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# An Annotated Checklist of Algae from the Order Synurales (Chrysophyceae) of Viet Nam

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**Abstract:** This paper presents an annotated list of the *Mallomonas* and *Synura* taxa (order Synurales, class Chrysophyceae) found in Viet Nam. This list is based on materials from long-term studies (from 2008 to 2020) of 371 freshwater localities in 18 provinces in the country. A total of 67 taxa (morphotypes) of the genus *Mallomonas* and 7 of the genus *Synura* were reported. For each species, the range of abiotic environmental parameters under which they were found is given, as well as comments on the distribution of these taxa within Viet Nam and the tropical region.

**Keywords:** Synurales; *Mallomonas*; *Synura*; Viet Nam; tropics



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## 1. Introduction

The algae of the order Synurales (Chrysophyceae) are unicellular or colonial organisms. They are distinguished from the other members of Chrysophyceae by their flagellar apparatus, cholorophyll-c composition, and the presence of bilaterally symmetrical silica scales that form an armor around the cell [1]. According to the latest review, the order includes three genera: *Mallomonas* Perty, *Synura* Ehrenberg, and *Neotessella* Jo, Kim, Shin, Škaloud & Siver [2]. The genera *Mallomonas* and *Synura* are among the most diverse in the number of species from this order and the whole Chrysophyceae class. The genus *Mallomonas* includes more than 200 species [1,3], and *Synura* includes more than 50 [4]. The species concept for this group is based on the morphology of scales and bristles, studied by transmission or scanning electron microscopy (TEM or SEM), and is considered one of the best among the protists [5]. Molecular data, in general, justify the scale and bristle morphology to provide reliable characteristics for species delimitation [4,6–10].

Studies of silica-scaled chrysophytes in the tropical region using electron microscopy began in the late 1970s [11]. To date, there is information about the flora of the synuralean algae of Bangladesh [11], Malaysia [12,13], Singapore [13], Sri Lanka [14], tropical China [15,16] and Australia [12], India [17,18], Nigeria [19,20], Papua New Guinea [21], Indonesia [22–24], Madagascar [25], Kenya [26], Republic of Chad [27], Zimbabwe [28], Cameroon [29,30], South Africa [31–33], Costa Rica [34], Jamaica [28], Ecuador [35], Guatemala [28], Panama [36], Belize [37], Colombia [28,38], and Brazil [28,39–42]. However, this region is still poorly studied and requires further research [1].

We have carried out long-term studies of the flora of Viet Nam, which made it possible to find and describe a large number of species of algae from the order Synurales. The studies covered various geographical parts of the country, such as Northern Viet Nam [43], mountainous and coastal regions of Central Viet Nam [44–48], Southern Viet Nam [49–51], and the flora of some islands [52]. Taking into account the number of studied habitats and

the number of published works, it became necessary to generalize data on the distribution of synuralean algae in Viet Nam. This is the aim of this work.

## 2. Materials and Methods

Plankton studies on different types of water bodies were carried out from 2008 to 2020 in various regions of Viet Nam [43–52]. In total, samples from 371 localities in Viet Nam were included in our studies of synuralean algae (Figure 1).

