Marine Benthic Macroalgal Flora of Taiwan

Part I Order Gracilariales (RHODOPHYTA)

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Preface

Marine red algae are a group of photosynthetic marine organisms evolved from cyanobacteria through the evolutionary mechanism of primary endosymbiosis in few billion years ago. It is still a mystery about how their unique triphase life cycle, alternation of three generations (tetrasporophyte, gametophyte and carposporophyte), evolved. It leaves lots of speculations in the evolutionary studies. Thanks to many marine flora surveys from temperature waters in the past few centuries, we are starting to be able to outline stories of red algal biogeography in northern Pacific and Atlantic Oceans. And yet, the marine flora in tropical Pacific Ocean remains largely unexplored, i.e. islands of Indonesia and Philippines. Many questions about the evolutionary histories of the tropical red algae in Indo-Pacific Oceans can not be answered due to lack of a detail study of the marine flora in the regions.

My primary goal of this red algal floral book is to provide a case-study using the Order Gracilariales from Taiwan with some details of their habit, seasonality and description of both vegetative and reproductive morphologies. My ultimate research goal is to document each macroalgal species occurring in warm water western Pacific Ocean in order to understanding their biogeography and evolutionary histories.

Showe-Mei Lin
June 2009

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Historical review

The marine macroalgal flora of Taiwan, an island bisected by the Tropic of Cancer, is considered both tropical and subtropical, and has been studied by numerous phycologists (summarized in Lewis and Norris 1987). The recorded number of species reaches over 500 (Lewis and Norris 1987; Chiang and Wang 1987; Huang 1990, 1991, 1999a, b, Huang & Chang 1999; Wang and Chiang 1993, Wang et al. 1993; Lin et al. 2002; also see Chiang 1992 for a review). The number of macro-algal species for the region has recently increased due to intensive investigations this past decade (Huang 1991, 1999a, Huang & Chang 1999; Wang et al. 1993), and numerous new species continue to be discovered (Lewis et al. 1996; Lin & Fredericq 2002, Lin et al. 2002, 2004a, 2004b, 2008, Lin & De Clerck 2006, Lin & Freshwater 2008, Lin unpublished data).

Red algae are exceptional for the great diversity in reproductive morphology and for their complex life histories. In particular, the economically important agar-containing family Gracilariaceae stand out in exhibiting a wide spectrum of reproductive traits that makes them unusually interesting for assessing their phylogenetic importance relative to classification criteria, as the comparative anatomy of the reproductive structures on the plant body has traditionally formed the basis for separating these families.

Previous studies have shown that the extant distribution of the marine macroalgal flora in southeastern Taiwan is mainly affected the Kuroshio Current (Lewis and Norris 1987; Wang and Chiang 1993, 2001; Lin 2002). This study reinforces the notion that the species composition of the marine flora in southeastern Taiwan shares many species with that of the northern Philippines and Indo-Pacific basin (see Kraft *et al*. 1999; Coppejans *et al*. 1999; Silva *et al*. 1996; Yoshida 1998). Undoubtedly, the number of marine macroalgae in Taiwan will continue to increase as more collecting is carried out and unidentified specimens on herbarium shelves are critically examined.

Order GRACILARIALES（龍鬚菜目）

Family Gracilariaceae（龍鬚菜科）

The Order Gracilariales, consisting of a single familly Gracilariaceae, was proposed by Fredericq & Hommersand (1989: 225) based on the homologous developmental processes of vegetative and reproductive initials, in terms of division of vegetative cells, formation of spermatangial parental, carpogonial branch and tetrasporangial initials, and direct fusion of the fertilized carpogonium with the sterile branches in addition to neighboring gametophytic cells prior to production of the gonimoblast initials. During the carposporophte development, inner gonimoblast cells become vacuolated and form a network connected one another via secondary pit connections and tubular nutritive cells produced from inner gonimoblasts, if present, will fuse with pericarp or the floor cells of the cystocarp.

There are four genera and thirteen species in the family Gracilariaceae currently recorded from Taiwan.

Key to genera

1a Thalli parasitic ..... ***Congracilaria*** **Yamamoto**
1b Thalli non-parasitic 2
2a Lacking nutritive filamentous tubes in the cavity of cystocarp and spermatangial sori borne the surface layer of cortex ..... ***Gracilariopsis*** **Dawson**
2b Nutritive filamentous tubes present in the cavity of cystocarp and spermatangial sori embedded in the cortex 3
3a Spermatangial sori being polycavernosa-type ..... ***Hydropuntia*** **Montagne**
3b Spermatangial sori in shallow to deep cup-shaped conceptacles ..... ***Gracilaria*** **Greville**

The genus *Congracilaria* Yamamoto (1986: 287)

Thalli up to 3 mm high, yellowish-brown, parasitic on *Gracilaria salicornia* (C. Agardh) Dawson; lack of penetrating rhizoids or differentiated basal tissue; gametophytes monoecious; spermatangia forming in deep, conceptacular cavities initiated from surface cells; procarp structure and cystocarp morphology similar to the non-parasitic genus *Gracilaria*, tubular nutritive cell or filaments present in cavities of cystocarps; bisporangia sometimes present as the only reproductive structure, presumably resulting from a meiotic cell division.

This is a monotypic genus with the generitype *Congracilaria babae* Yamamoto.

Congracilaria babae Yamamoto 1986

CHINESE NAME: 小寄生龍鬚菜

BASIONYM: N.A.

TYPE LOCALITY: Okinoerabu I., southern Japan.

TAIWAN DISTRIBUTION: widely distributed along the coastlines of Taiwan and neighboring islands.

SPECIMENS EXAMINED: **Kenting National Park, southern Taiwan**: 1) Wan Li Dong, coll. S.-M. Lin, 23 July 2002.

HABITAT AND SEASONALITY: The collections were made seasonally from late summer, July. Plants were found in tide pools or grew subtidally, 1-2 m deep. The seawater temperature in the waters of Taiwan ranges from 18˚ to 25˚C.

HABIT AND VEGETATIVE MORPHOLOGY: Plants form minute (to 3 mm high), yellowish-brown pustular outgrowths on *Gracilaria salicornia* (C. Agardh) Dawson. No penetrating rhizoids or differentiated basal tissue are present, the parasite consisting of progressively smaller cells until an abrupt transition to the shallow cortex.

REPRODUCTIVE STRUCTURES: Gametophytes are monoecious, and some also bear bisporangia. Procarp structure and cystocarp morphology are similar to *Gracilaria*, including the production of "tubular nutrient cells", although cystocarps are only slightly protuberant. Plants are monoecious, the spermatangia forming in deep, conceptacular cavities initiated by surface cell divisions.

Note: Showe-Mei Lin's unpublished data.

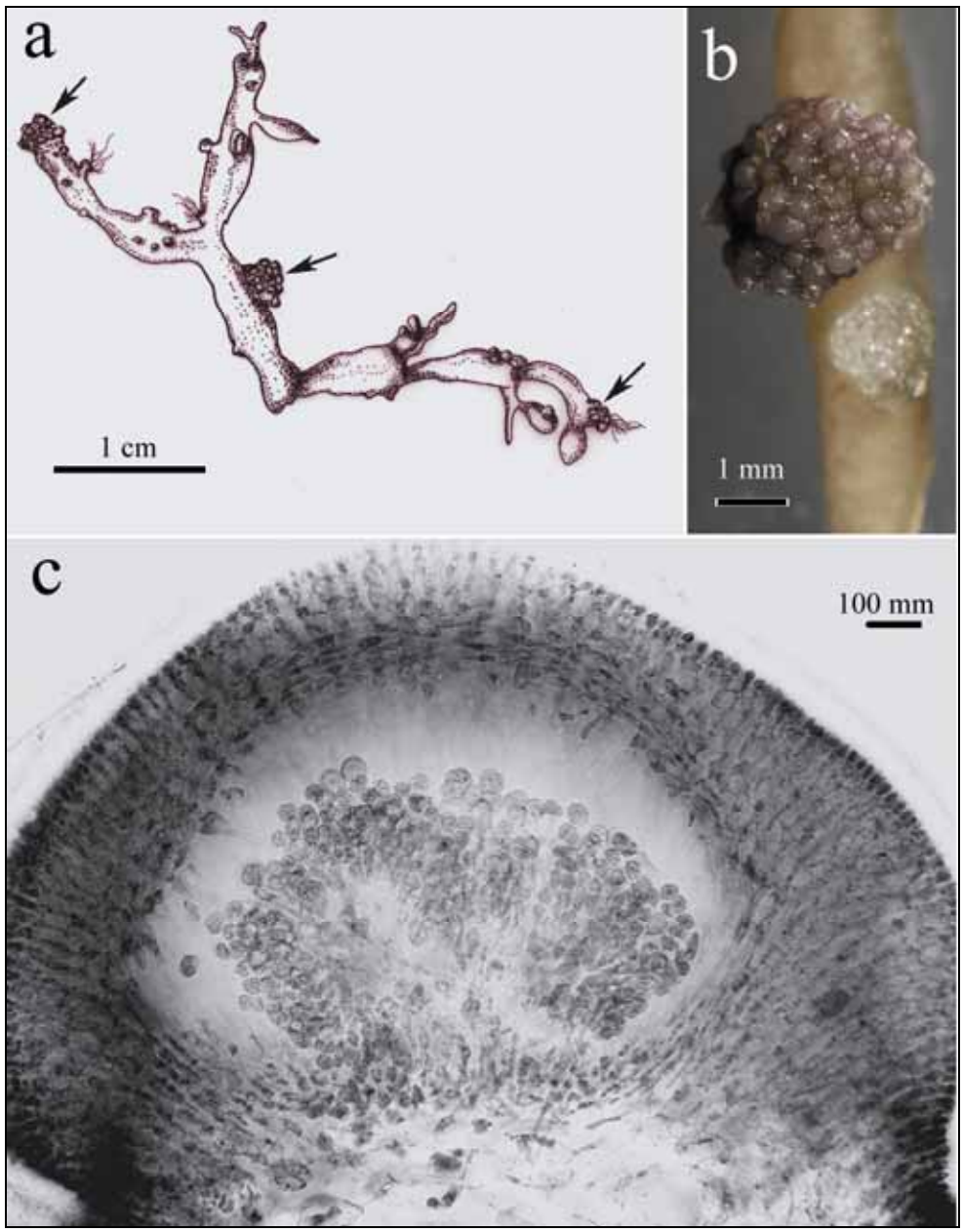

Figure 1: *Congracilaria babae* Yamamoto (GRACILARIACEAE)

a. Hand drawing of the thalli (arrows) parasitic on *Gracilaria salicornis*. b. Close up of cystocarpic thalli parasitic on *Gracilaria salicornis*. c. Cross-section through a cystocarp showing the carposporophyte and pericarp.

The genus *Gracilaria* Greville (1830: 121)

Thalli are upright bushy to prostrate, cylindrical, terete or slightly or broadly flattened, 4-30 (-60) cm in height. Apical growth is uniaxial but appearing multiaxial. Thalli are composed of 1-2 (-4) cell layers of pigmented, small cortical cell and colorless, large medullary cells. Gametophyte and tetrasporophyte are isomorphic and the gametophytes are mostly diocious. Tetrasporangia are initiated superficially from cut off through an oblique, longitudinal cell division, and then expand and divide twice to produce four cruciately arranged tetraspores at maturity. A carpogonial branch is 2-celled borne on a supporting cell derived from a cortical cell. Soon after fertilization, the sterile branches flanking the carpogonial branch fuse directly onto the fertilized carpogonium. Fusion-cell formation progressively involves the sterile branches and neighboring vegetative cells. At an early stage of gonimoblast development, the incorporated, multinucleate fusion cell cuts off uninucleate gonimoblast cells in clusters. The innermost cells of the gonimoblasts soon become multinucleate and vacuolate. Later, the vacuolated cells between different gonimoblast clusters are confluent by numerous secondary pit-connections. The vegetative cells in the floor of the cystocarp become darkly stained and slightly elongated and are secondarily pit-connected with the inner cells of gonimoblasts near the floor. Tubular nutritive cells are mostly present in the cavity or the floor of cystocarp. Spermatangial parent filaments are initiated from outer cortical cells, then produce and release spermatangia successively to form a shallow (Textorii-type) or deep (Verrucosa-type) conceptacles.

