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Stream Macroalgae of the Fiji Islands: A Preliminary Study[1]

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ABSTRACT: Twenty-seven stream segments sampled in August 1994 on the three largest Fiji Islands ranged considerably in channel size (maximum width 1–20 m, maximum depth 20–>100 cm) and mean current velocity (1–118 cm sec^{-1}). Water temperatures tended to be warm (23–30°C), pH was neutral to slightly alkaline (7.2–8.6), and specific conductance was quite variable (40–510 $\mu S\ cm^{-1}$). Mean number of species per stream segment was 2.6 and ranged from one to five. In the 71 populations of stream macroalgae sampled, only 15 species were identified: seven Cyanophyta, six Chlorophyta, and two Rhodophyta. All of these species represent new records for the freshwater algal flora of Fiji. Macroalgal cover ranged from <1 to >76% (mean ca. 36%) of the stream bottom and was positively correlated to maximum depth and mean current velocity. The most widespread species that occurred on all three islands were the cyanophytes *Phormidium retzii* (C.Ag.) Gom. and *P. subfuscum* Kütz. and the chlorophyte *Spirogyra* sp. 2 (17, 9, and 19 segments, respectively). Morphological forms included nine mats, three free filaments, and one each of gelatinous colonies, crusts, and tufts. Eleven of the 15 species were in the vegetative state. There were nine species of stream macroalgae on Vitu Levu and eight each on Vanua Levu and Taveuni. The Sørenson's similarity index was highest for the last two islands and lowest for the first two islands.

OCEANIC ISLANDS of the Pacific are of interest in terms of the biogeography of freshwater organisms because many of these organisms are intolerant of high salinities and must colonize from great distances by jump-dispersal (Pielou 1979). Transport may occur by migrating birds or by wind currents (Johansson 1976). The Hawaiian Islands are the best-studied complex for freshwater algae (e.g., Fungladda et al. 1983, Vis et al. 1994, and references therein). In the South Pacific, there have been few freshwater algal studies. Diatoms were recorded from Vanuatu and New Caledonia (Manguin 1938, 1962) and Viti Levu of the Fiji Islands (Foged 1987); Characeae were surveyed in the Fiji, Somoan, and Society Islands (Wood 1962, 1963).

Stream macroalgae are those species that occur in flowing freshwater and have a mature thallus that is benthic and a discrete structure recognizable with the naked eye (Sheath and Cole 1992). Morphological forms include mats, colonies, gelatinous and free filaments, tissuelike thalli, crusts, and tufts. The different forms have various adaptive features to tolerate drag-related stress. The only concerted examination of stream macroalgae from Pacific Islands is that of Vis et al. (1994) for the four largest Hawaiian Islands. The findings reported here of the three largest Fiji Islands is the first survey of stream macroalgae from the South Pacific.

MATERIALS AND METHODS

Twenty-seven stream segments were sampled on the islands of Vitu Levu, Vanua Levu, and Taveuni during the period of 12–18

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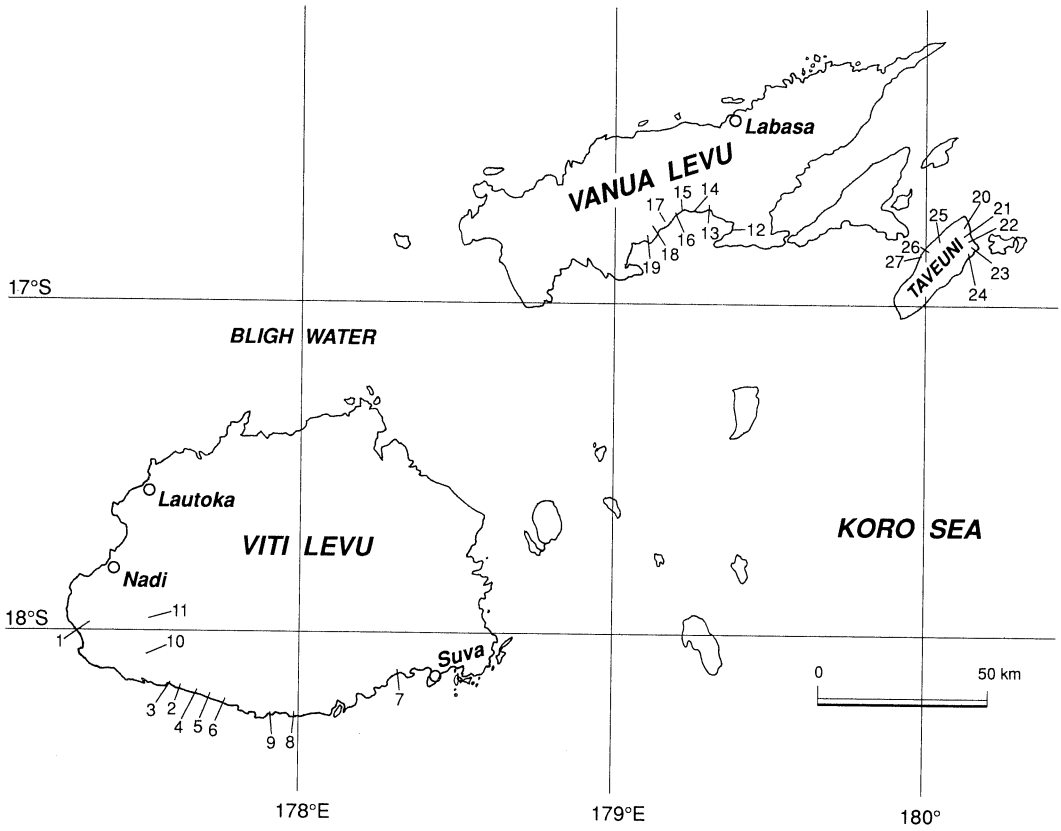


