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Taxonomic Challenges and Distribution of Gracilarioid Algae (Gracilariales, Rhodophyta) in Tanzania

A. S. Buriyo[1], E. C. Oliveira[2], M. S. P. Mtolera[3] and A. K. Kivaisi[1]
[1]Botany Department, University of Dar es Salaam, P.O. Box 35060, Dar es Salaam, Tanzania;
[2]Instituto de Biociências, Dept. de Botânica, Universidade de São Paulo, 05508-900 São Paulo, SP. Brazil;
[3]Institute of Marine Sciences, University of Dar es Salaam, P.O. Box 668, Zanzibar, Tanzania

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Abstract: This paper reviews the taxonomical literature of the gracilarioid algae from Tanzania, and provides information about their ecology and distribution based on an intensive regime of local collection. Its aim was to provide names, even if on a preliminary basis, for local gracilarioid taxa. Our revision shows that species misidentification is widespread and that some species are in need of further critical taxonomic study. Nine species of *Gracilaria* are reported in the region, including one unidentified *Gracilaria* or *Gracilariopsis.*

INTRODUCTION

The red algal genus *Gracilaria* Greville is of considerable economic importance for the production of agar (Oliveira et al., 2000). *Gracilaria* species are also utilized as human food, mostly in salads and soups (Arasaki & Arasaki, 1983), as feed for marine animals such as abalone (Ajisaka & Chiang, 1993), as potential candidates for nutrient removal for wastewater treatment (Fralick et al., 1981) and as biomass for energy generation (Ryther et al., 1979; Hanisak & Ryther, 1986; Flowers & Bird, 1990).

Dawson (1949) noted that *Gracilaria*, despite being a very polymorphic genus, has remarkably constant reproductive structures. However, gross morphology, and anatomy are still utilized as major taxonomic criteria for specific identification in the group (Oliveira, 1984). Until 1989, the genus was placed under the family Gigartinaceae, but studies on its reproductive development showed that it should be better placed in a new family, Gracilariaceae, and a new order, Gracilariales (Fredericq and Hommersand, 1989). This family currently contains seven genera, with *Gracilaria* being by far the largest (Fredericq & Hommersand 1989, 1990). After considerable confusion the taxonomy of the 'gracilarioid' algae now seems to be stabilizing (Bellorin et al., 2002).

The most detailed survey of Tanzanian *Gracilaria* was made by Jaasund (1976) with a more comprehensive list of species and nomenclatural update given by Silva et al. (1996). However, neither of these publications provide detailed information on the distribution of the species in Tanzania. *Gracilaria* in Tanzania is mentioned in other studies (Mshigeni & Wevers, 1979; Semesi, 1979; Buriyo, 1999; Mwandya et al., 2001; Mmochi et al., 2002; Msuya & Neori, 2002), but these specific identifications should be treated with caution.

This paper reviews the literature pertinent to *Gracilaria* in Tanzania, presents macro-morphological descriptions of the collected taxa and provides original information on their distribution in the mainland and islands of Tanzania.

Corresponding Author: ASB.
E-mail: aburiyo@hotmail.com *or* buriyo@amu.udsm.ac.tz

Review of the literature dealing with the genus *Gracilaria* in Tanzania

The most reliable document on the taxonomy of Tanzanian algae is that of Jaasund (1976), which reported seven species of *Gracilaria*, namely *G. arcuata*, *G. corticata*, *G. crassa*, *G. edulis*, *G. fergusonii*, *G. millardetii* and *G. salicornia*. However, according to Mshigeni & Wevers (1979) and Semesi (1979), the diagnostic characteristics of *G. millardetii* and *G. corticata* are confusing and needed investigation. Semesi (1979), analysing the agar from three species of *Gracilaria*, suggested that the species referred to as *G. millardetii* was synonymous with *G. corticata*. Mshigeni & Wevers (1979) suggested that *G. millardetii* in Tanzania was conspecific with *G. corticata.* Semesi (1979, Fig. 10) illustrated the species she referred to as *G. millardetii*, which resembles Fig. 1 of Mshigeni & Wevers (1979) for *G. corticata* but this does not match Jaasund's key and hand-drawn illustration (Jaasund, 1976; Fig. 169).