There are around ca. 150 species of *Gracilaria* described from around the world, 9 species recognized from Taiwan in this study.

Key to species of *Gracilaria*

1a Thalli with distinctly flattened blades 2

1b Thalli cylindrical or terete 5

2a Thullus margin denticulate, spermatangial sori in shallow conceptacles 3

2b Thullus margin smoothly, spermatangial sori in deep cup-shaped conceptacles ..... *G. punctata*

3a Thallus more or less prostrate, less bushy ..... *G. vieillardii*

3b Thallus bushy, upright with strong basal stipe 4

4a Bearing marginal or surface proliferation ..... *G. huangii*

4b Lack of marginal or surface proliferation ..... *G. spinulosa*

5a Main axes less than 2 mm in diameter, branches slender 6

5b Main axes more than 2 mm in diameter, branches coarse 8

6a Branches 3-4 mm in diameter without any constriction ..... *G. canaliculata*

6b Branches 2-3 mm in diameter with heavily to slightly constriction 7

7a Thalli bushy 3-10 cm high with arcuate branches ..... *G. arcuata*

7b Thalli prostrate 3-5 cm long with strong articulate branches ..... *G. salicornis*

8a Branches 5- 10 cm long, with slightly constricted bases, sometimes with intercalary constriction ..... *G. blodgettii*

8b Branches 10-20 cm long without intercalary constriction ..... *G. firma*

Gracilaria arcuata Zanardini 1858

CHINESE NAME: 弓龍鬚菜

BASIONYM: N.A.

TYPE LOCALITY: Aqaba, Jordan.

TAIWAN DISTRIBUTION: widely distributed along the coastlines of Taiwan and neighboring islands. Kenting National Park, southern Taiwan; Pratas Island.

SPECIMENS EXAMINED: **Kenting National Park, southern Taiwan**: 1) Wan Li Dong, coll. S.-M. Lin, 23 July 2002. 2) Long Keng**,** coll. S.-M. Lin, 20 July 2001. 3) Feng Chui Sha, coll. S.-M. Lin, 18 March 2003. 4) Chuan Fan Shi**,** coll. S.-M. Lin, 5 February 2006. **Pratas Island**: coll. S.-M. Lin, 4-9 March 2005.

HABITAT AND SEASONALITY: The collections were made seasonally from March through July. Plants were found in tide pools or grew subtidally, 1-2 m deep. The seawater temperature in the waters of Taiwan ranges from 18˚ to 25˚C.

HABIT AND VEGETATIVE MORPHOLOGY: Thalli are 5-10 cm in height, erect, cartilaginous, greenish purple to red in color, arising from a discoid holdfast. Main and lateral branches are mostly arcuate, terete throughout, sometimes slightly constricted at the base.

REPRODUCTIVE STRUCTURES: Gametophytes were not examined in this study. Tetrasporangia are produced from inner cortical cell, tetrahedrally divided, 22-26 μm by 35-45 μm in diameter.

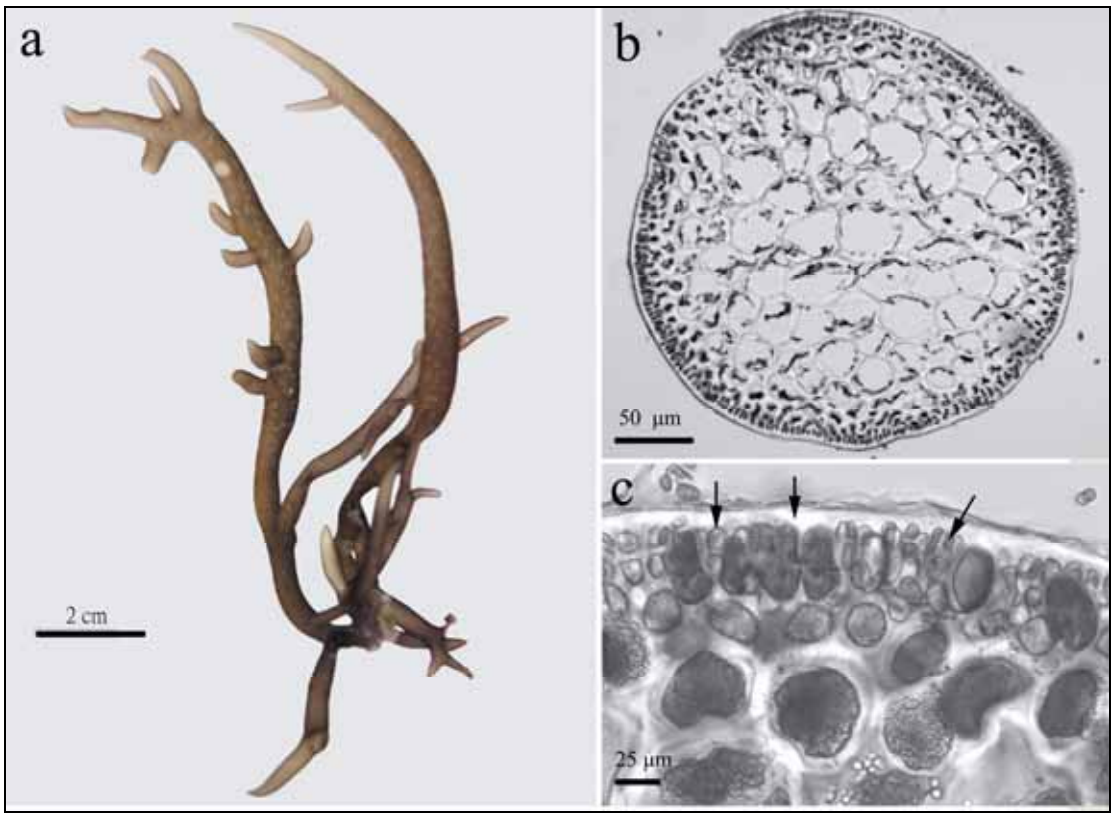

Figure 2: ***Gracilaria arcuata*** **Zanardini** (GRACILARIACEAE)

a. A tetrasporic plant. b. Cross-section through a branch. c. Tetrasporangia (arrows).

Gracilaria blodgettii Harvey 1853

CHINESE NAME: 芋根龍鬚菜

BASIONYM: N.A.

TYPE LOCALITY: Key West, Florida, USA.

TAIWAN DISTRIBUTION: distributed along the coastlines of southwestern Taiwan.

SPECIMENS EXAMINED: **Kenting National Park, southern Taiwan**: 1) Feng Chui Sha, coll. S.-M. Lin, 10 July 2002.

HABITAT AND SEASONALITY: The collections were made seasonally from late summer, July. Plants were found in tide pools or grew subtidally, 1-2 m deep. The seawater temperature in the waters of Taiwan ranges from 18˚ to 25˚C.

HABIT AND VEGETATIVE MORPHOLOGY: Thalli are 10-20 in height, erect, fragile to cartilaginous, greenish, purple to red in color, arising from a discoid holdfast. Main and lateral branches are mostly arcuate, terete throughout, sometimes slightly constricted at the base.

REPRODUCTIVE STRUCTURES: Cystocarps are not constricted at base, inner gonimoblasts filamentous and highly reticulated, carposporangia forming in small cluster in chains, pyriform to sphaere, 40-45 μm in diameter.

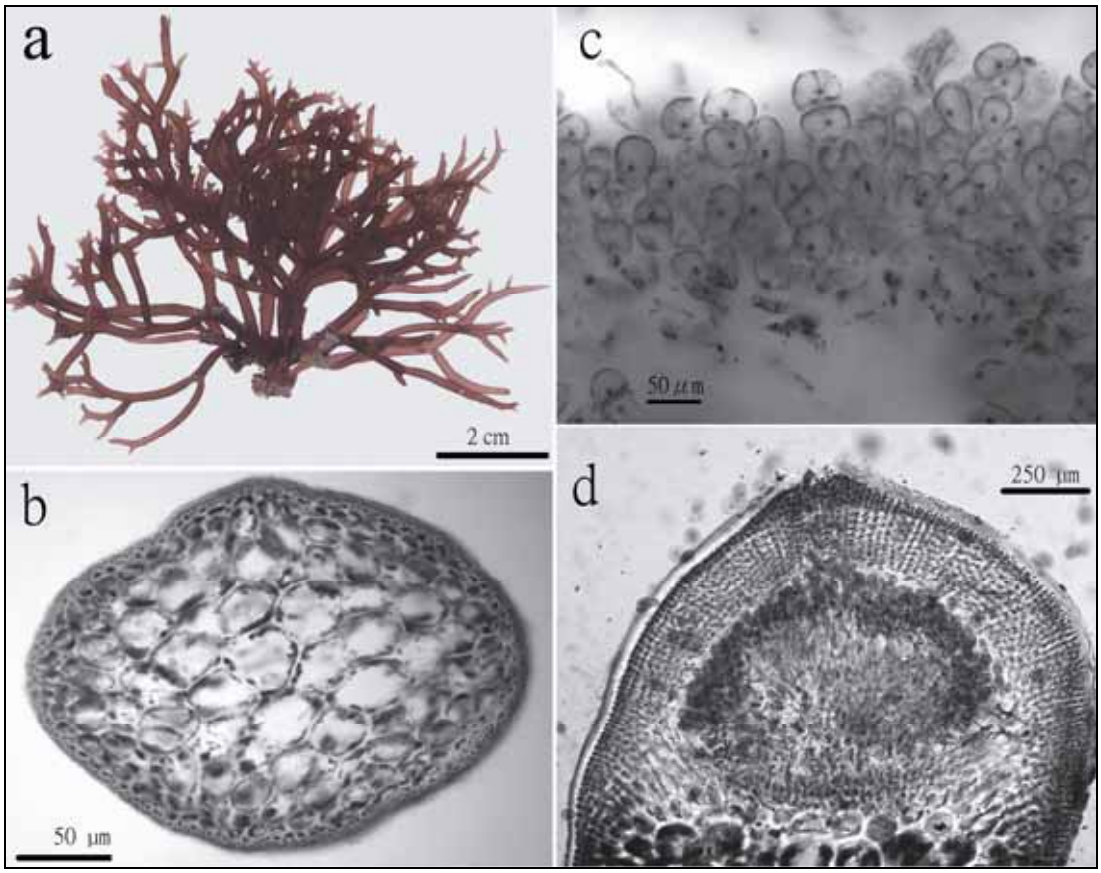

Figure 3: *Gracilaria blodgettii* Harvey (GRACILARIACEAE)

a. Habit. b. Cross-section through a branchlet. c. Close up of clustered carposporangia. d. Mature cystocarp.

Gracilaria canaliculata Sonder 1871

CHINESE NAME: 管龍鬚菜

BASIONYM: *Sphaerococcus canaliculatus* Kützing.

SYNONYM: *Ceramianthemum crassum* (Harvey ex J. Agardh) Kützing; *Gracilaria crass* Harvey ex J. Agardh.

