (O.F.Müller) Nitzsch ex Dujardin	MacCaughey (1918b)	
<i>Salpingoeca pyxidium</i> Kent	MacCaughey (1918b)	
<i>Trachelomonas hispida</i> (Perty) F.Stein	MacCaughey (1918b)	
<i>T. oblonga</i> var. <i>truncata</i> Lemmermann	MacCaughey (1918b)	
<i>T. volvocina</i> var. <i>minuta</i> Lemmermann	MacCaughey (1918b)	

All the major taxonomic groups of freshwater macroalgae found in the Hawaiian Islands are represented in taro fields (e.g. cyanobacteria, red and green algae, diatoms, yellow-green algae), but some taxa differ in their degree of specialization to the taro field habitat. For example, some genotypes of *Spirogyra* (which likely represent distinct species) are known exclusively from taro fields, while others are found in multiple habitat types (Neumann 2011; Neumann & Sherwood, in prep.). Forty cyanobacteria, 34 green algae, two red algae, one chrysophyte, one tribophyte, eight euglenoids, and two diatoms are reported in total (Table 1); these 88 taxonomic records include those from our own collections and others from the literature. Records from only the literature comprised 58% of the total, while 28% were from our collections only, and 14% were shared.

Freshwater algae have been a component of Hawaiian taro fields for hundreds of years, and those species specialized to this habitat may have been introduced with taro plants or soil from other tropical Pacific regions. Future research into the freshwater algal community composition of taro fields in other regions of the Pacific, especially those with documented human migrations to the Hawaiian Islands, will allow further insights into the biogeographic origins and degree of endemism of the Hawaiian taro field algal flora.

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