FIGURE 1. Distribution of stream segments sampled in the Fiji Islands. Numbers correspond to those in Tables 2 and 3.

August 1994 (Figure 1, Table 1). At each site, a 20-m length was entirely examined for macroalgae, and cover was estimated as previously described (Sheath et al. 1986). Maximum width and depth, mean current velocity, water temperature, pH, and specific conductance were measured. Samples were immediately fixed in 2.5% calcium carbonate–buffered glutaraldehyde for identification and morphometric analysis. For light microscopy, samples were examined and photographed with a microscope (Olympus BHS) and photographic system (PM-10AK).

Pearson product-moment correlations were determined among stream physicochemical characteristics, species numbers, and cover ranks based on the Minitab statistical package (Minitab 1993). To compare floristic associations among the islands, the Sørenson's similarity index was calculated (Mueller-Dombois and Ellenberg 1974).

RESULTS AND DISCUSSION

The stream segments sampled varied considerably in terms of maximum width and depth, and these two characteristics were positively correlated ($P < 0.05$) (Table 2). Mean current velocities tended to be slow to moderate (with the exception of stream numbers 7, 13, and 23 [83–118 cm sec^{-1}]) because we collected in one of the drier months (New Zealand External Intelligence Bureau 1986). Water temperatures ranged from 23 to 27°C. The pH values were neutral to slightly alkaline (7.2–8.2), and pH was positively correlated to stream width ($P < 0.05$). Specific

TABLE 1

LOCATION OF FIJI STREAM SAMPLING SITES

1. Vitu Levu
   1. Queen's Hwy, 0.9 km north of marker 60.6, 24.3 km north of Yadua
   2. Queen's Hwy, marker 117.1, 0.5 km east of Naviti
   3. Queen's Hwy, bridge at marker 112.4
   4. Queen's Hwy, 85 km marker to Suva, 2 km east of Korolevu
   5. Queen's Hwy, 6.2 km east of Rte 4
   6. Queen's Hwy, 4.8 km east of Rte 5
   7. Queen's Hwy, 25 km west of Suva
   8. Queen's Hwy, bridge at marker 56.2, 1 km west of Galoa
   9. Queen's Hwy, bridge at marker 70.5, 0.1 km east of Korovisilou
   10. Sigatoka Garden Hwy, marker 1.9, 1.9 km north of Sigatoka
   11. Sigatoka Garden Hwy, bridge at marker 7.3, 17.6 km north of Sigatoka
2. Vanua Levu
   12. Savusavu-Labasa Hwy, 2 km north of Savusavu
   13. Wailevu Rd at Savusavu-Labasa Hwy
   14. Wailevu Rd, 3 km from Savusavu-Labasa Hwy
   15. Wailevu Rd, 6 km from Savusavu-Labasa Hwy
   16. Wailevu Rd, 9 km from Savusavu-Labasa Hwy
   17. Wailevu Rd, 12 km from Savusavu-Labasa Hwy
   18. Wailevu Rd, 15 km from Savusavu-Labasa Hwy
   19. Wailevu Rd, 20 km from Savusavu-Labasa Hwy
3. Taveuni
   20. Eastern Rd, 7.4 km south of airport
   21. Eastern Rd, 9.3 km south of airport
   22. Eastern Rd, 11.4 km south of airport
   23. Eastern Rd, 12.5 km south of airport
   24. Eastern Rd, 14.2 km south of airport at Tavolo Forest Park Reserve
   25. Western Rd, 2 km north of Somosomo
   26. Western Rd, 0.3 km north of Somosomo
   27. Western Rd, 5 km south of Somosomo