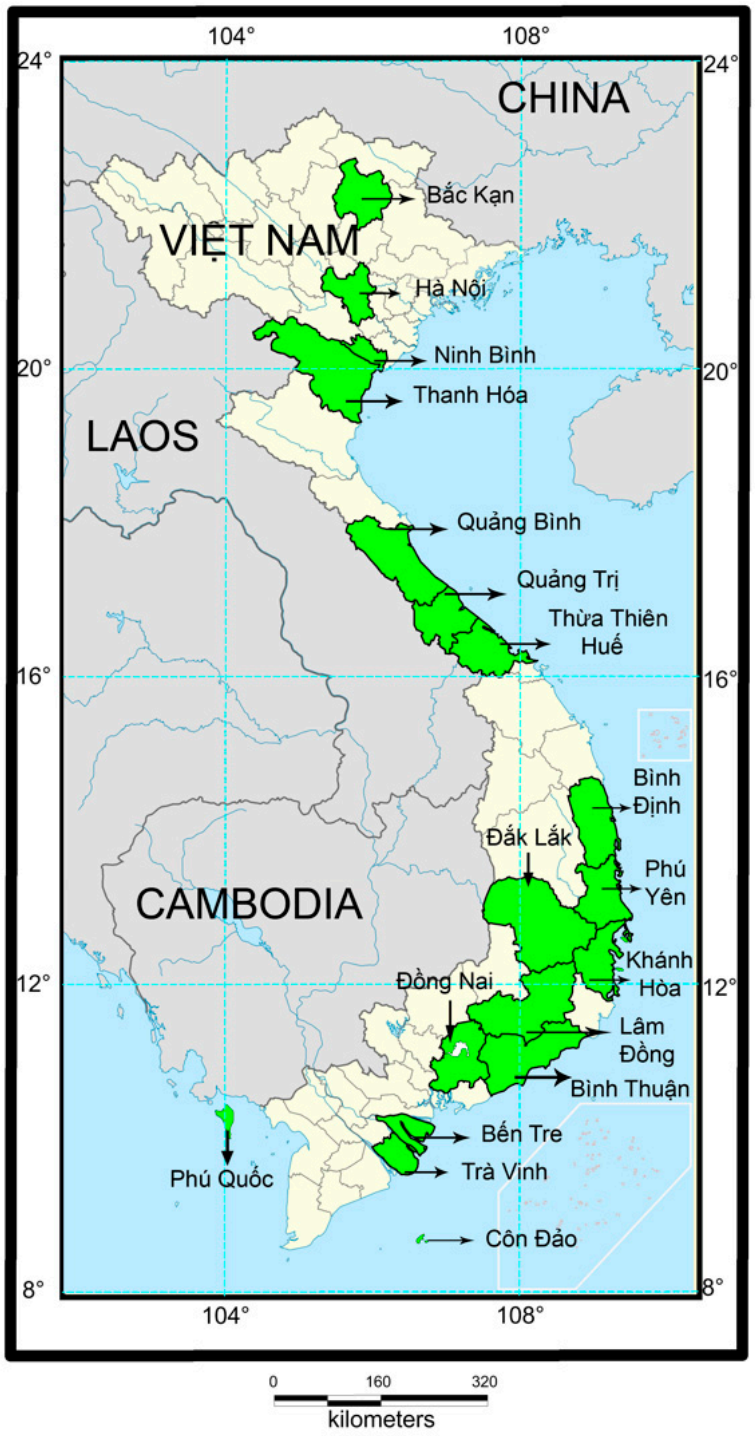


**Figure 1.** Geographical position of the studied area.

The samples were collected from 18 provinces located in the northern, central, and southern parts of the country. Below is a list of the provinces studied, the abbreviations used in the text (in bold), and the years of sampling:

Bắc Kạn Province—**BB**, 2019 [43];
Hà Nội administrative area—**BV**, 2019 [43];
Ninh Bình Province—**NB**, 2019 [43];
Thanh Hoá Province—**TH**, 2019 [43];
Quảng Bình Province—**QB**, 2016 [48];
Quảng Trị Province—**QT**, 2019 [48];
Thừa Thiên Huế Province**—TTH**, 2019 [48];
Bình Định Province—**BD**, 2018 [48];
Phú Yên Province—**PY**, 2018 [48];
Khánh Hòa Province—**KH**, 2008–2018 [44–46,48];
Đắk Lắk Province—**DL**, 2010, 2014 [48];
Lâm Đồng Province—**LD**, 2010, 2012, 2014, 2018 [47,48];
Đồng Nai Province—**DN**, 2010, 2012, 2014, 2015, 2018 [49,51];
Bình Thuận Province—**BT**, 2012–2014 [51];
Bến Tre and Trà Vinh provinces (Mekong Delta)—**M**, 2018 [50];
Kiên Giang Province, Phú Quốc Island—**PQ**, 2015 [52];
Bà Rịa—Vũng Tàu Province, Con Dao Archipelago, Côn Sơn Island—**CD**, 2015 [52].

Sampling occurred during expeditions of the Joint Vietnam–Russia Tropical Science and Technology Research Center ("Ecolan 3.2" project). Basic characteristics of the localities, climate parameters, and distribution of described species are represented in [43–52].