Taxonomic problems are also evident for the group of species comprising *G. crassa*, *G. canaliculata, G. fergusonii* and *G. salicornia*. The illustration given for *G. fergusonii* by Semesi (1979, Fig. 9) is similar to *G. canaliculata,* but does not match the illustration of Jaasund (1976, Fig. 174) for *G. fergusonii*. Semesi's (1979) explanation that the species is abundant in Tanzania is also supported by the distribution of *G. fergusonii* given by Jaasund (1976). Furthermore, Semesi (1979) reported that *G. crassa* was "abundantly distributed on rocky shores of Tanzania". If we consider *G. crassa* to be synonymous to *G. canaliculata*, the later is, however, not widely distributed in Tanzania. Furthermore, Semesi's illustration (Fig. 11 in Semesi, 1979) does not match *G. canaliculata*; the description on the color, "straw-yellow or greenish", distribution and illustrations are similar to the characteristics of *G. salicornia*, but the binomial taxonomy of this species remains uncertain.

Based on Semesi's illustration (Semesi, 1979, Fig. 11), Buriyo (1999) adopted the name *G. crassa* for collected specimens of the species referred to in this paper as *G. cornea* (synonym: *G. fergusonii*). Thus, studies reporting on seasonality of biomass, agar yield and quality of *G. crassa* by Buriyo (1999) are actually of *G. cornea*. The *Gracilaria* species used as a biofilter to treat effluents in the integrated fishponds systems at Makoba, Unguja Island, was a non-constricted morphotype of *G. salicornia*, and not *G. crassa* as referred to by Mwandya et al. (2001); Msuya & Neori (2002) and Mmochi et al. (2002).

Both the survey of the literature and the naming of *Gracilaria* specimens deposited in the Department of Botany, University of Dar es Salaam, revealed that the taxonomy of this genus in Tanzania remains uncertain.

The above account on the taxonomic problems of the genus in Tanzania justified the present study, involving extensive sampling from a wide range of habitats, in order to compare the morphology, anatomy and molecular features to arrive at a better identification of the local species.

MATERIALS AND METHODS

Specimens were collected from various habitats in the intertidal and upper subtidal zones along the coastal regions of Tanzania mainland (Mtwara, Lindi, Coast region, Dar es Salaam and Tanga) and Islands of Unguja, Pemba and Mafia (Fig.1). In each region four to eight locations (depending on the size and ecological diversity) were surveyed for *Gracilaria* species at least twice in different seasons (southeast and northeast monsoon), between January 2002 and July 2003. The collected specimens were preserved in 5% formaldehyde in seawater and vouchers were dried in silica gel. In the laboratory specimens were compared to descriptions in the literature and available specimens in the herbaria of the Botany Departments, University of Dar es Salaam and University of São Paulo (SPF), Brazil. The identification presented in this paper relies only on gross morphology. Reproductive morphology and molecular studies are underway.

RESULTS AND DISCUSSION

Taxonomy

Nine species of gracilarioid algae were found at the 44 collecting sites from Tanzania mainland and the islands of Unguja, Pemba and Mafia (Fig 1).