conductance was mostly low (<190 μS cm^{-1}), with the exception of stream numbers 9–11 on Vitu Levu (Table 2, Figure 1). The pH and conductance values are higher than those reported by Ash et al. (1986) (pH 5.0–6.5, conductance 14–18 μS cm^{-1}) for a highland crater catchment and lake on Taveuni, but the pH values are similar to those of Foged (1987) for Viti Levu (7.0–9.0).

Macroalgal species number per stream segment ranged from one to five (Table 2) and was not significantly correlated to any of the physicochemical characteristics measured. The mean number of species per segment, 2.6, is lower than that of the Hawaiian Islands (3.4 [Vis et al. 1994]) and the Caribbean Islands (3.1 [Sheath and Cole 1992]). The overall diversity of stream macroalgae in Fiji is also low. In the 27 stream segment samples, 71 populations of stream macroalgae were collected, composed of only 15 species: seven Cyanophyta, six Chlorophyta, and two Rhodophyta (Table 3). This compares to 114 populations and 34 species in 34 stream segments in Hawai'i (Vis et. al. 1994).

The macroalgal cover ranged from <1 to >76% of the stream bottom (Table 2). Cover was positively correlated to stream maximum depth and mean current velocity ($P < 0.05$). It may be that deeper, faster-flowing streams do not desiccate as readily as others and hence are more favorable habitats. The approximate mean cover of 36% is higher than that of Hawaiian streams (ca. 27% [Vis et al. 1994]) or tropical streams in North America (ca. 14% [Sheath and Cole 1992]). This indicates that, although Fijian streams vary widely in terms of macroalgal cover and they are relatively poor in diversity, they tend to have relatively high cover values compared with those of other tropical regions. Much of the lowland area sampled was partially disturbed, and high nutrients may account for this trend. All of the surveys were conducted during the dry period, so seasonality should not be a major factor.

To our knowledge, all of the 15 species of stream macroalgae collected in this study are new records for the freshwater algal flora of the Fiji Islands (Table 3) (Wood 1962, Foged 1987). The most widespread species, which occurred on all three islands, were the cyanophytes *Phormidium retzii* (C.Ag.) Gom. (17 segments) and *P. subfuscum* Kütz. (9 segments) and the chlorophyte *Spirogyra* sp. 2 (19 segments). *Phormidium retzii* is also the most widely distributed stream macroalga in Hawai'i (Vis et al. 1994) and in North America (Sheath and Cole 1992). In Fiji, eight species were collected at only one location. In terms of morphological forms, there were nine mats, three free filaments, and one each of gelatinous colonies, crusts, and tufts.

TABLE 2

CHARACTERISTICS OF FIJI STREAMS SAMPLED

STREAM[a]	MAX. WIDTH (m)	MAX. DEPTH (cm)	MEAN CURRENT VELOCITY (cm sec^{-1})	TEMPERATURE (°C)	pH	SPECIFIC CONDUCTANCE ($\mu S\ cm^{-1}$)	MACROALGAE	
							SPECIES NUMBERS	COVER SCALE[b]
1	8	>100	56	26	7.6	180	4	3
2	8	37	49	26	7.8	170	3	3
3	5	46	26	26	8.0	160	3	5
4	8	37	42	27	8.2	140	1	5
5	5	47	51	26	7.9	110	2	5
6	5	>100	46	27	7.9	130	3	5
7	10	>100	118	27	7.9	70	1	5
8	5	>100	64	23	7.8	100	3	6
9	8	>100	52	26	7.8	140	2	4
10	3.5	48	21	30	8.2	510	2	5
11	2.3	42	1	30	7.7	310	1	2
12	1.5	30	25	26	7.2	510	2	2
13	5	>100	85	27	7.9	120	3	5
14	4	48	21	26	8.0	90	4	4
15	20	>100	37	26	8.4	90	3	5
16	2.4	23	30	27	7.4	90	1	2
17	7	55	32	27	8.6	100	2	2
18	4	60	28	27	7.7	120	1	2
19	12	>100	15	27	8.2	90	2	4
20	5	50	21	27	8.1	50	5	4
21	12	50	18	27	8.0	50	3	4
22	5	34	15	27	8.0	60	3	2
23	20	71	83	26	8.0	50	5	3
24	5	>100	60	24	8.2	40	1	2
25	2.3	30	23	25	7.9	50	5	3
26	8	>100	56	25	8.0	60	3	4
27	1	30	56	25	7.6	80	3	4

[a] For locations see Figure 1 and Table 1.
[b] 0, 0%; 1, <1%; 2, 1–10%; 3, 11–25%; 4, 26–50%; 5, 51–75%; 6, 76–100% (Sheath et al. 1986).