Samples were collected using a plankton net with 20 µm mesh. For electron microscopy studies, an aliquot of each sample was washed three times by repeated centrifugation with deionized water. Drops of each washed sample were dried directly onto stubs for Scanning Electron Microscopy (SEM) or grids for Transmission Electron Microscopy (TEM) or digested (4–5 min) in sulfuric acid with potassium dichromate before mounting. For SEM studies, samples were dried on aluminum stubs, coated with gold for 10 min with a JEE-4X (JEOL, Tokyo, Japan) sputter coater, and observed with a JEOL 6510 LV scanning electron microscope. For TEM studies, samples were dried onto formvar-coated grids (EMS FF200-Cu-50, Electron Microscopy Sciences, Hatfield, PA, USA) and observed with a JEM-1011 TE microscope. Specific conductance, pH, and temperature measurements were made with a Hanna HI 9828 device (Hanna Instruments, Inc., Smithfield, RI, USA).

## 3. Results

A total of 74 taxa from the order Synurales were identified at the 371 localities in Viet Nam.

***Mallomonas acaroides*** Perty emend. Iwanoff (Figure 2A).

This species was found in five localities in three provinces of Viet Nam: **LD**, **BB**, **NB**.

Parameters: pH 6.5–8.2 (7.4 ± 0.4), specific conductance 16–368 (174 ± 63) µS $cm^{-1}$, temperature 20–31 (24 ± 2) °C.

This is a widespread species and common component of phytoplankton in water bodies and rivers in temperate latitudes [1]. It is rare in the tropics where it was recorded previously in China [15,16] and the mountainous regions of Zimbabwe [28].

***M. adamas*** Harris & Bradley (Figure 2B).

This species was found in 14 localities in seven provinces: **PQ, DN**, **LD**, **KH**, **BD**, **PY**, **TTH**.

Parameters: pH 5.7–7.5 (6.5 ± 0.2), specific conductance 6–100 (50 ± 8) µS $cm^{-1}$, temperature 25–37 (32 ± 1) °C.