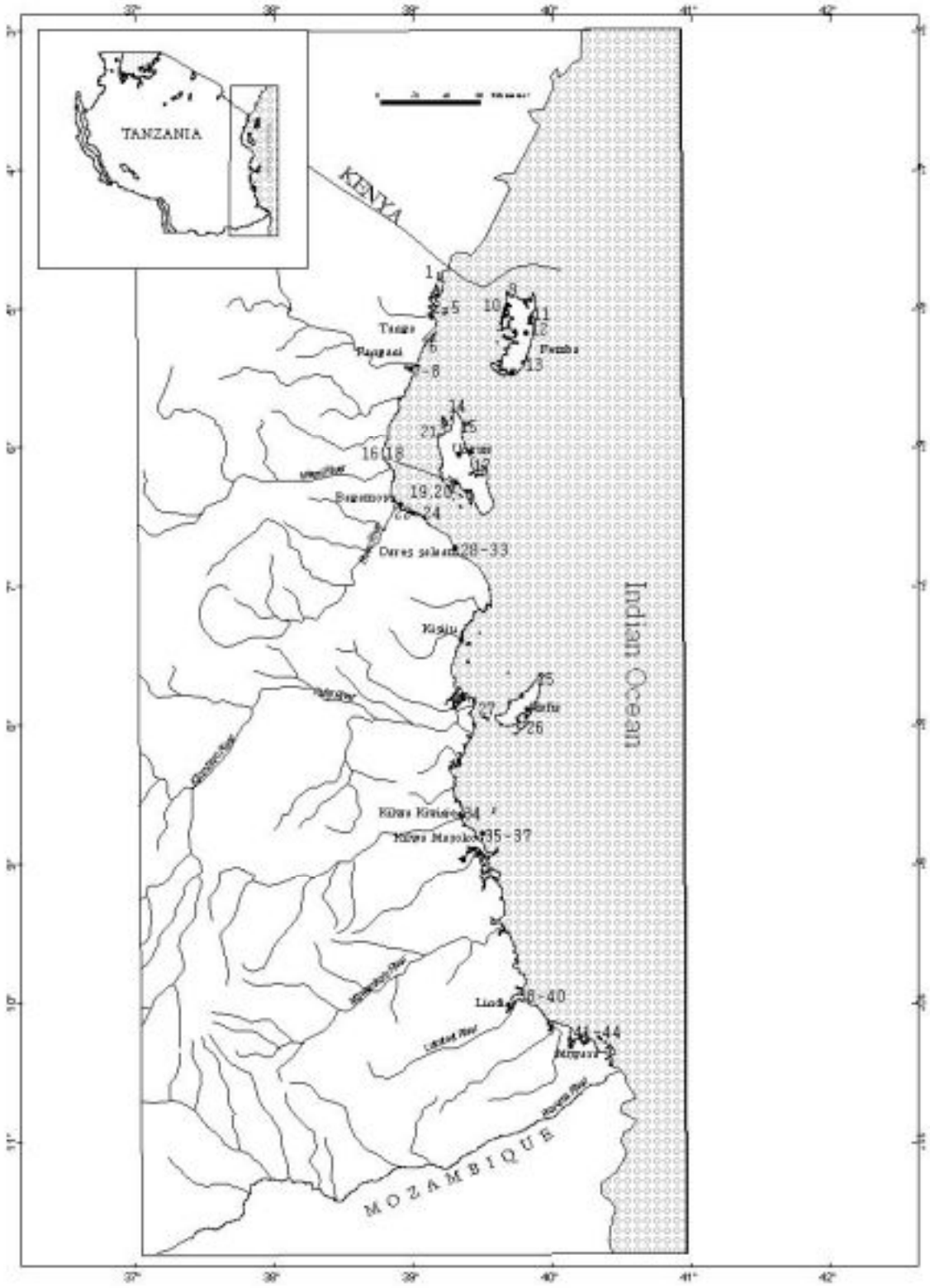


Fig. 1. Map showing study sites and distribution of gracilarioid algae along the coast of Tanzania

We did not find all 12 species reported by Silva et al. (1996), all attributed to the genus *Gracilaria*. However, one should consider that whereas our results were based on collections, those of Silva et al. (1996) were based on the literature. All the species documented in Jaasund (1976) were collected in the present study, with two additional species—*G. truncata* Kraft and *Gracilaria* sp. (?). Considering that identification based only on gross morphology is not enough to distinguish species in this polymorphic group of algae, a clearer picture of the gracilarioid algae present in Tanzania will only emerge after a detailed study of the anatomy of reproductive structures supported by gene sequencing.