Mats are the most common form in streams of Hawai'i (Vis et al. 1994), North America, and Europe (Sheath and Cole 1992). However, in the latter two regions, gelatinous colonies are the second most frequently collected form. In Fiji, only one species was sexually reproducing, *Spirogyra setiformis* (Roth) Kütz.; two had asexual sporangia, *Cloniophora macrocladia* (Nordst.) Bourr. and *Thorea violacea* (Thore) Desvaux; one had resting akinetes, *Cylindrospermum muscicola* Kütz.; and the remaining 11 species were vegetative (Figures 2–19). The percentage of vegetative forms (73%) is similar to that in Hawai'i (75% [Vis et al. 1994]) and North America (78% [Sheath and Cole 1992]).

Among the three islands sampled, Viti Levu (1) had nine species and Vanua Levu (2) and Taveuni (3) each had eight species of stream macroalgae (Table 3, Figure 1). The Sørenson's similarity indices for the three islands are as follows: 1 and 2, 0.47; 1 and 3, 0.59; 2 and 3, 0.63. It is noteworthy that the smallest island, Taveuni (3), has relatively more species in common with the two largest islands (1 and 2) than they have with each other.

From the 15 species collected in Fijian streams, five were identified from a similar survey of Hawai'i, *Phormidium retzii*, *P. subfuscum*, *Rhizoclonium hieroglyphicum* (C.Ag.) Kütz., *Stigeoclonium subsecundum* Kütz., and

TABLE 3

DISTRIBUTION OF STREAM MACROALGAE IN THE FIJI ISLANDS

TAXON	STREAM SEGMENT[a]
Cyanophyta	
Oscillatoriales	
Microcoleus acutissimus Gardner	6
Phormidium retzii (C.Ag.) Gom.	2, 3, 5, 6, 8, 10, 11, 12, 14, 15, 18, 20, 21, 22, 25, 26, 27
P. subfuscum Kütz.	1, 14, 15, 20, 21, 22, 23, 25, 27
P. tinctorium Kütz.	2, 3, 25
Nostocales	
Cylindrospermum muscicola Kütz.	19
Scytonema crispum (C.Ag.) Bornet	23
Stigonematales	
Nostochopsis lobatus Wood emend. Geit.	13
Chlorophyta	
Chaetophorales	
Cloniophora macrocladia (Nordst.) Bourr.	1, 12, 13, 17, 20, 23
Stigeoclonium subsecundum Kütz.	9
Cladophorales	
Rhizoclonium hieroglyphicum (C.Ag.) Kütz.	19
Zygnematales	
Mougeotia sp.	20
Spirogyra setiformis (Roth) Kütz.	1
Spirogyra sp. 2	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 14, 15, 17, 21, 22, 23, 25, 26, 27
Rhodophyta	
Batrachospermales	
Thorea violacea (Thore) Desvaux	8
Hildenbrandiales	
Hildenbrandia angolensis Welw. ex West & West	14, 16, 20, 23, 24, 25, 26