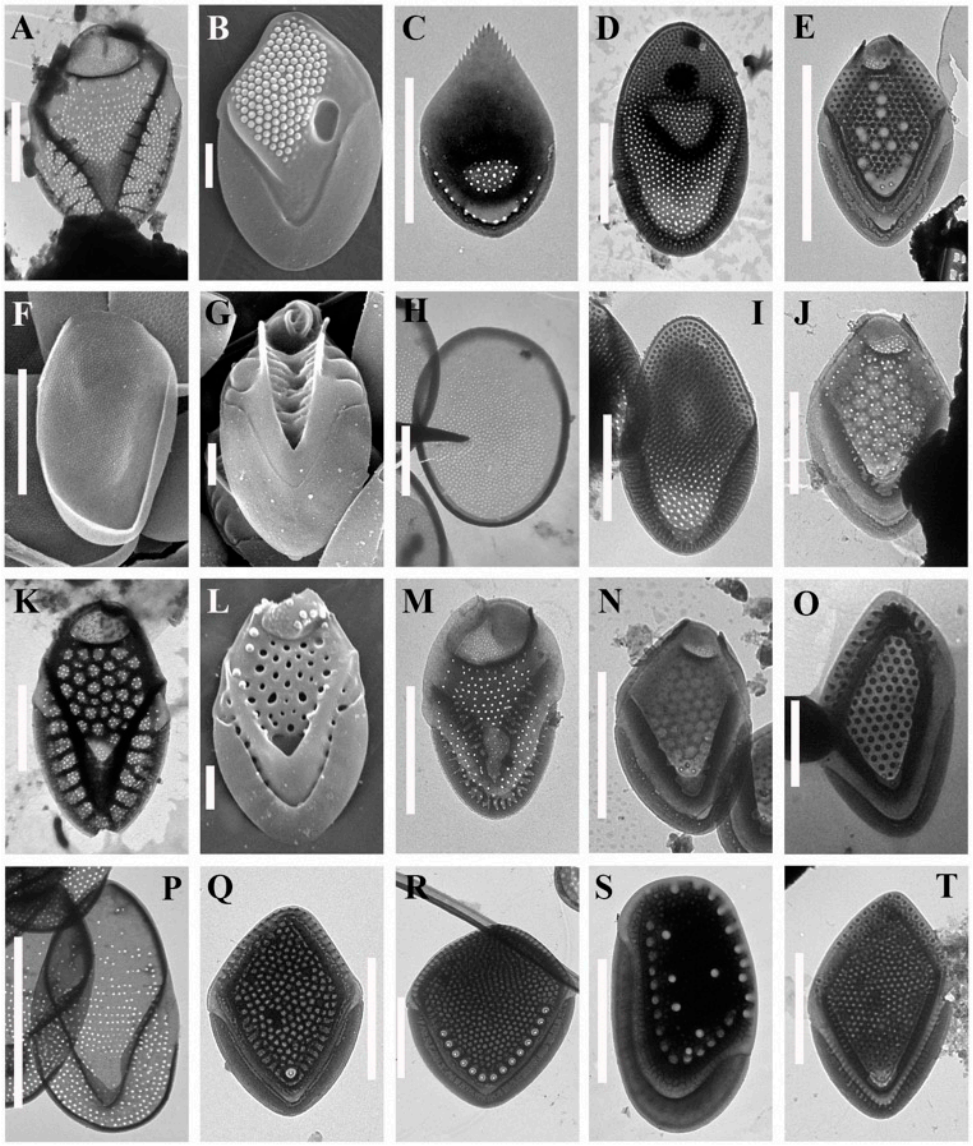


**Figure 2. Scales of *Mallomonas*** (**A**) *M. acaroides*. (**B**) *M. adamas*. (**C**) *M. akrokomos*. (**D**) *M. bangladeshica*. (**E**) *M. binocularis*. (**F**) *M. bronchartiana*. (**G**) *M. cattiensis*. (**H**) *M. caudata*. (**I**) *M. ceylanica*. (**J**) *M.collucata*. (**K**) *M. crassisquama*. (**L**) *M. crassisquama* var. *papillosa*. (**M**) *M.* cf. *cristata*. (**N**) *M. distinguenda*. (**O**) *M. elevata* [48]. (**P**) *M. elongata*. (**Q**) *M. favosa* f. *favosa*. (**R**) M. *favosa* f. *gemina*. (**S**) *M. fimbriata*. (**T**) *M. fragariformis*. Scale bars: (**F**,**P**): 5 µm; (**A**,**C**,**D**–**E**,**H**–**I**,**K**,**M**–**N**,**Q**–**T**): 2 µm; (**B**,**G**,**J**,**L**,**O**,**S**): 1 µm. TEM: (**A**,**C**,**D**–**E**,**H**–**K**,**M**–**T**); SEM: (**B**,**F**,**G**,**L**).

A rare species that occurs sporadically in different regions—in Australia and in a number of countries in Europe and Asia [1]. In the tropical region, it has been recorded in Malaysia [12].

***M. akrokomos*** Ruttner (Figure 2C).

This species was found in four localities in three provinces: **LD**, **PY**, **TTH**.

Parameters: pH 5.9–6.8 (6.5 ± 0.2), specific conductance 22–138 (85 ± 30) µS $cm^{-1}$, temperature 24–35 (31 ± 3) °C.

It is considered a cosmopolitan species [1]; however, unpublished molecular data indicate that this species represents a complex of cryptic taxa. The tropical strain we isolated forms a separate branch on the phylogenetic tree (unpublished). In the tropics, this morphotype was rarely noted in Brazil [28], Zimbabwe [28], China [15,16], India [17,18], and Ecuador [35].

***M. bangladeshica*** (Takahashi & Hayakawa) Siver & Wolfe (Figure 2D).

This species was found in seven localities in five provinces: **KH**, **DL**, **PY**, **BV**, **TTH**.

Parameters: pH 5.8–7.5 (6.6 ± 0.3), specific conductance 74–250 (137 ± 25) μS $cm^{-1}$, temperature 28–36 (31 ± 1) °C.

It is a rare, mostly tropical species [1]. This species is known from Bangladesh [11], Sri Lanka [14], tropical China [15,16], India [18], Indonesia [22], and Papua New Guinea [21]. Two localities are known in Europe, Romania [53] and Portugal [54].

***M. binocularis*** Siver (Figure 2E).

This species was found in four localities in three provinces: **DN**, **KH**, **TTH**.

Parameters: pH 4.8–6.9 (5.5 ± 0.6), specific conductance 10–96 (42 ± 22) μS $cm^{-1}$, temperature 24–34 (29 ± 3) °C.

This is a very rare species, previously considered endemic to North America. This taxon was described from a pond in Florida, USA [55]. Subsequently, it was also found in North Carolina and southern New Jersey, USA [56]. Identification of this species in Viet Nam indicates its wider distribution.

***M. bronchartiana*** Compère (Figure 2F).

This species was found in 38 localities in eight provinces: **CD**, **DN**, **KH**, **BT**, **DL**, **BD**, **PY**, **QT**.