Key to the gracilarioid species (modified from E. Oliveira, unpub. data)

1. a. Thallus membranaceous, strap-shaped 2
   b. Thallus cylindrical to flattened 4
2. a. With tooth-like marginal proliferations ..... *G. millardetii*
   b. Thallus margin smooth 3
3. a. Well branched and regularly bifurcated, width mostly uniform throughout the thallus ..... *G. corticata.*
   b. Irregularly branched, thallus width varying from base to apex ..... *G. truncata.*
4. a. Thallus completely cylindrical 5
   b. Thallus compressed to flattened, at least partially 8
5. a. Thallus usually with regular constrictions, sausage-like ..... *G. salicornia.*
   b. Thallus always without constrictions 6
6. a. Plants shorter (5–10 cm) and thicker (2–3 mm), with curved unilateral branches ..... *G. arcuata.*
   b. Plants longer and thinner, without unilateral branching 7
7. a. Plants up to 20 cm long, irregularly branched, on rocky shores ..... *G. edulis.*
   b. Plants up to 150 cm long, irregularly branched ..... *Gracilaria* ? sp.
8. a. Plants erect, cylindrical or partially compressed ..... *G. cornea.*
   b. Plants prostrate, compressed, attached to the substrate at several points ..... *G. canaliculata.*

Brief description of ecology and morphology of collected species

Gracilaria arcuata Zanardini

Found at only two stations and in both areas, plants attached on permanently submerged *Halimeda* segments. Dark red, greenish or purple, variable in size, 5–35 cm high and 2–3 mm thick, cylindrical, with irregular branching and a tendency in many plants to be unilateral while branches like the axis, may be more or less arcuate. The tips of the branches and the short lateral branchlets are sharply acute (Jaasund, 1976, Fig. 173).

Gracilaria canaliculata Sonder

Attached firmly on rocks by a basal disc and supplementary bundles of secondary rhizoids wherever the thallus touches the substrate. Found at the lowest spring tide mark and the upper subtidal in areas exposed to surf. The thallus is compressed or cylindrical, bright red, fleshy, cartilaginous, dichotomously branched, 3–7 cm in length and 3–5 mm in diameter (Coppejans et al., 1997; Jaasund, 1976). We consider *G. crassa* (Jaasund, 1976, Fig. 170) to be synonymous to *G. canaliculata.*

Gracilaria cornea J. Agardh

Attached firmly on rocks in the lower intertidal area. Where the intertidal is relatively flat the species is also abundant in mesolittoral tidal pools. The thallus is cylindrical, succulent, dichotomous top-branching, 5–8 cm long, 3–4 mm thick, pale red and brown to reddish-brown in colour. Common on rocky shores of Tanzania (Jaasund, 1976 Fig. 174 as *G. fergusonii*; Semesi, 1979, Fig. 11 and Buriyo, 1999, Fig. 3 as *G. crassa*). Our field observations show that plants growing in areas exposed to surf are relatively thicker and a may be slightly compressed. This morphological plasticity might explain the problems associated with its previous identification. The specimens illustrated by Jaasund (Fig.174 as *G. fergusonii*) and Buriyo (1999, Fig. 3, as *G. crassa*) are regarded in this paper as *G. cornea*.

Gracilaria corticata (J. Agardh) J. Agardh

Commonly found as an epiphyte on *Thalassodendron* stems in tidal pools, lagoons and

permanently immersed areas. It also attaches to rocks and coral fragments in tidal pools. The thallus is various shades of red, green, yellow and brown; flat, initially with regular bifurcations, later the pattern may change due to lateral proliferations. About 10 cm long and 2–3 mm broad. It is a common species of the shores of Tanzania (Jaasund, 1976 Fig. 168 plate 7, but the free-hand drawing (Fig. 168) cannot be referred with certainty; Mshigeni & Wevers, 1979; Fig.1).