TYPE LOCALITY: Wagap, New Caledonia.

TAIWAN DISTRIBUTION: widely distributed along the coastlines of Taiwan and neighboring islands. Green Island, northeastern & southern Taiwan, Pratas Island.

SPECIMENS EXAMINED: **Kenting National Park, southern Taiwan**: 1) Xiang Jiao Wan, coll. S.-M. Lin, 8 January 2002. 2) Hou Wan, coll. S.-M. Lin, 7 February 2002. 3) Outlet of 3rd nuclear plant, coll. S.-M. Lin, 4 September 2002.

HABITAT AND SEASONALITY: The collections were made seasonally from late summer through the next spring. Plants were found in tide pools or grew subtidally, 1-2 m deep. The seawater temperature in the waters of Taiwan ranges from 18˚ to 25˚C. Marine, plants rowing at 1-5 m depths on coral reefs. This alga is rich in agar and floridean starch, often applied to animal feed or industrial use.

HABIT AND VEGETATIVE MORPHOLOGY: Thalli are terete, 5-13 cm in height, attached to the substratum by a large discoid holdfast and by secondary holdfasts formed on lower portion of branches. Branches are subdichotomously, unconstricted with obtuse apices. Fresh plants firm in texture and are light to bright red in color. Surface of the branches are usually covered with many translucent white spots throughout. Hair cell are present, borne in clusters visible as white spots on the frond surface. Medullary cell are polygonal to spherical, increasing gradually in size towards the center; cortex of main branches 2-3(-4) cells think, either irregular in shape or broader than length and the cell shapes consistent within a given section.

REPRODUCTIVE STRUCTURES: Reproductive structures were not found in this study.

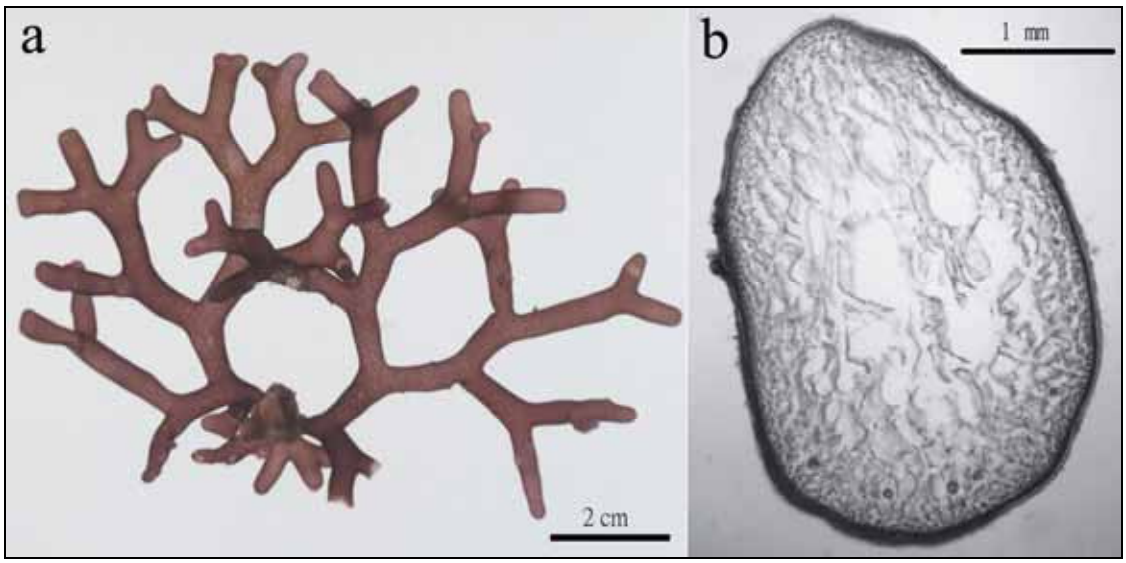

Figure 4: *Gracilaria canaliculata* Sonder (GRACILARIACEAE)

a. Habit. b. Cross-section through a branch.

Gracilaria firma Chang et Xia 1976

CHINESE NAME: 粗龍鬚菜

BASIONYM: N.A.

TYPE LOCALITY: Guangdong Province, south China.

TAIWAN DISTRIBUTION: widely distributed along the coastlines of Taiwan and neighboring islands.

SPECIMENS EXAMINED: **Kenting National Park, southern Taiwan**: 1) Wan Li Dong, coll. S.-M. Lin, 23 July 2002.

HABITAT AND SEASONALITY: The collections were made seasonally from late summer, July. Plants were found in tide pools or grew subtidally, 1-2 m deep. The seawater temperature in the waters of Taiwan ranges from 18˚ to 28˚C.

HABIT AND VEGETATIVE MORPHOLOGY: Thalli are up to 30 cm in height, erect arising from an conspicuous, discoid holdfast attached to oyster shells or oyster bamboo shelves in the water. Thalli are terete, bearing slender lateral branches with tapering or hooked apices.

REPRODUCTIVE STRUCTURES: Cystocarps are relatively small, 600-750 μm in diameter, central fusion cell large.

Note: This species is the most common culture species in southern Taiwan. Molecular analysis shows that it is closely related to the marine culture species, *G. firma*, from Vietnam and was misidentified as *Gracilaria tenuistipitata* var. *liui* in Chiang (1985) and the following authors.

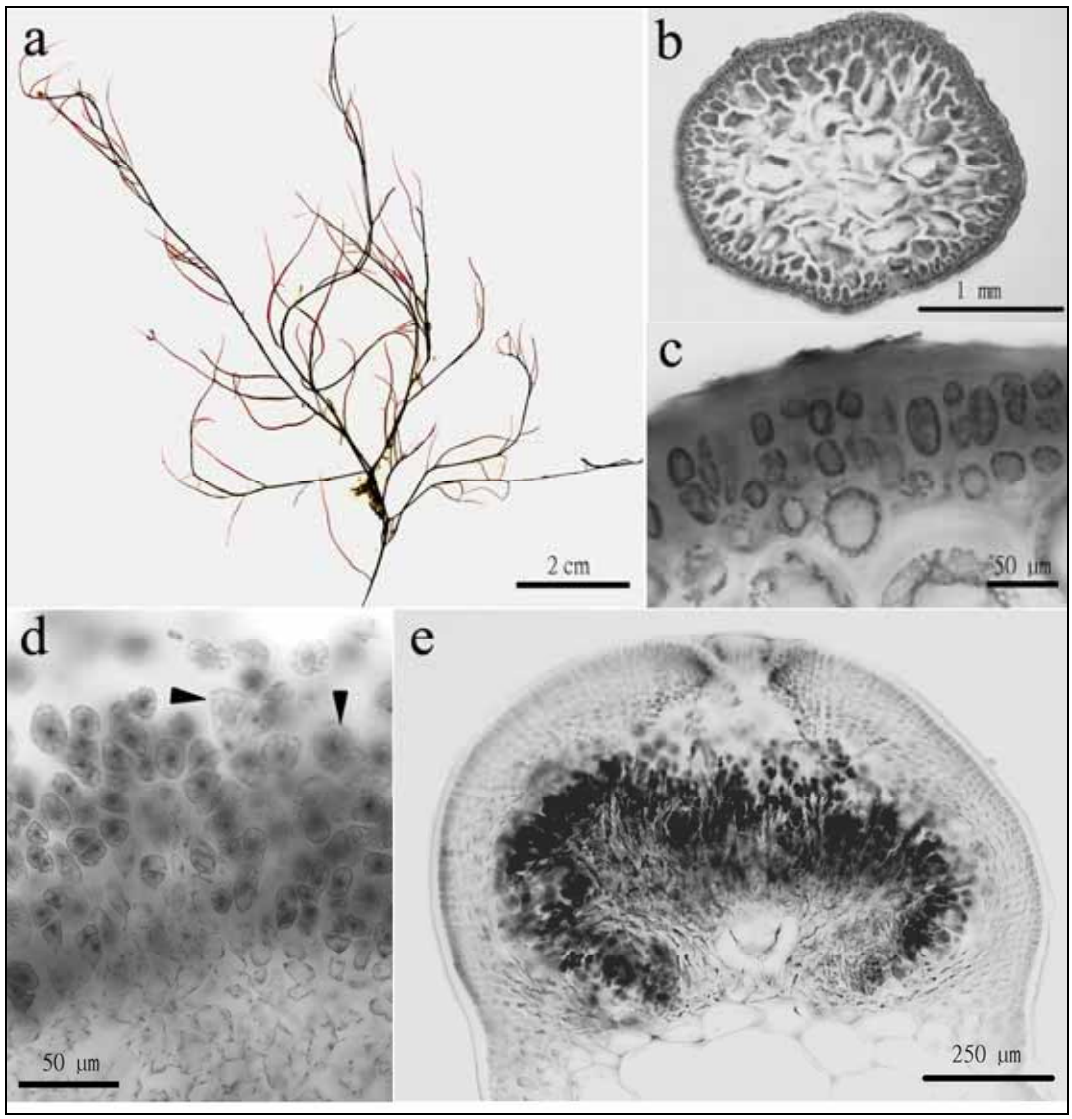

Figure 5: ***Gracilaria firma*** **Chang et Xia** (GRACILARICEAE)

a. Habit. b. Cross-section through a branch. c. Close up of tetrasporangia. d. Carposporangia (arrowheads). e. Mature cystocarp.

Gracilaria huangii S.-M. Lin et De Clerck 2006

CHINESE NAME: 黃氏龍鬚菜

BASIONYM: N.A.

TYPE LOCALITY: Sail Rock, Kenting National Park, southern Taiwan.

TAIWAN DISTRIBUTION: Widely distributed along the coastlines of Taiwan: Kenting National Park (southern Taiwan) and northeastern Taiwan.

SPECIMENS EXAMINED: **Kenting National Park, southern Taiwan**: 1) Chuan Fan Shi, coll. S.-M. Lin& KJY, 10 January 2002; 2) Wan Li Dong, coll. S.-M. Lin, 17 April 2005; 3) Hou Wan, coll. S.-M. Lin, 7 February 2007. N**ortheastern Taiwan**: 1) Ta Hsiang Lan, coll. Allen Liu, 31 August 2002; 2) Keelung, coll. S.-M. Lin, 17 May 2009.

HABITAT AND SEASONALITY: The collections were made seasonally from early winter to late summer, November-August. Plants were found in tide pools or grew subtidally, 1-5 m deep.

HABIT AND VEGETATIVE MORPHOLOGY: Thalli are erect, 4-8 cm high, consisting of 3-5 irregularly dichotomously branched, flattened blades, 4-15 mm wide, arising from a short stipe, 3-18 mm long, with a discoid holdfast, 2-4 mm in diameter. The blades are often rose to dark red, occasionally, appearing in green. The margins of the blades are associated with spines or lobes and numerous, tiny lobes or bladelets are also found on the surfaces of blades. The blades are 250-500μm thick, composed of 1-2 layers of pigmented cortical cells, 5-6 μm in diameter, 1-2 layers of subcortical cells, 12-20 μm in diameter, and 1-3 layers of medullary cells, 75-160 μm in diameter.