Parameters: pH 4.8–8 (6.7 ± 0.1), specific conductance 26–382 (109 ± 14) μS $cm^{-1}$, temperature 25–36 (32 ± 0.1) °C.

A revision of published records related to *M. bronchartiana* [57] made it possible to confirm that the taxon was previously recorded in a number of African countries [27,28,58], the Amazon tropics [40], Jamaica [28], Malaysia [12], India [17], and Indonesia [22].

***M. cattiensis*** Gusev, Doan-Nhu & Nguyen-Ngoc (Figure 2G).

This species was described from Viet Nam [59] and was found in 13 localities in seven provinces: **DN**, **KH**, **BT**, **DL**, **BD**, **PY**, **TTH**.

Parameters: pH 4.8–7.6 (6.5 ± 0.2), specific conductance 22–592 (109 ± 45) μS $cm^{-1}$, temperature 25–36 (31 ± 1) °C.

This species was also recorded on the Java Island, Indonesia [22], and in Papua New Guinea, where it was identified as *M. morrisonensis* ([21], 1993, Figures 10 and 11, p. 115).

***M. caudata*** Iwanoff (Figure 2H).

This species was found in 48 localities in 13 provinces: **DN**, **LD**, **KH**, **BT**, **BB**, **QB**, **DL**, **BD**, **PY**, **BV**, **TH**, **QT**, **TTH**.

Parameters: pH 5.9–8.6 (7.1 ± 0.1), specific conductance 16–235 (74 ± 7) μS $cm^{-1}$, temperature 17–35 (28 ± 1) °C.

This species belongs to widespread taxa, especially in the temperate zone [1]. In the tropics, it has been recorded in Brazil [28,39], Panama [36], the tropics and subtropics of China [15,16], and India [17,18].

***M. ceylanica*** Dürrschmidt & Cronberg (Figure 2I).

This species was found in 15 localities in nine provinces: **CD**, **KH**, **BT**, **QB**, **DL**, **BD**, **NB**, **QT**, **TTH**.

Parameters: pH 5.5–7.8 (6.8 ± 0.2), specific conductance 33–666 (226 ± 58) μS $cm^{-1}$, temperature 17–37 (30 ± 2) °C.

This species was originally described from Sri Lanka [14]. Later, it was found only in a few tropical water bodies in China [16], India [17,18], and South Korea [9].

***M. collucata*** Gusev & Kulikovskiy (Figure 2J).

This species was described from Viet Nam [60] and was found in one locality in one province: **PQ**.

Parameters: pH 5.3, specific conductance 17 μS $cm^{-1}$, temperature 29 °C. This species is endemic to Viet Nam.

***M. crassisquama*** (Asmund) Fott (Figure 2K).

This species was found in 62 localities in 12 provinces: **DN**, **LD**, **KH**, **QN**, **QB**, **DL**, **BD**, **PY**, **BV**, **TH**, **QT**, **TTH**.

Parameters: pH 6.0–8.6 (7.1 ± 0.1), specific conductance 16–373 (76 ± 7) µS cm$^{-1}$, temperature 17–37 (29 ± 1) °C.

It is a widespread species, especially in temperate latitudes [1]. This species is less common in the tropics; it is known from Sri Lanka [14], Jamaica [28], Zimbabwe [28], Colombia [28,38], Guatemala [28], China [15,16], India [18], Nigeria [19,20], Brazil [40], and Ecuador [35].

***M. crassisquama*** var. ***papillosa*** Siver & Skogstad (Figure 2L).

This species was found in four localities in two provinces: **LD** and **QB**.

Parameters: pH 6.5–7.1 (6.8 ± 0.2), specific conductance 16–110 (55 ± 24) µS cm$^{-1}$, temperature 18–24 (22 ± 2) °C.

This is a rare taxon. It was believed that the distribution of this taxon was limited to the northern regions of temperate latitudes [1,61]. Our findings refute this assumption. However, it should be noted that this variety has a dubious status. It differs from the type variety *M. crassisquama* only in the presence of large and conspicuous papillae on the scale surface [1,62]. However, some studies have shown that the presence, size, and number of papillae on the surface of the scales of the *M. crassisquama* morphotype are rather variable features, to the extent that scales covered with papillae or without papillae can be present on the same cell [63]. However, since revisions and more detailed comparative studies of *M. crassisquama* var. *crassisquama* and *M. crassisquama* var. *papillosa* have not been made, we consider *M. crassisquama* var. *papillosa* in this work as an independent taxon.