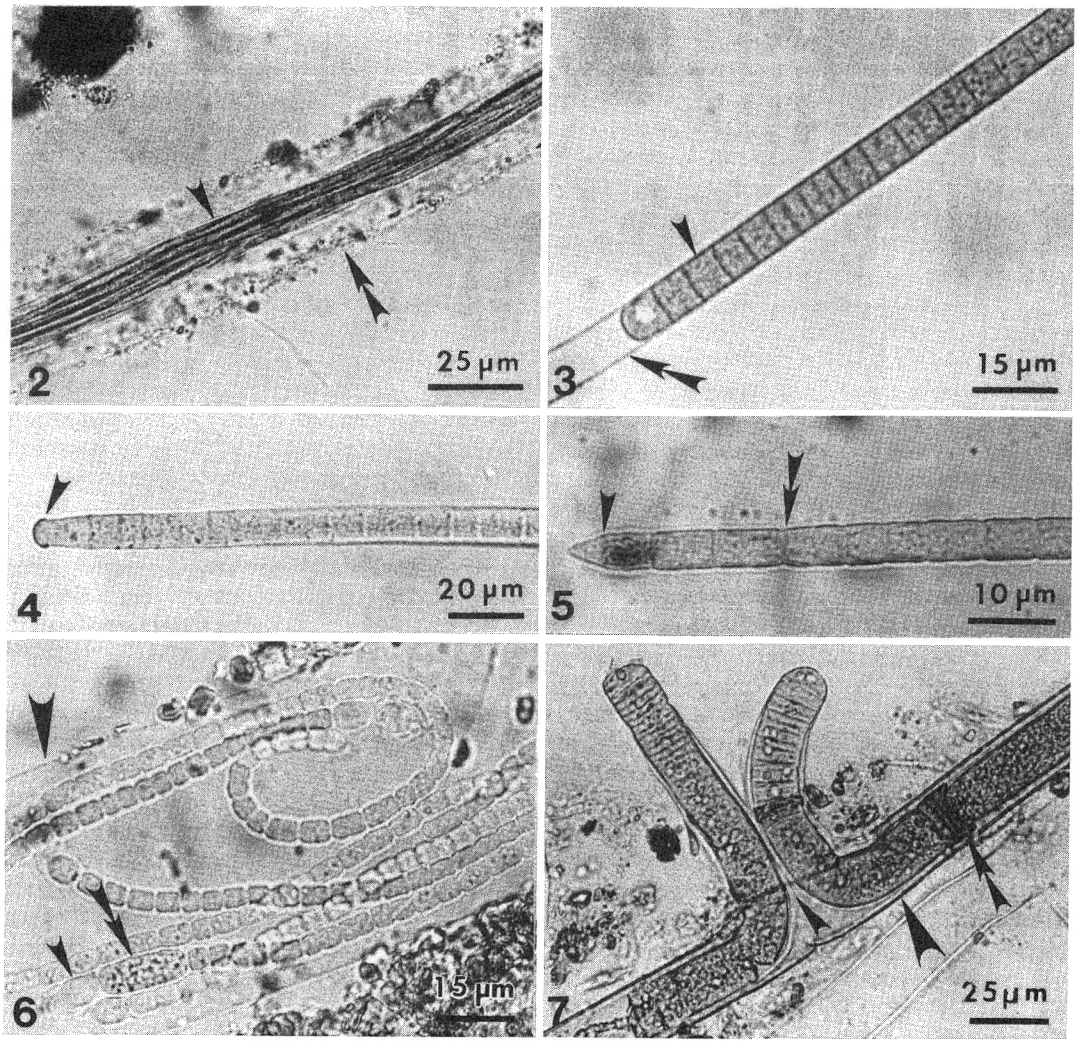
[a] See Figure 1 and Table 1 for locations.

Hildenbrandia angolensis Welw. ex West & West (Table 3) (Vis et al. 1994). In addition, *Spirogyra* sp. 2 and *Mougeotia* sp. are similar to some populations from Hawai'i. The stream macroalgal flora of Fiji is quite distinct in composition from that reported from Yap of the Caroline Islands (Lobban et al. 1990) and the Gombak River, Malaya (Ratnasabapathy 1975).