REPRODUCTIVE STRUCTURES: The trtrasporophytes and gametophytes are isomorphic and the gametophytes are dioecious. Reproductive structures are scattered over both surfaces of the blades. The cystocarps are borne on both surfaces of the fertile blades and on the marginal bladelets. Occasionally, the top of a cystocarp was found to bear a tiny bladelet. After fertilization, the sterile branches

flanking the carpogonial branch fuse directly onto the fertilized carpogonium. Fusion-cell formation progressively involves the sterile branches and neighboring vegetative cells The multinucleate fusion cell cuts off uninucleate gonimoblast cells in clusters. The innermost cells of the gonimoblasts become multinucleate and vacuolate, and the vacuolated cells between different gonimoblast clusters are confluent by numerous secondary pit-connections. Tubular nutritive cells are rarely present in the cavity of cystocarp. Carposporangia are uninucleate, 18-25 μm wide by 20-30 μm long and are borne in branched chains. Mature cystocarps are hemispherical and slightly constricted at the base,1.2-2.2 mm in diameter with the inner gonimoblast cells 75-115 μm long by 40-60 μm wide.

Spermatangial parent filaments are initiated from outer cortical cells, then produce and release spermatangia successively to from a shallow depression. Mature spermatangia are scattered over the surface of male gametophytes in shallow, *textorii*-type conceptacles. Tetrasporangia are initiated superficially from terminal cells cut off through an oblique, longitudinal cell division of outer cortical cells, and then expand and divide twice to produce four cruciately arranged tetraspores at maturity.

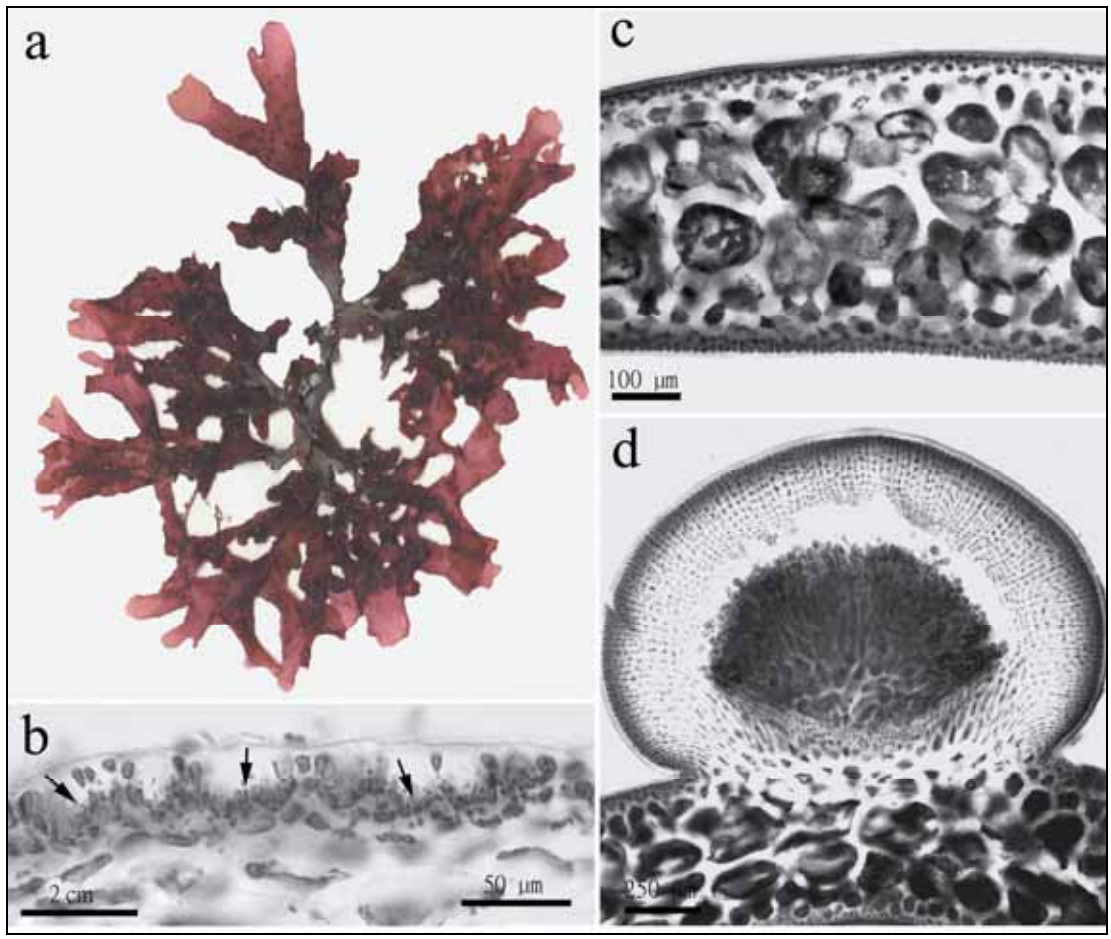

Figure 6: ***Gracilaria huangii*** **S.-M. Lin & De Clerck** (GRACILARIACEAE)

a. Habit. b. Spermatangial conceptacles (arrows). c. Cross-section through a blade. d. Cross-section through a mature cystocarp.

Gracilaria punctata (Okamura)Yamada 1941

CHINESE NAME: 班點龍鬚菜

BASIONYM: *Rhodymenia punctata* Okamura.

TYPE LOCALITY: Tosa, Japan.

TAIWAN DISTRIBUTION: widely distributed along the coastlines of Taiwan and neighboring islands. Kenting National Park, southern Taiwan. Orchid Island.

SPECIMENS EXAMINED: **Kenting National Park, southern Taiwan**: 1) Xiang Jiao Wan, coll. S.-M. Lin, 12 July 2002; 2) Long Keng, coll. S.-M. Lin, 3 January 2002; 3) Chuan Fan Shi, coll. S.-M. Lin, 10 January 2002; 4) Wan Li Tong, coll. S.-M. Lin, 17 April 2005; 5) Feng Chui Sha, coll. S.-M. Lin, 17 April 2005; 6)Xiao Gang Kou, coll. S.-M. Lin, 13 March 2003. Orchid Island: 1) Wu Kong Dong, coll. S.-M. Lin, 17 April 2002; 2) Shuang Shi Yan, coll. S.-M. Lin, 19 April 2002.

HABITAT AND SEASONALITY: The collections were made seasonally from January through July. Plants were found in tide pools or grew subtidally, 1-2 m deep. The seawater temperature in the waters of Taiwan ranges from 18˚ to 25˚C.

HABIT AND VEGETATIVE MORPHOLOGY: Thalli are erect, 4.5-8.7 cm high, consisting of irregularly to pseudodichotomously branched blades, arising from a discoid holdfast, 2.5-5 mm in diameter, usually with a stipe. The margins of blades are wavy, ruffled or entire and the surfaces of blades contain scattered brown to dark red spots, sometimes with colorless hairs. Blades are 260-560 μm thick, composed of 1-2 layers of pigmented cortical cells, 1-2 layers of subcortical cells, and 1-2-3 layer of medullary cells. Blades are rose red to dark red. Tetrasporocytes are scattered over the thallus surface embedded in nemathecia, surrounded by elongated cortical cells.

REPRODUCTIVE STRUCTURES: Mature tetrasporangia were not found in any of the tetrasporic plants examined. Spermatangial conceptacles are scattered over the thallus surface and were cup shaped when young, but become confluent as in the *Polycavernosa*-type conceptacle at maturity. Cystocarps are hemispherical, constricted at the base, 1.5-2.1 mm in diameter, scattered over the thallus. The cavity

of cystocarp is formed before the gonimoblast initials are cut off from the multinucleate fusion cell. Tubular nutritive cells are absent in the cystocarp cavity and are restricted to the base of the carposporophyte where they penetrate the floor of the cystocarp. Carposporangia are uninucleate, 15-20 µm wide by 20-28 µm long, and are borne in straight chains.

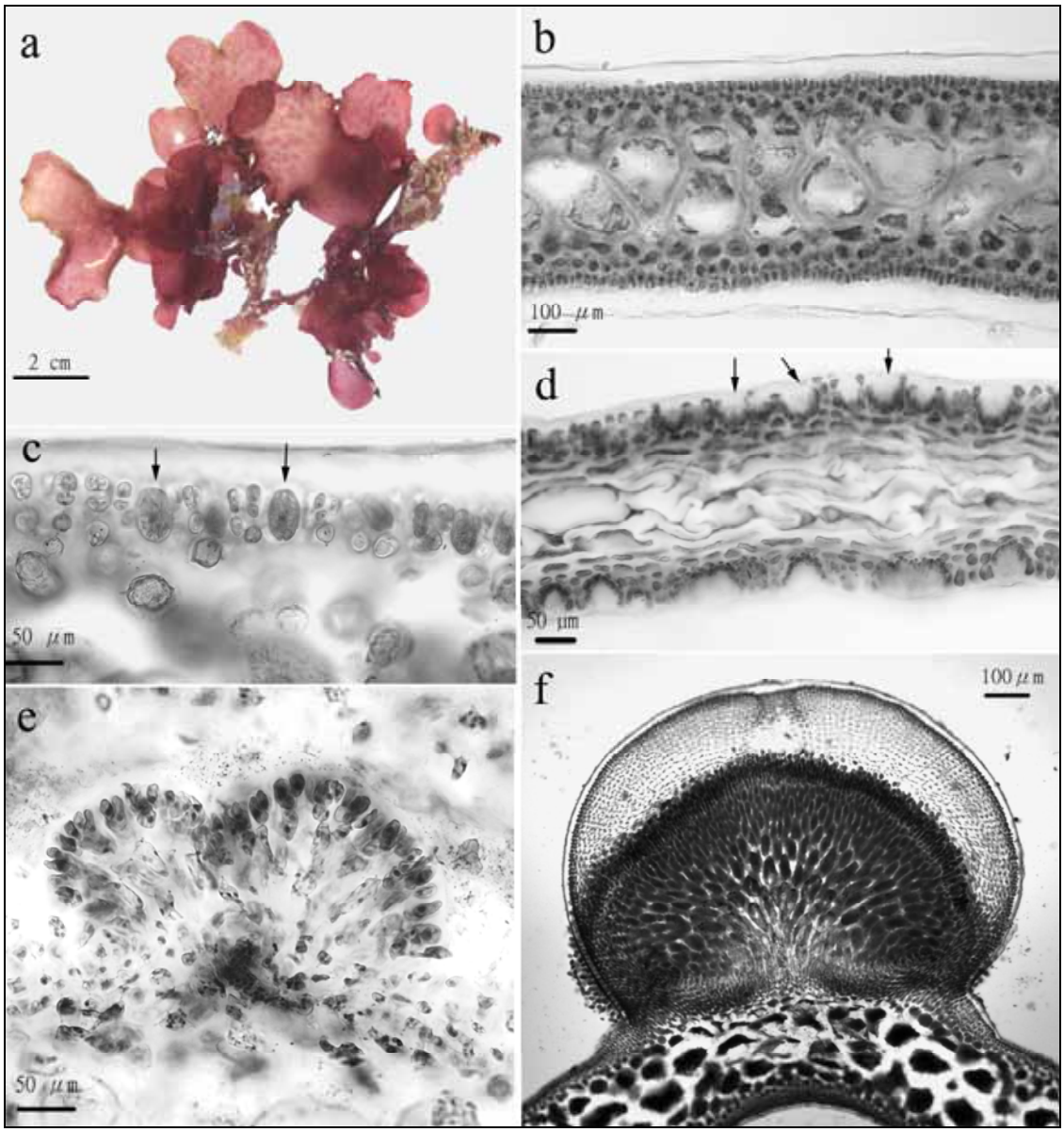

Figure 7: ***Gracilaria punctata*** **(Okamura)Yamada** (GRACILARIACEAE)

a. Habit. b. Cross-section through a bladelet. c. tetrasporangia initials (arrows). d. Close up of spermatangial conceptacles (arrows). e. Close up of immature cystocarp. f. Cross-section of a fully mature cystocarp.