***Gracilaria edulis* (J. Agardh) Silva**
Attached on small rocks in intertidal pools, but also present along tidal streams or small channels and is normally solitary. Plants may be more than 20 cm high, cylindrical, 1–2 mm in diameter, red or greenish in color, with irregular branching; basal branches may be partially buried in the sand. Two morphological forms have been recognized. One is long, up to 30 cm, pale red or greenish, solitary and less branched with a distinctive central growing axis. It grows in clear, exposed, sandy tidal pools and tidal streams/channels. The second form is much branched, up to 20 cm high, greenish to brownish-red in color. This form was collected mostly from areas with somewhat turbid water, on sand-muddy substrate, along tidal streams. This morphotype resembles more closely the illustration of Jaasund (1976, Fig. 172.) Specimens deposited in the herbarium, at the Botany Department, University of Dar es Salaam, collected from Kigombe, Tanga and identified as *G. verrucosa* also belong to this species.

***Gracilaria millardetii* (Montagne) J. Agardh**
Attached on rocks at the lowest tidemark and upper subtidal. Thallus red, flattened, irregularly branched with small proliferations, a few cm long and 2–7-mm broad. Similar to *G. corticata* but more delicate, irregular and densely branched. It resembles fronds of *G. corticata* regenerating from wounds, or plants found in places with high wave exposure. The idea of conspecificity between these two species in Tanzania requires further reproductive and molecular studies.

***Gracilaria salicornia* (C. Agardh) Dawson**
Commonly attached on sponges, small shells or rock platforms; forming creeping, well-attached cushions on surf-exposed rocky surfaces. It grows erect in pools and sheltered places on eulittoral and shallow sublittoral zones. Growth forms are very variable, depending on the habitats. Basically there are two major forms: the cushion type, which grows on exposed rocky platforms and has regular constrictions, and the second type, which seldom has constrictions, and is easily confused with *G. cornea* in areas where they grow together. *Gracilaria salicornia* is the most common species of the genus in Tanzania (Jaasund, 1976; Coppejans et al., 1997)

G*racilaria truncata* Kraft
Attached on rocks in the lower intertidal zone. Thallus brown to greenish, foliaceous, with a few strap-shaped blades, wider at the base and narrowing to the apices, marginal proliferations are very common, about 15 cm long and up to 6 mm wide. A very rare species in Tanzania.

***Gracilaria* sp.?**
The species was found at only one station on Pemba Island, among old *Halimeda* segments in a sheltered mangrove tidal stream, permanently submerged at 1–2 m depth during lowest spring tide. The thallus is cylindrical, bright or pale red, up to 1.5 m long, and 1–2 mm in diameter; irregularly branched, with numerous branchlets emerging from the major branches. Plants lie prostrate over sand, with some parts of the thallus embedded in the substrate, or epiphytically on *Halimeda.* It was reported in Kenya (H. Oyieke, pers. commun.) as *G. verrucosa* (Huds.) Papenfuss. Correct identification of the generic affinity of this species, whether *Gracilaria* or a *Gracilariopsis* Dawson, requires the study of sexually fertile specimens.

Distribution of gracilarioid algae in Tanzania

The results on the distribution of gracilarioid algae in Tanzania are summarized in Table 1.