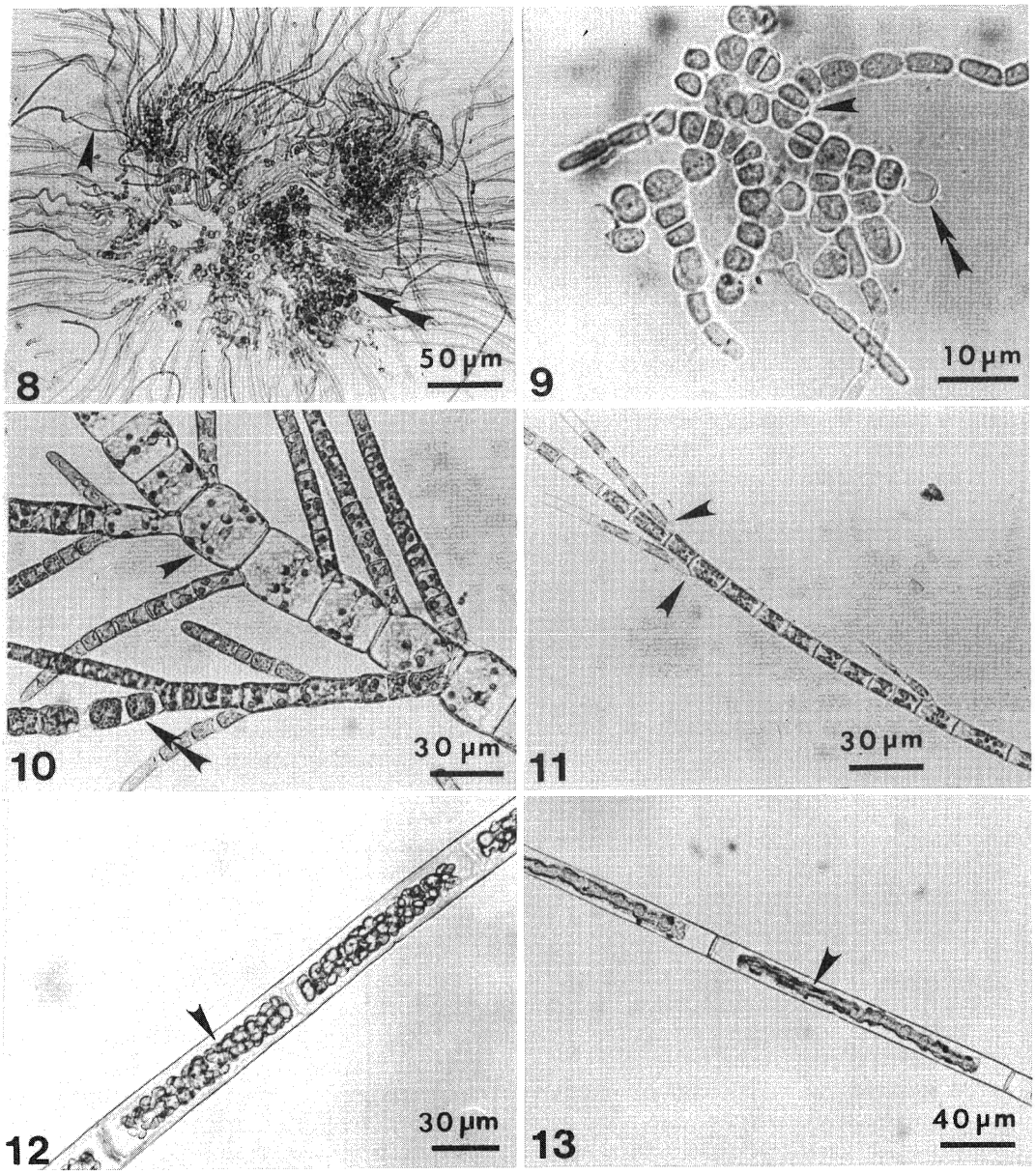
Because all of the species collected are new records for Fiji, photographs and brief descriptions of each are given in Figures 2–19. The physicochemical characteristics of the streams inhabited by each species can be obtained from Tables 2 and 3. There were no obvious calciophiles in this flora, because no species were confined to the relatively high ion waters of streams 10–12. Similarly, no species were limited to fast-flowing streams with the exception of *Nostochopsis lobatus* Wood emend. Geit. (85 cm sec^{-1}).