Gracilaria salicornis E.Y. Dawson 1954

BASIONYM: 綴龍鬚菜

BASIONYM: *Sphaerococcus salicornia* C. Agardh.

BASIONYM: *Gracilaria cacalia* (J. Agardh) Dawson; *Gracilaria minor* (Sonder) Durairatnam; *Sphaerococcus salicornia* C. Agardh; *Corallopsis salicornia* (C. Agardh) Greville; *Corallopsis dichotoma* Ruprecht; *Corallopsis salicornia* var. minor Sonder; *Corallopsis opuntia* J. Agardh; *Corallopsis concrescens* Reinbold; *Gracilaria cacalia* (J. Agardh) E.Y. Dawson.

TYPE LOCALITY: Probably in Manila, Philippine Islands *fide* Dawson (1954).

TAIWAN DISTRIBUTION: widely distributed along the coastlines of Taiwan and neighboring islands. Kenting National Park, southern Taiwan, Taitung, eastern Taiwan.

SPECIMENS EXAMINED: **Kenting National Park, southern Taiwan**: 1) Long Keng, coll. S.-M. Lin, 3 Janaury 2002; 2) Wan Li Tong, coll. S.-M. Lin, 4 October 2001; 3) Feng Chui Sha, coll. S.-M. Lin, 10 July 2002. **Eastern Taiwan**: 1) Shan Yuan, coll. S.-M. Lin, 27 August 2002.

HABITAT AND SEASONALITY: The collections were made seasonally from late summer through spring. Plants were found in tide pools or grew subtidally, 1-2 m deep. The seawater temperature in the waters of Taiwan ranges from 18˚ to 25˚C. Marine, plants growing inter-tidally attached to coral reefs.

HABIT AND VEGETATIVE MORPHOLOGY: Thalli are prostrate, forming a loose turfy mat, up to 7 cm in length, attached to the coral debris or sandy substrate in areas where the water is turbid. Main axes arise from an irregularly discoid holdfast, or many aggregated holdfasts form an expanded basal crust. Thalli are consisting of articulated, terete, sub-clavate to clavate segments, swollen at the distal end and constracted at base. Branchings are irregulary sub-dichotomously to trichotomous to alternate.

REPRODUCTIVE STRUCTURES: Reproductive structures not observed.

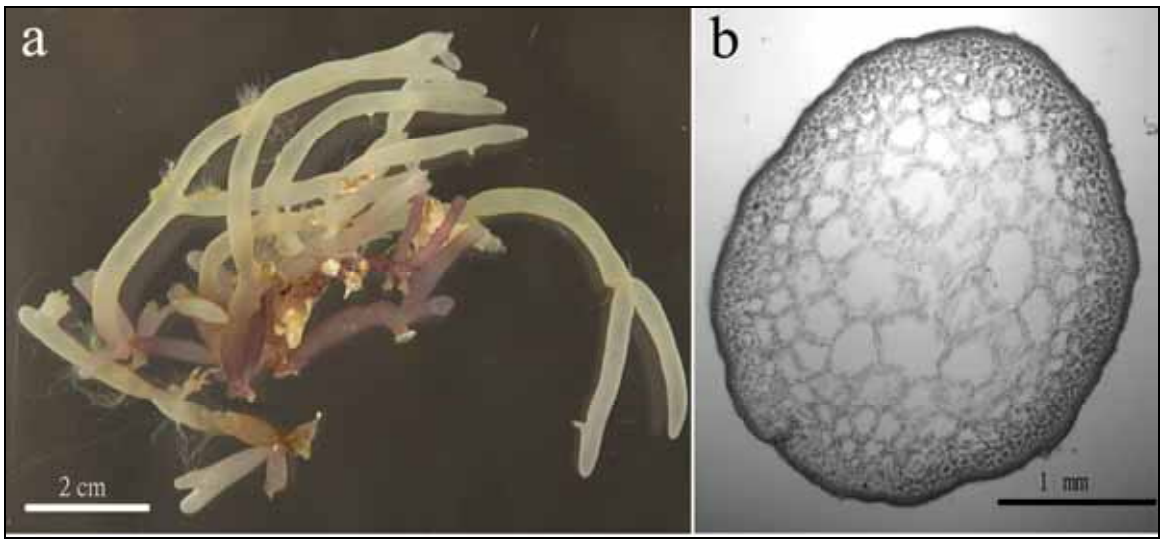

Figure 8: ***Gracilaria salicornis*** **E.Y. Dawson** (GRACILARIACEAE)

a. Habit. b. Cross-section through a branch.

Gracilaria spinulosa (Okamura) Chang et Xia 1976

CHINESE NAME: 刺邊龍鬚菜

BASIONYM: *Rhodymenia spinulosa* Okamura.

SYNONYM: *Gracilaria purpurascens* f. *spinulosa* (Okamura) Yamada.

TYPE LOCALITY: Tainan, southern Taiwan.

TAIWAN DISTRIBUTION: widely distributed along the coastlines of Taiwan: Kenting National Park, southern Taiwan; Ping Tung, southern Taiwan; Tai Nan, southern Taiwan; Tai Tung, eastern Taiwan; Keelung, northern Taiwan.

SPECIMENS EXAMINED: **Kenting National Park, southern Taiwan**: 1) Xiang Jiao Wan, coll. S.-M. Lin, 12 March 2001; 2) Long Keng, coll. S.-M. Lin, 2 April 2001; 3) Feng Chui Sha, coll. S.-M. Lin, 21 July 2001; 4) Wan Li Tong, coll. S.-M. Lin, 4 October 2001; 5) Chuan Fan Shi, coll. S.-M. Lin, 11 December 2001; **Pingtung**: 1) Lin Bian, coll. S.-M. Lin, 12 January 2006; **Tainan**: 1) Qie Ding, coll. S.-M. Lin, 16 July 2002; **Taitung**: 1) Xiao Ye Liu, coll. S.-M. Lin, 12 April 2005; 2) Fu Gang Harbor, coll. S.-M. Lin, 8 March 2003.

HABITAT AND SEASONALITY: The collections were made seasonally from late summer through late spring. Plants were found in tide pools or grew subtidally, 1-2 m deep. The seawater temperature in the waters of Taiwan ranges from 18˚ to 25˚C.

HABIT AND VEGETATIVE MORPHOLOGY: Thalli are bushy and erect, 4-8 cm long, consisting of loose to dense, irregularly dichotomously branched, flatten blades, 2-7 mm wide, arising from a discoid holdfast, 2-3 mm in diameter, occasionally with a short stipe. The margins of blades are toothed or rarely entire. Blades are 110-160 (-405) μm in thickness, composed of 1-2 layers of pigmented cortical cells, 1-2 layers of sub-cortical cells, and 2-3 layers of medullary cells. Blades are rose red to dark red, occasionally greenish in color. Spermatangia are scattered over the surface of male gametophytes in shallow, *textorii*-type conceptacles. Tetrasporangia are cruciate, scattered over the surface of the thallus except the basal part.

REPRODUCTIVE STRUCTURES: Cystocarps are hemispherical and slightly constricted at the base, 1.1-1.4 mm in diameter, scattered over the mid to upper part of the thallus. Gonimoblast initials are cut off from the multinucleate fusion cell. Tubular nutritive cells are present in the cystocarp cavity and in the floor of the cystocarp and inner gonimoblast cells are 55-28 µm long by 25-35 µm wide. Carposporangia are uninucleate, borne in branched chains, 15-20 µm wide by 15-23 µm long.

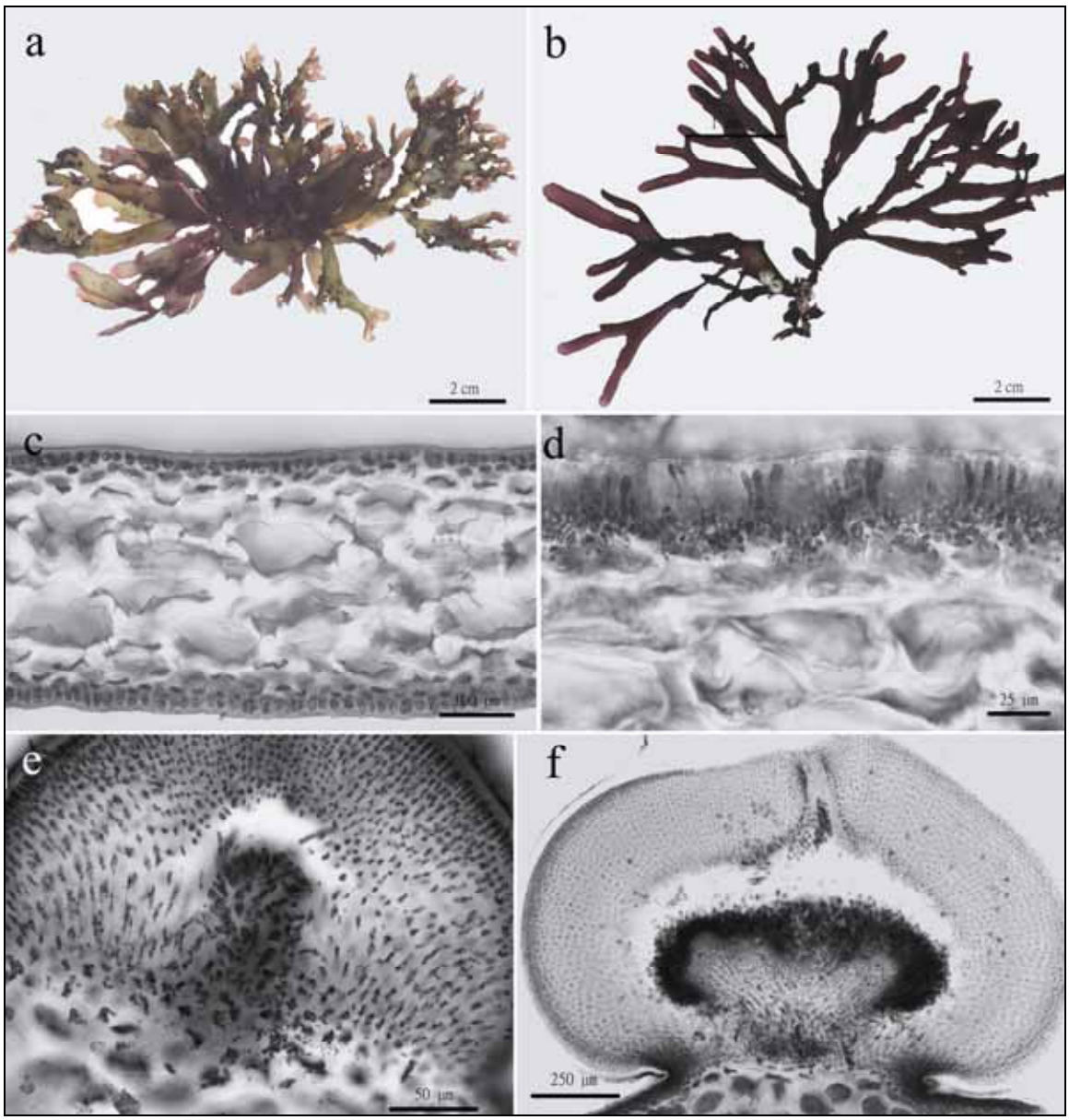

Figure 9: *Gracilaria spinulosa* (Okamura) Chang & B.M.Xia (GRACILARIACEAE)

a. Habit: female plant. b. Habit: male plant. c. Cross-section through a blade. d. Cross-section through spermatangial conceptacles (arrows). e. Immature cystocarp. f. Mature cystocarp.