Gracilaria cornea, *G. corticata* and *G. salicornia* are the most common species. Species with restricted distribution are *G. arcuata*, *G. canaliculata*, *G. truncata* and *Gracilaria* sp.? Regions with highest diversity of *Gracilaria* species are Pemba island, Dar es Salaam and Lindi (6 species each) while Coast region (*Mkoa wa*

Table 1. Distribution of gracilarioid algae along the coast of Tanzania. Numbers correspond to those on map (Fig.1)

Location No.	Name of location	Village, district and region	*Gracilaria* species found								
			G. arcuata	*G. canaliculata*	*G. cornea*	*G. corticata*	*G. edulis*	*G. millardetii*	*G. salicornia*	*G. truncata*	*Gracilaria* sp.
1	Chundo-kiroba	Moa, Muheza, Tanga			X						
2	Ulenge island	Tanga municipality			X	X			X		
3	Kwale island	Tanga municipality			X	X			X		
4	Jambe island	Tanga municipality							X		
5	Mwambani	Tanga municipality							X		
6	Kigombe	Muheza, Tanga				X	X		X		
7	Ushongo Mtoni	Pangani, Tanga				X			X		
8	Fungu ya Zinga	Ushongo, Pangani			X						
9	Kigomasha, Mnarani,	Micheweni, Pemba			X				X		
10	Fundo island	Wete, Pemba			X				X		
11	Shengejuu	Masota, Wete, Pemba				X	X		X		
12	Pangamkungu, Mjini Kiuyu	Kiuyu, Wete, Pemba	X			X	X		X		X
13	Kiwani	Mkoani, Pemba									
14	Saza-Ndogo Nungwi	Nungwi Mnarani,N. Unguja			X	X	X		X		
15	Matemwe	Matemwe, North Unguja									
16	Uzi island	Unguja Ukuu,Ctrl Unguja	X			X	X		X		
17	Kisiwa-panya/ Mtongoma	Chwaka, Central Unguja	X			X	X		X		
18	Kisakasaka	Kisakasaka, Unguja				X	X		X		
19	Fumba beach	South Unguja			X	X			X		
20	Komonda island	Fumba, South Unguja			X	X			X		
21	Kiyongwe	Bumbwini, Unguja				X	X		X		
22	Nunge	Bagamoyo, Coast				X			X		
23	Mwamba-Mjini	Bagamoyo, Coast							X		
24	Mlingotini	Bagamoyo, Coast							X		
25	Ras Mkumbi	Mafia island, Coast			X				X		
26	Juani isaland	Mafia island, Coast			X				X		
27	Bwejuu island	Mafia island, Coast			X				X		
28	Mbweni	Kinondoni, Dar es Salaam									
29	Mbudya island	Kunduchi, Dar es Salaam			X	X			X		
30	Msasani-Masaki	Kinondoni, Dar es Salaam			X	X			X		
31	Oyster Bay	Kinondoni, Dar es Salaam		X	X	X		X	X	X	
32	Mji Mwema	Kigamboni, Dar es Salaam							X		
33	Geza Ulole	Kigamboni, Dar es Salaam				X			X		
34	Kilwa Kivinje	Kilwa, Lindi				X			X		
35	Masoko Pwani	Kilwa Masoko, Lindi			X		X				
36	Jimbiza	Kilwa Masoko, Lindi				X			X		
37	Kilwa Kisiwani	Kilwa, Lindi							X		
38	Ruvu B	Lindi rural District		X	X				X		
39	Mchinga B	Lindi rural District							X		
40	Ngande	Lindi Town Council				X		X	X		
41	Mgao-Mkaya	Mtwara rural District				X			X		
42	Mkungu	Mtwara Town Council			X	X			X		
43	Miseti	Mtwara Town Council							X		
44	Msanga Mkuu	Mikindani Bay, Mtwara			X	X	X		X		

Pwani in Kiswahili) has the lowest diversity (3 species). Oyster Bay rock shore in Dar es Salaam region, with its gently sloping topography, provides various microhabitats and is colonised by a rich flora including six *Gracilaria* species. Lindi region also has two beaches, Ngande and Ruvu B, with a gently sloping topography and rich flora, which includes six *Gracilaria* species. Pemba Island has mangrove-sheltered places with tidal streams, which provide habitats for *G. arcuata* and *Gracilaria* sp.? at Kiuyu.

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