CONCLUSIONS

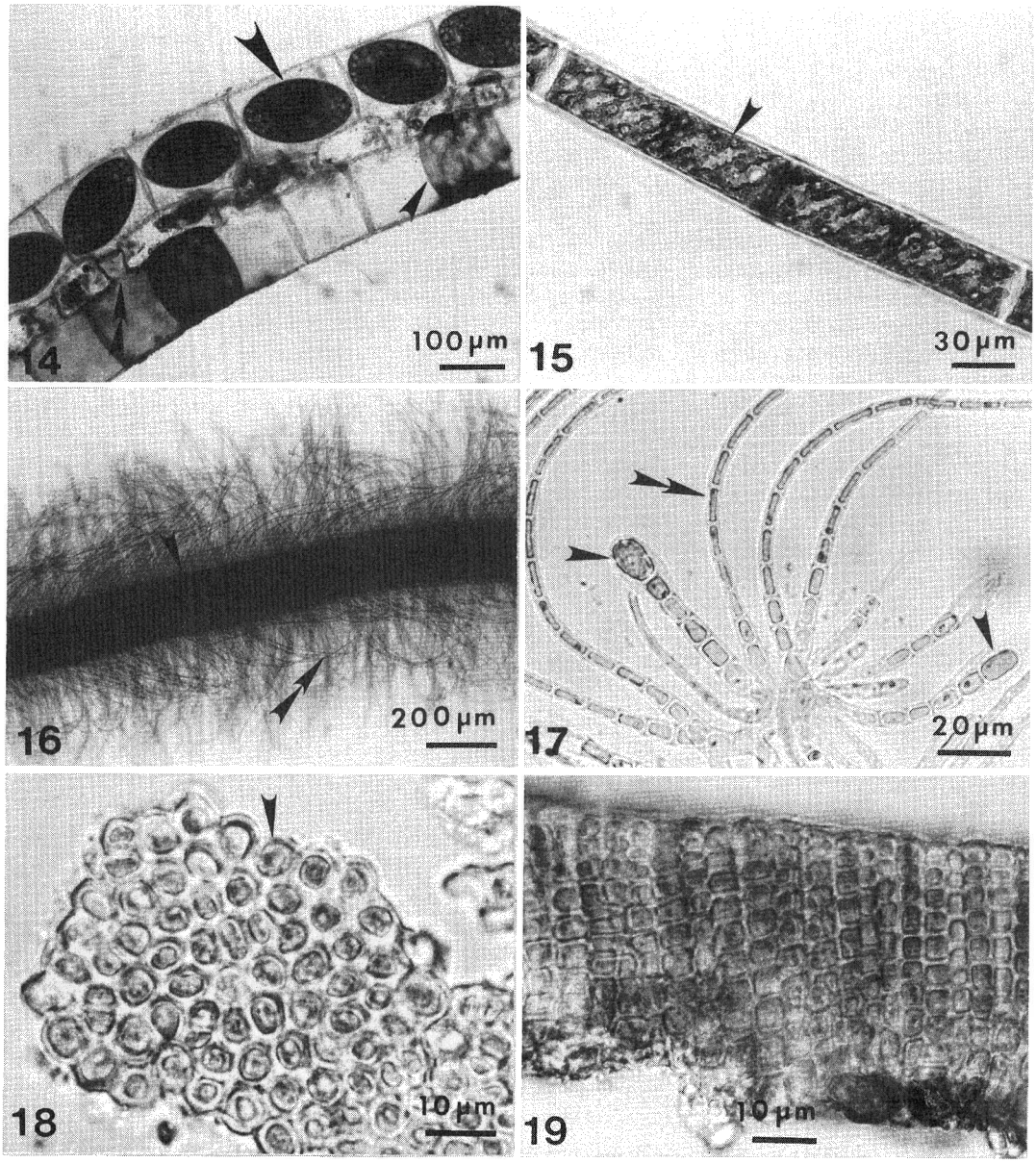
This preliminary study of Fijian streams revealed a relatively depauperate macroalgal flora of only 15 species, yet all of them are new records for the island group. The species include widespread representatives as well as rarely encountered members. The low incidence of sexual and asexual reproduction may account in part for the small diversity, because few of these species have resting spores that would readily survive long-distance transport. In addition, once transported, dispersal within Fiji would be limited largely to thallus fragmentation. It is clear that more detailed



FIGURES 2–7. Mat-forming Cyanophyta of Fiji streams. (2) *Microcoleus acutissimus*: parallel, pale blue-green filaments (arrowhead) that are not constricted at the cross walls. They are contained within a broad, colorless sheath (double arrowhead). (3) *Phormidium retzii*: bright bluish filaments with variously lengthened cells (arrowhead), mostly unconstricted at the cross walls, conical apical cell, and a thin, colorless sheath (double arrowhead). (4) *Phormidium subfuscum*: pale bluish filament with no constriction at cross walls, prominent apical cap (arrowhead), and barely discernible sheath. (5) *Phormidium tinctorium*: pale bluish filament with acutely conical apical cell (arrowhead), elongate cells, obvious constrictions at the cross walls (double arrowhead), and barely discernible sheath. (6) *Cylindrospermum muscicola*: bluish, entangled filaments in a colorless sheath (large arrowhead) having quadrate to cylindric cells, constrictions at the cross walls, terminal heterocysts (small arrowhead), and adjacent ovate akinete (double arrowhead). (7) *Scytonema crispum*: bluish, double false-branched (small arrowhead) filament with short cells, slight constrictions at the cross walls, quadrate heterocysts (double arrowhead), and contained within a brownish sheath (large arrowhead).