Gracilaria vieillardii P.C. Silva 1987

CHINESE NAME: 齒葉龍鬚菜

BASIONYM: N.A.

SYNONYM: *Gracilaria denticulata* (Kützing) Weber-van Bosse; *Sphaerococcus denticulatus* Kützing.

TYPE LOCALITY: Wagap, New Caledonia.

TAIWAN DISTRIBUTION: Widely distributed along the coastlines of Taiwan and neighboring islands: Kenting National Park, southern Taiwan; Taitung, eastern Taiwan; Orchid island and Green Island.

SPECIMENS EXAMINED: **Kenting National Park, southern Taiwan**: 1) Wan Li Dong, coll. S.-M. Lin, 23 July 2002. 2) Hou Wan, coll. S.-M. Lin, 4 October 2001. 3) Sail Rock, coll. S.-M. Lin, 10 December 2001. **Eastern Taiwan**: 1) Taitung, coll. F.-K. Huang, 8 March 2003. 2) Xiao Ye Liu, coll. S.-M. Lin, 12 May 2005. **Orchid Island**: 1) Wu Kong Dong, coll. S.-M. Lin, 17 April 2003. 2) Shuang Shi Yan, coll. S.-M. Lin, 19 April 2002.

HABITAT AND SEASONALITY: The collections were made seasonally from early winter through late summer. Plants were found in tide pools or grew subtidally, 1-2 m deep. The seawater temperature in the waters of Taiwan ranges from 18˚ to 25˚C.

HABIT AND VEGETATIVE MORPHOLOGY: Thalli are slightly prostrate or erect, 2.5-6 cm long, and consist of irregularly dichotomously branched, flattened blades, 3-12 mm wide, arising from a conspicuous, discoid holdfast, 3-11 mm in diameter, occasionally with a short stipe. The margins of young blades are mostly entire; when old, upper parts of blades possess fine marginal spines. Blades are 255-395 μm in thickness, composed of 2 layers of pigmented cortical cells, 2-3 layers of subcortical cells, and a 3-layered medulla composed of cell. Blades are bright to dark red or greenish in color when exposed to sunlight.

REPRODUCTIVE STRUCTURES: Spermatangial and tetrasporic plants were not observed. Cystocarps are hemispherical and slightly constricted at the base, 1.5-1.9 mm in diameter. Tubular nutritive cells are mostly restricted to the base of the carposporophyte and the inner gonimoblast cells are interconnected to form a network. Carposporangia are uninucleate, borne in branched chains, 12-15 µm wide by 15-20 µm long.

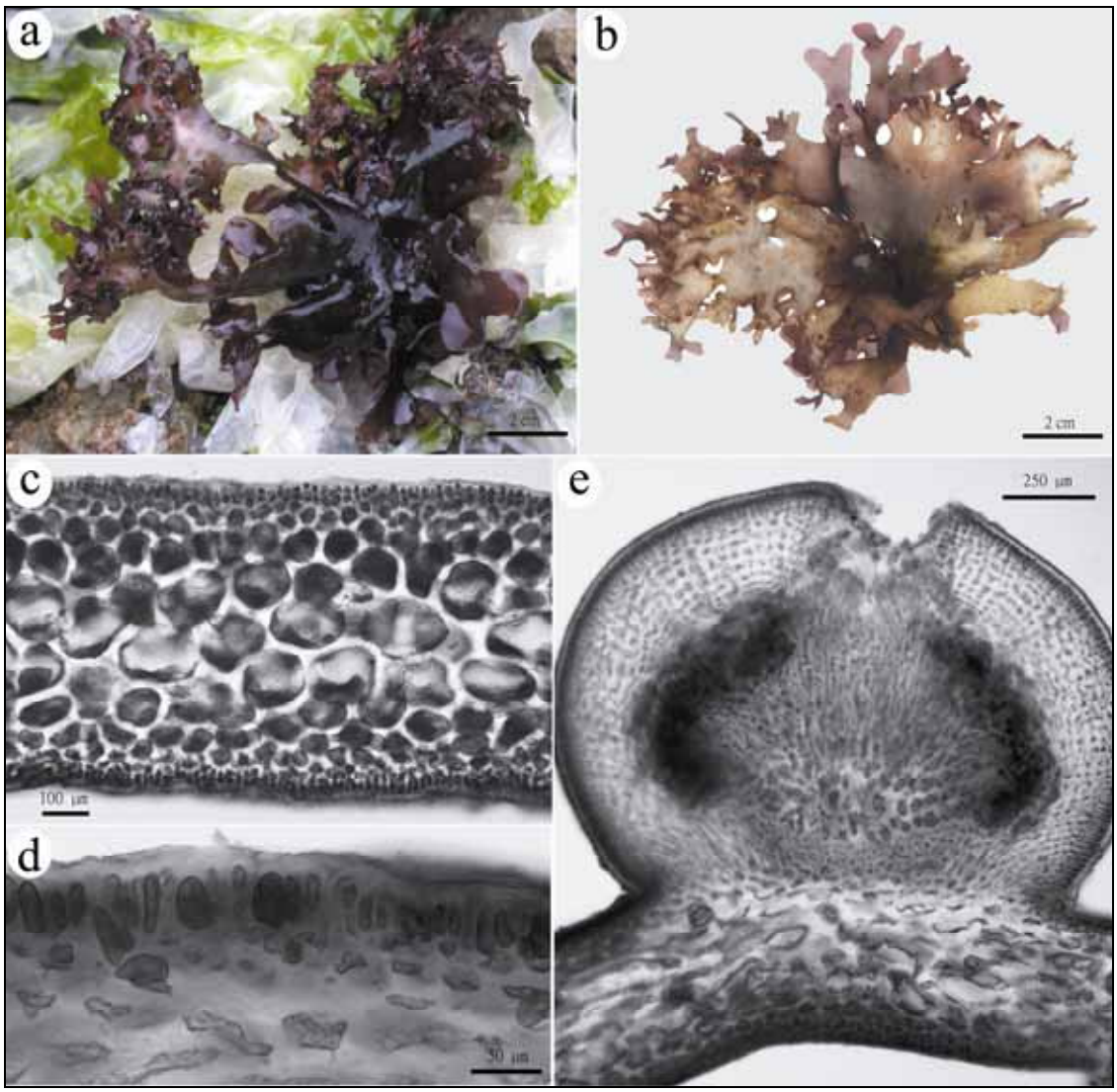

Figure 10: ***Gracilaria vieillardii*** **P.C. Silva** (GRACILARIACEAE)

a. Fresh plant in the field. b. Habit. c. Cross-section through a blade. d. Close up of tetrasporangia. e. Cystocarp.

The genus *Hydropuntia* Montagne 1842

Thalli are terete to slightly compressed, bushy or prostrate arising from discoid holdfast or creeping multicellular haptera. Cortex and medulla and growth pattern are the same as described fro the genus *Gracilaria*. Life history, Carpogonial branches and early fusion-cell formation are also similar to that of *Gracilaria*. Liao and Hommersand (2003) showed that the gonimoblast filaments completely fill the cystocarp cavity and the darkly staining elongate inner gonimoblasts bearing clusters of carposporangia in short branched chains. Tubular cells are present. Spermatangia are produced in deep conceptacles, which will be fused into polycovernosa-type of conceptacles, a strikingly different structure from what have seen in the species of *Gracilaria*.

This genus was recently resurrected by Gurgel and Fredericq (2004) and contains about 15 currently accepted species. Two species occur in Taiwan.

Key to species of *Hydropuntia*

1a Thalli upright and bushy, terete, 10-15 cm in height .....*H. edulis*

1b Thalli compressed and prostrate, forming in a mat ..... *H. eucheumatoides*

Hydropuntia edulis (S.G. Gmelin) Gurgel et Fredericq 2004

CHINESE NAME: 可食水龍鬚菜

BASIONYM: *Gracilaria edulis* (S.G. Gmelin) Silva.

SYNONYM: *Fucus coralloides* Poiret; *Fucus lichenoides* Turner; *Sphaerococcus lichenoides* C. Agardh; *Gracilaria lichenoides* Greville; *Ceramianthemum lichenoides* Kuntze; *Polycavernosa fastigiata* Chang et Xia; *Hydropuntia fastigiata* (Chang et Xia) Wynne.

TYPE LOCALITY: 'India orientalis'.

TAIWAN DISTRIBUTION: widely distributed along the coastlines of Taiwan and neighboring islands. Kenting National Park, southern Taiwan; Liou Ciou Isle.

SPECIMENS EXAMINED: **Kenting National Park, southern Taiwan**: 1) Nan Wan, coll. S.-M. Lin, 16 August 2001; 2) Chuan Fan Shi, coll. S.-M. Lin, 21 August 2001; **Pingtung**: 1)Liou Ciou Isle , coll. S.-L. Liu, 15 August 2002.

HABITAT AND SEASONALITY: The collections were made in late summer. Plants were found in tide pools or grew subtidally, 1-2 m deep. The seawater temperature in the waters of Taiwan ranges from 18˚ to 25˚C.

HABIT AND VEGETATIVE MORPHOLOGY: Thalli are cartilanious, erect, arising from a small, discoid holdfast attached to coral reef, up to 15 in height. Branchings are terete, irregularly subdichotomous, tapered and bifurcate at the distal ends, light to dark brown in color. Medullary cells are gradually changed outward. The corex are consisting of 2-3-celled outer layers and 2-3 inner cortical celled layers.

REPRODUCTIVE STRUCTURES: Cystocarps are relatively small, 500-700 μm in diameter, carposporangia small borne in chains, nutritive filamentous cells absent in the cavity of cystocarp. Spermatangial sori were not found in this study.

Note: Taiwan specimens have been recorded as *Gracilaria coronopifolia*, a species originally described from Hawaii, in the past decades. Molecular analysis suggested

G. coronopifolia is only restricted to Hawaii islands (personal communication with Dr. Sherwood from University of Hawaii, USA).

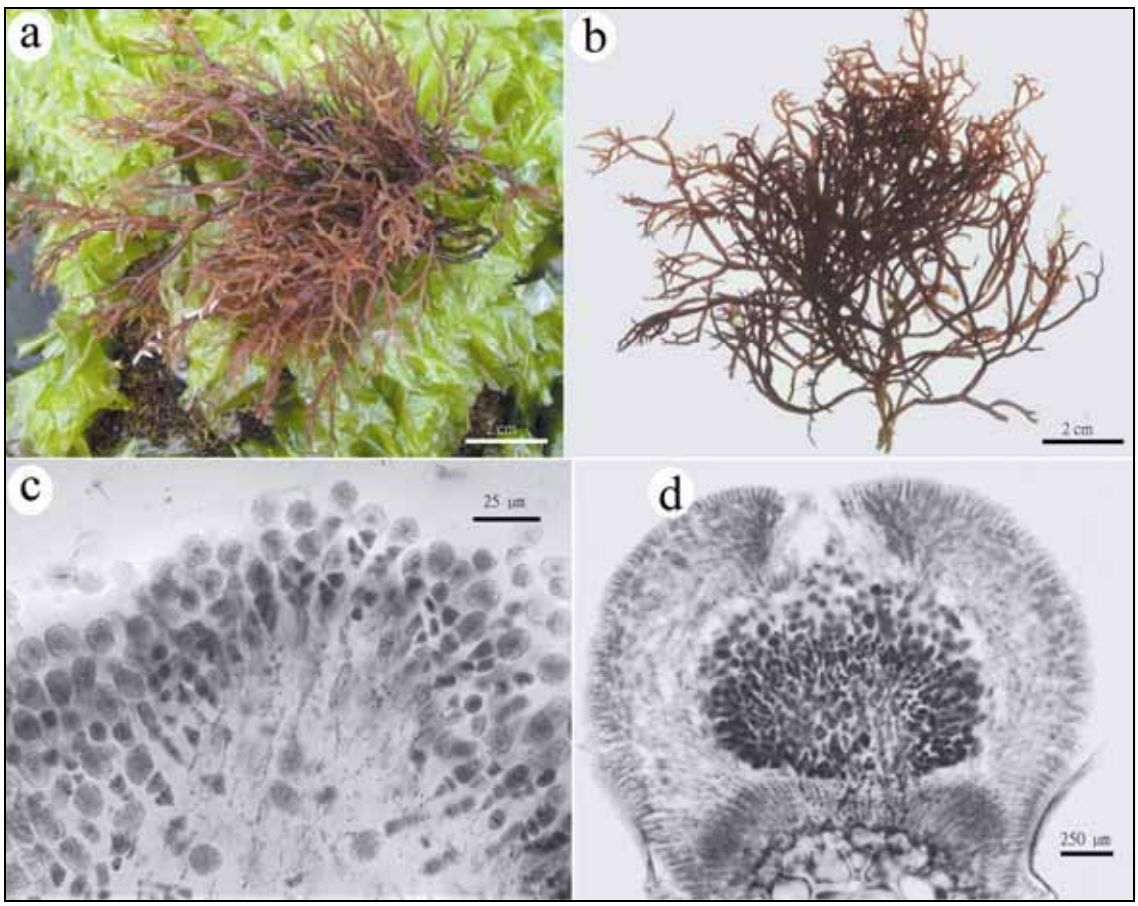

Figure 11: *Hydropuntia edulis* (S.G. Gmelin) Gurgel & Fredericq (GRACILARIACEAE)

a. Fresh plant in the field. b. Habit. c. Close up of carposporangia. d. Mature cystocarp.

Hydropuntia eucheumatoides (Harvey) Gurgel & Fredericq 2004

CHINESE NAME: 麒麟水龍鬚菜

BASIONYM: *Gracilaria eucheumatoides* Harvey.

TYPE LOCALITY: Ryukyuretto, Japan.

TAIWAN DISTRIBUTION: widely distributed along the coastlines of Taiwan and neighboring islands. Kenting National Park, southern Taiwan: Wind Blow Sand, Outfall; Taitung , eastern Taiwan: Chi Fei; Green island: Dabaisha, Shrlang.

SPECIMENS EXAMINED: **Kenting National Park, southern Taiwan**: 1) **Feng Chui Sha**, coll. S.-M. Lin, 21 July 2001; 2) Outlet of 3rd nuclear plant, coll. S.-M. Lin, 10 October 2002. **Taitung**: 1) Ji Hui, coll. S.-L. Liu, 26 August 2002. **Green Island**: 1) Da Bai Sha, coll. S.-M. Lin, 26 April 2002; 2) Shi Lang, coll. S.-L. Liu,28 August 2002.

HABITAT AND SEASONALITY: The collections were made seasonally from late summer, July. Plants were found in tide pools or grew subtidally, 1-2 m deep. The seawater temperature in the waters of Taiwan ranges from 22˚ to 28˚C.

HABIT AND VEGETATIVE MORPHOLOGY: Thalli are prostrate, cartilaginous, forming loose or thick clumps attached to coral reefs by means of discoid hapters, up to 15 cm in length. Thalli are coarse, consisting of irregular flattened branches, up to 1 cm in width. The margins of flattened branches are mostly with coarse teeth of short spines.

REPRODUCTIVE STRUCTURES: Reproductive structures were not found, but the spermatangial sori have been reported to be *polycavernosa*-type.

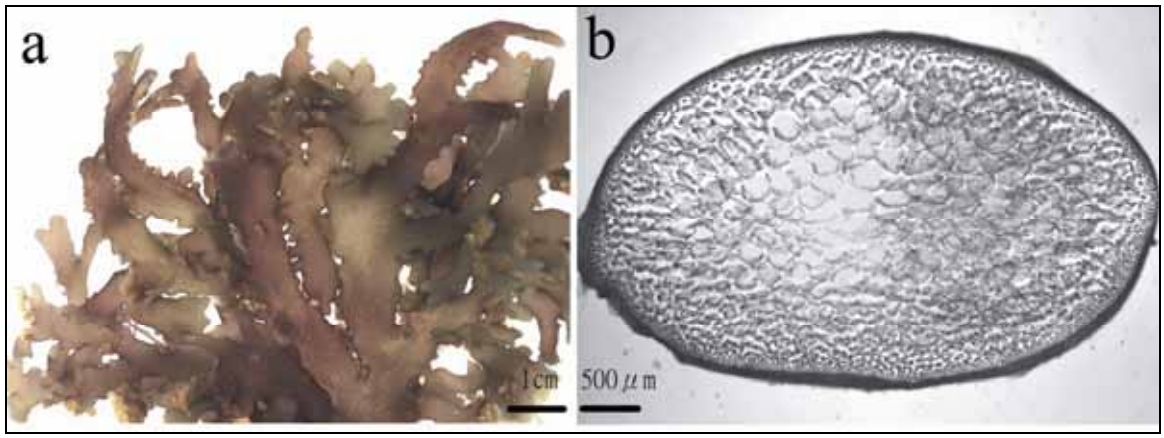

Figure 11: ***Hydropuntia eucheumatoides*** **(Harvey) Gurgel & Fredericq** (GRACILARIACEAE)

a. Habit. b. Cross-section through a flattened branch.

The genus *Gracilariopsis* Dawson 1949

Thalli are erect, terete, cartilaginous, 8–30 (-60) cm in height arising from a small, discoid holdfast. Branches mostly slender and are composed of 1–2 (–3) layers of pigmented, ovoid cortical cells, 1–2 layers of subcortical cells, and a medullacomposed of large, thin-walled cells. The tetrasporophytes and gametophytes are isomorphic. Tetrasporangia are superficial, initiated from outer cortical cells through oblique, longitudinal cell divisions of terminal cells. They later expand and divide transversely and then undergo longitudinal division to produce four cruciately arranged tetraspores at maturity. Cystocarps are scattered over the fertile branches, dome-shaped and broad-based. Carpogonial branches are borne on an intercalary supporting cell and consist of a carpogonium and hypogynous cell flanked by a pair of sterile filaments. The formation of the pericarp and fusion cell is more or less complete prior to gonimoblast initiation. Gonimoblast lobes are initiated before a cavity forms between the pericarp and fusion cell. At early cystocarp development, the pit-connections between the pericarp cells at the level of the fusion cell break down to initiate a schizogenous cavity. The innermost gonimoblast cells are united by numerous secondary pit connections, whereas the lower gonimoblast cells continue pit-connecting to the floor cells. Tubular nutritive cells are completely absent. The spermatangial sori were formed superficially (Chorda-type), not in any conceptacles.

There is only one species recorded from Taiwan (see Lin 2008).

Gracilariopsis chiangii S.-M. Lin 2008

CHINESE NAME: 江氏擬龍鬚菜

BASIONYM: N.A.

TYPE LOCALITY: Tou-Cheng City, I-Lan County, northern Taiwan.

TAIWAN DISTRIBUTION: widely distributed along the northern and southern coastlines of Taiwan.

SPECIMENS EXAMINED: **Kenting National Park, southern Taiwan**: 1) Chuan Fan Shi, coll. S.-M. Lin, 10 January 2002; 2) Wan Li Tong, coll. S.-M. Lin, 5 May 2003; 3) Feng Chui Sha, coll. S.-M. Lin, 18 March 2003.

HABITAT AND SEASONALITY: The collections were made seasonally from early winter through early summer. Plants were found in tide pools or grew subtidally, 1-2 m deep. The seawater temperature in the waters of Taiwan ranges from 18˚ to 25˚C.

HABIT AND VEGETATIVE MORPHOLOGY: Thalli are erect, cartilanious, arising from a discoid holdfast, up to 20 cm in height, brown to purple red in color. Thalli are terete, unbranched, or irregularly branched from basal part of the thallus.

REPRODUCTIVE STRUCTURES: Carposporangia are small, borne in chains, and nutritive filamentous cells are absent in the cavity of cystocarp. Spermatangial sori are *chorda*-type.

Note: This alga in Taiwan was previously recorded as *Gracilaria chorda* (see Chiang 1985).

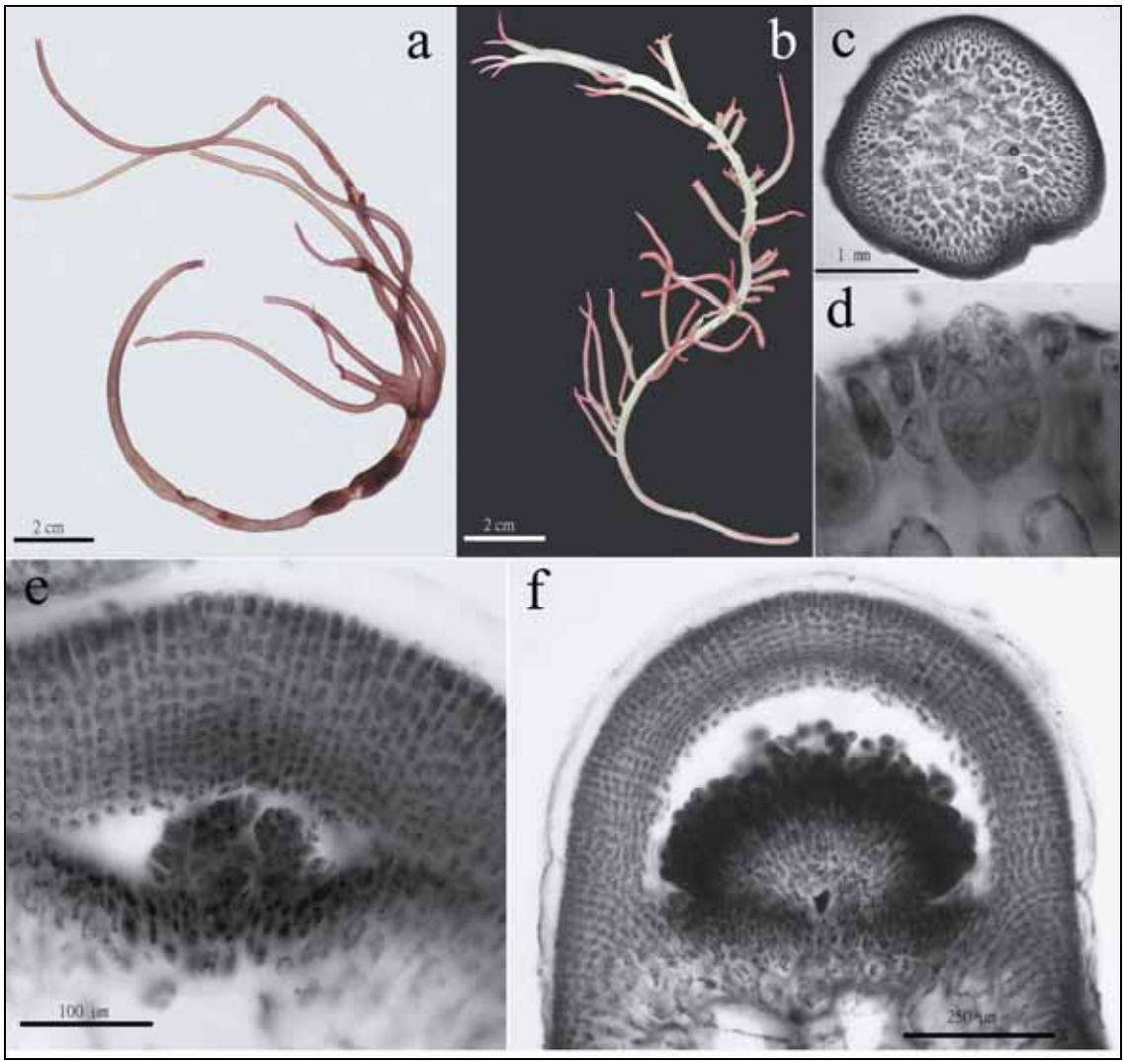

Figure 13: *Gracilariopsis chiangii* S.-M. Lin (GRACILARIACEAE)

a. Habit. b. Close up of a branch bearing many branchlets. c. Cross-section through a branchlet. d. Close up of tetrasporangium. e. Immature cystocarp. f. Mature cystocarp.