FIGURES 8–13. Colonial Cyanophyta and filamentous Chlorophyta of Fiji streams. (8–9) *Nostochopsis lobatus*: (8) Gelatinous bluish colony composed of radially arranged, little-branched erect filaments (arrowhead) and true-branched basal filaments (double arrowhead); (9) true-branched basal filaments (arrowhead) with terminal, pedicellate heterocysts (double arrowhead). (10) *Cloniophora macrocladia*: greenish filament composed of barrel-shaped main axis cells (arrowhead) that are much larger than those of the branches. Note parietal bandlike chloroplast and zoosporangia on branch (double arrowhead). (11) *Stigeoclonium subsecundum*: greenish filament with alternate, elongate branches (arrowheads). Note parietal bandlike chloroplast. (12) *Rhizoclonium hieroglyphicum*: greenish, unbranched filament with parietal, reticulated chloroplast (arrowhead). (13) *Mougeotia* sp.: greenish, unbranched filament with axial, platelike chloroplast (arrowhead).



FIGURES 14–19. Mat-forming Chlorophyta and filamentous and crustose Rhodophyta of Fiji streams. (14) *Spirogyra setiformis*: greenish, unbranched filaments with plane end walls and cells with a few, spiraling chloroplasts (small arrowhead). Filaments conjugate with both cells, forming conjugating tubes (double arrowhead), and zygospores are elliptical with smooth wall layers (large arrowhead). (15) *Spirogyra* sp. 2: greenish, unbranched filament with plane end walls and thin and elongate cells containing tightly spiraled chloroplasts (arrowhead). (16–17) *Thorea violacea*: (16) Reddish filament with little secondary branching, a main axis (arrowhead), and dense lateral, determinate assimilatory filaments (double arrowhead); (17) base of assimilatory filaments (double arrowhead) with monosporangia (arrowheads) on short filaments. (18–19) *Hildenbrandia angolensis*: (18) Crimson-colored crust in surface view with densely packed cells (arrowhead); (19) cross section with well-defined rows of cells.

studies are needed before we have a clear understanding of distributional patterns of stream macroalgae in Pacific islands.

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LITERATURE CITED

ASH, W. S. J., J. BRODIE, and P. RYAN. 1986. The flora, fauna and water chemistry of Tagimaucia Crater, a tropical highland lake and swamp in Fiji. Freshwater Biol. 16: 509–520.

FOGED, N. 1987. Diatoms from Viti Levu, Fiji Islands. Bibl. Diatomol. 14: 1–194, 33 pl.

FUNGLADDA, N., I. KACZMARSKA, and S. R. RUSHFORTH. 1983. A contribution to the freshwater diatom flora of the Hawaiian Islands. Bibl. Diatomol. 2: 1–103.

JOHANSSON, C. 1976. Freshwater algal vegetation in the Azores. Bol. Soc. Broteriana 50: 117–141.

LOBBAN, C. S., F. K. DAILY, W. A. DAILY, R. W. HOSHAW, and M. SCHEFTER. 1990. Periphyton, excluding diatoms and desmids from Yap, Caroline Islands. Micronesica 23: 27–40.

MANGUIN, E. 1938. Contribution à la flore diatomique des Nouvelles-Hébrides. Bull. Soc. Bot. Fr. 85: 14–18, 2 pl.

———. 1962. Contribution à la connaissance de la flore diatomique de la Nouvelle-Calédonie. Mem. Mus. Nat. Hist. Nat. Ser. B, 12(1): 1–40.

MINITAB. 1993. Minitab reference manual, release 9 for Windows. Minitab, State College, Pennsylvania.

MUELLER-DOMBOIS, D., and H. ELLENBERG. 1974. Aims and methods of vegetation ecology. Wiley, New York.

NEW ZEALAND EXTERNAL INTELLIGENCE BUREAU. 1986. Atlas of the South Pacific. Wellington, New Zealand.

PIELOU, E. C. 1979. Biogeography. Wiley, New York.

RATNASABAPATHY, M. 1975. Preliminary observations on Gombak river algae at the Field Studies Centre, University of Malaya. Phykos 14: 15–23.

SHEATH, R. G., and K. M. COLE. 1992. Biogeography of stream macroalgae in North America. J. Phycol. 28: 448–460.

SHEATH, R. G., M. O. MORISON, J. E. KORCH, D. KACZMARCZYK, and K. M. COLE. 1986. Distribution of stream macroalgae in south-central Alaska. Hydrobiologia 135: 259–269.

VIS, M. L., R. G. SHEATH, J. A. HAMBROOK, and K. M. COLE. 1994. Stream macroalgae of the Hawaiian Islands: A preliminary study. Pac. Sci. 48: 175–187.

WOOD, R. D. 1962. Preliminary report on Characeae of Australia and the South Pacific. Bull. Torrey Bot. Club 89: 250–253.

———. 1963. Characeae in Samoa. Bull. Torrey Bot. Club 90: 225–229.