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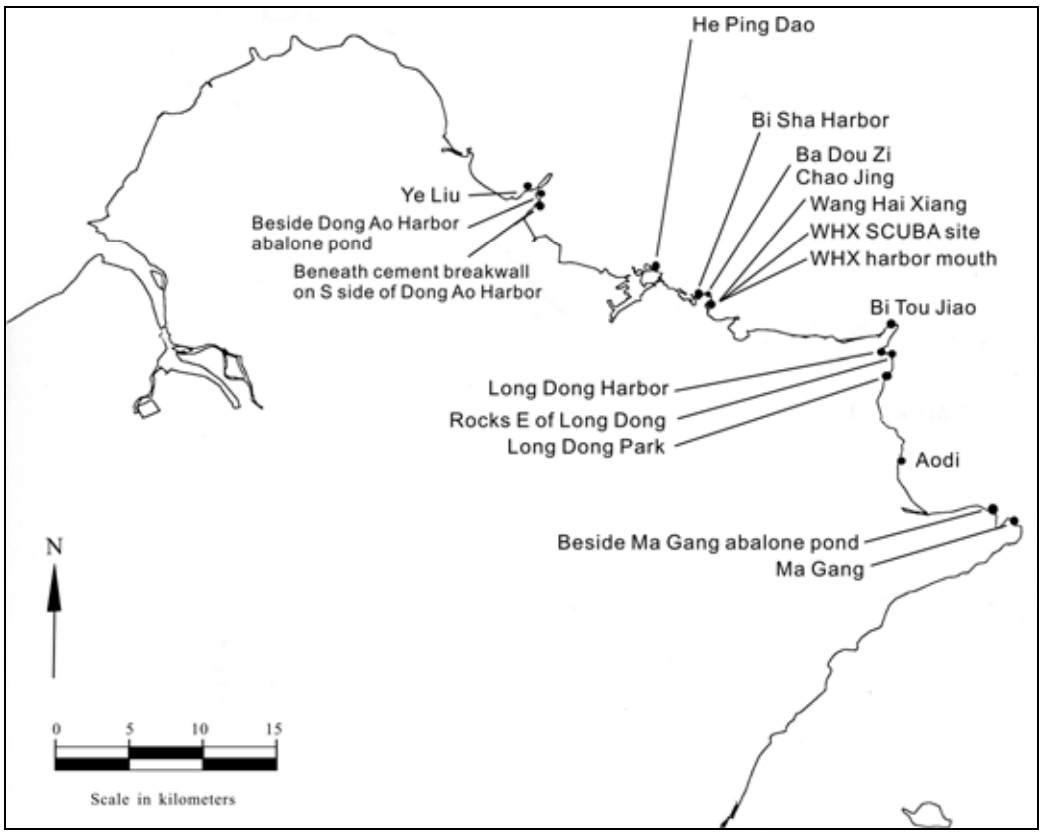
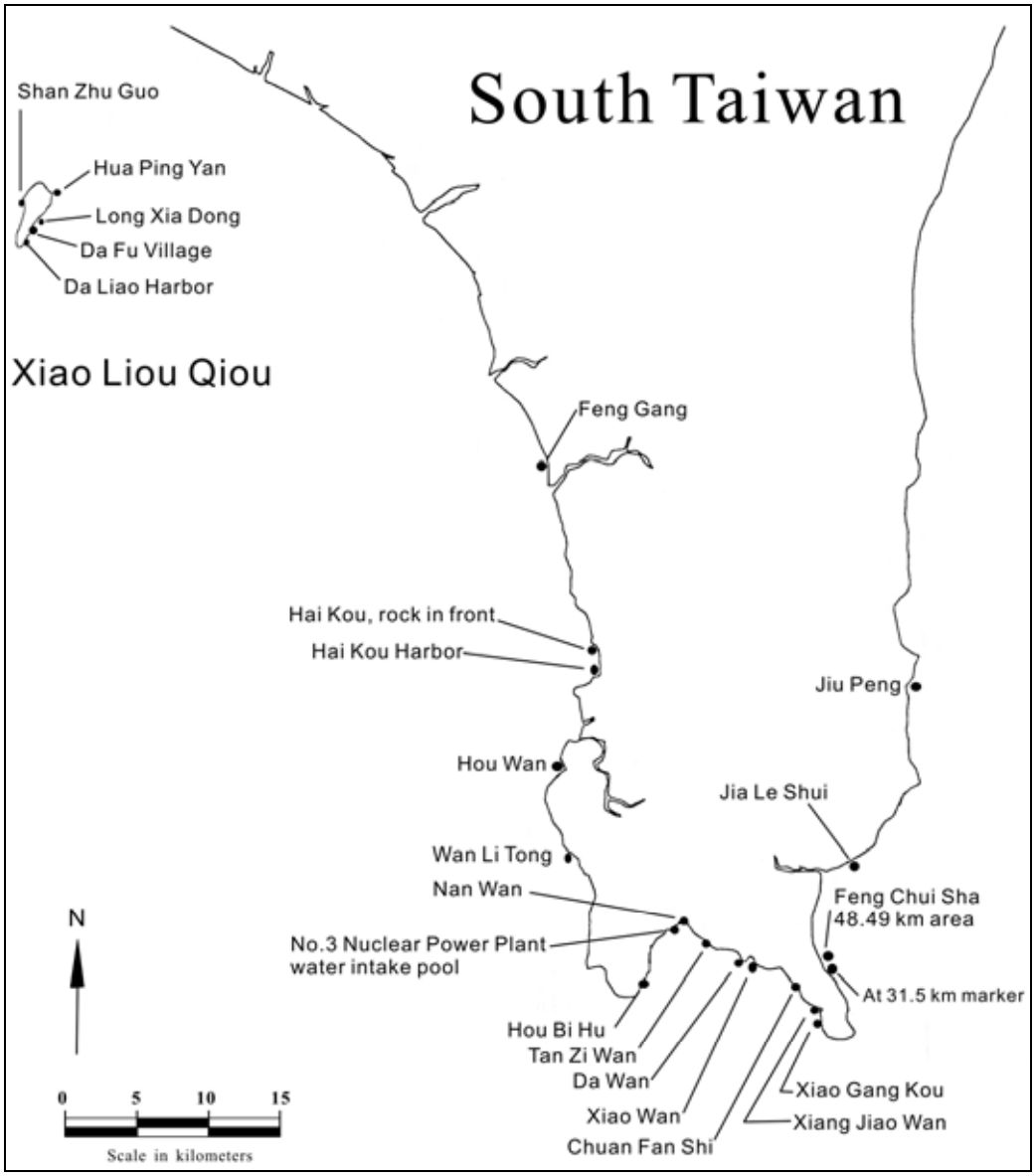
Appendix I: collecting sites of the species of the Gracilariaceae in Taiwan, Green Island and Orchid Island.

(1) Collecting sites in eastern Taiwan, Green Island and Orchid Island:

(2) Collecting sites in northern Taiwan:



(3) Collecting sites in southern Taiwan:



Apendix II: The collecting sites in Chinese and Hanyu Pinyin around Taiwan, Xiao Liou Qiou, Green Island and Orchid Island.

採集地名	漢語拼音 (Hanyu Pinyin)
磯崎	Ji Qi
石梯坪	Shi Ti Ping
石雨傘	Shi Yu San
小港港口	Xiao Gang Harbor
小港港口西	Xiao Gang Harbor(W)
三仙台	San Xian Tai
基翬	Ji Hui
成功港	Cheng Gong Harbor
小野柳	Xiao Ye Liu
富岡漁港	Fu Gang Harbor
杉原	Shan Yuan
野柳	Ye Liu
野柳東澳港九孔池旁	Beside Dong Ao Harbor abalone pond
野柳東澳港往基隆方向海堤下	Beneath cement breakwall on S side of Dong Ao Harbor
和平島	He Ping Dao
碧砂港	Bi Sha Harbor
望海巷	Wang Hai Xiang
望海巷潛水處	WHX Scuba site
望海巷下船處	WHX harbor mouth
龍洞港	Long Dong Harbor
龍洞東邊岩石	Rocks E of Long Dong
龍洞公園	Long Dong Park
馬崗九孔池旁	Beside Ma Gang abalone pond
馬崗	Ma Gang
綠島	Green Island

南寮港	Nan Liao Harbor
機場	Airstrip, GI
中寮港	Zhong Liao Harbor
公館港	Gong Guan Harbor
東岸沙灘	
大湖港	Da Hu Harbor
睡美人岩	Shui Mei Ren
大白沙	Da Bai Sha
蘭嶼	Orchid Island
雙獅岩	Shuang Shi Yan
軍艦岩前	In front of Jun Jian Yan
東清灣	Dong Qing Wan
情人洞	Qing Ren Dong
野銀村前	In front of Ye Yin Village
永興農場	Yong Xing Farm
鋼盔岩	Gang Kui Yan
鋼盔岩前水池	Pools in front of Gang Kui Yan
儲存場前	In front of Chu Cun Chang
龍頭	Long Tou
核廢料場前	In front of Nuclear Waste Harbor
軍管前水池	Pool in front of Jun Guan
紅頭村前	In front of Hong Tou Village
機場	Airstrip,OI
椰油	Ye You
椰油潛水店前	In front of Ye You dive store
開元港	Kai Yuan Harbor
小琉球	Xiao Liou Qiou
山豬溝	Shan Zhu Guo
花瓶岩	Hua Ping Yan
龍蝦洞	Long Xia Dong
大福村	Da Fu Village
大寮港	Da Liao Harbor
楓港	Feng Gang

海口前岩石	Hai Kou, rock in front
海口港	Hai Kou Harbor
後灣	Hou Wan
萬里桐	Wan Li Tong
南灣	Nan Wan
核三廠入水口	No.3 Nuclear Power Plant water intake pool
後壁湖	Hou Bi Hu
潭子灣	Tan Zi Wan
大灣	Da Wan
小灣	Xiao Wan
船帆石	Chuan Fan Shi
香蕉灣	Xiang Jiao Wan
小港口	Xiao Gang Kou
墾丁公路31.5 km標示牌處	At 31.5 km marker
風吹沙 48 公里處	Feng Chui Sha 48 km area
風吹沙 49 公里處	Feng Chui Sha 49 km area
佳樂水	Jia Le Shui
九鵬(棚)	Jiu Peng
澳底	Ao Di
八斗子	Ba Dou Zi
潮境	Chao Jing
鼻頭角	Bi Tou Jiao
五孔洞	Wu Kong Dong
柴口	Chai Kou
柚子湖	You Zi Hu

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