***M.* cf. *cristata*** Dürrschmidt (Figure 2M).

This taxon was found in 11 localities in seven provinces: **PQ**, **DN**, **BT**, **QB**, **DL**, **PY**, **TTH**.

Parameters: pH 5–7.3 (6.1 ± 0.3), specific conductance 13–63 (36 ± 5) µS cm$^{-1}$, temperature 18–34 (30 ± 2) °C.

*Mallomonas cristata* was described from Chile [64]. It was later found in many habitats throughout the world [1]. In the tropical region, the species is known from Madagascar [25], Brazil [41,42], and Ecuador [35]. Specimens from Viet Nam differ mainly by serrated bristles, while only 1–2 small teeth on the distal portion of bristles were originally described for *M. cristata*. The structure of the bristles is one of the characteristics for distinguishing species of the genus *Mallomonas*, in particular, in the sections *Mallomonas* and *Striatae* [65–67]. With a high degree of probability, this is a new species for science, but additional studies of the scales and bristle morphology and molecular data are needed to describe it.

***M. distinguenda*** Gusev, Doan-Nhu, Nguyen-Ngoc & Kapustin (Figure 2N).

This species was described from Viet Nam [68] and was found in nine localities in four provinces: **PQ**, **DN**, **BT**, **TTH**.

Parameters: pH 4.6–6.9 (5.7 ± 0.4), specific conductance 10–311 (58 ± 34) µS cm$^{-1}$, temperature 24–34 (30 ± 1) °C.

This species is endemic to Viet Nam.

***M. elevata*** Han Soon Kim (Figure 2O).

This species was found in nine localities in five provinces: **LD**, **KH**, **BD**, **PY**, **TTH**.

Parameters: pH 4.7–7.4 (5.8 ± 0.3), specific conductance 6–248 (61 ± 26) µS cm$^{-1}$, temperature 23–35 (31 ± 1) °C.

The species was recently described from the subtropics of South Korea [69]. We found this species for the first time outside the type habitat.

***M. elongata*** Reverdin (Figure 2P).

This species was found in three localities in two provinces: **QB**, **PY**.

Parameters: pH 7.0–7.4 (7.2 ± 0.1), specific conductance 117–118 (118 ± 1) µS cm$^{-1}$, temperature 18–36 (26 ± 11) °C.

*Mallomonas elongata* is considered as a widespread species in temperate latitudes [1]. In the tropical region, the species was found in Brazil [28,40], the highlands of Colombia [28], the mountainous regions of Guatemala, the tropical and subtropical regions of China [15], and India [18]. *Mallomonas elongata* is characterized by the acute or rounded V-rib, which is hooded and continuous with the short anterior submarginal rib; scales and V-rib outlines

are often asymmetrical [65,70]. Previous records of *M. elongata* from Asia [12,15,16] and all the above-mentioned records in the tropics correspond to a different morphotype, which is probably a new species not yet described (see *Mallomonas* sp. 1 in [43,49]).

***M. favosa*** f. ***favosa*** K.H. Nicholls (Figure 2Q).

This species was found in 34 localities in 10 provinces: **PQ**, **CD**, **DN**, **LD**, **KH**, **BT**, **DL**, **BD**, **PY**, **TTH**.

Parameters: pH 4.6–7.8 (6.1 ± 0.2), specific conductance 3–380 (69 ± 14) µS cm$^{-1}$, temperature 24–38 (32 ± 1) °C.

*Mallomonas favosa* f. *favosa* is considered a cosmopolitan species [71]. It was described in Canada [72] and was later reported from other parts of the world [1]. In the tropical region, *Mallomonas favosa* f. *favosa* was found in Malaysia [12], China [16], Papua New Guinea [21], and Brazil [41,42].

***M. favosa*** f. ***gemina*** Dürrschmidt & Croome (Figure 2R).

This species was found in 53 localities in 11 provinces: **PQ**, **CD**, **DN**, **KH**, **BT**, **DL**, **BD**, **PY**, **NB**, **QT**, **TTH**.

Parameters: pH 4.6–8.0 (6.4 ± 0.1), specific conductance 10–923 (154 ± 29) µS cm$^{-1}$, temperature 24–39 (32 ± 0.1) °C.

*Mallomonas favosa* f. *gemina* was described in Malaysia [12] and was later found in Indonesia [21], South Korea [73], and Madagascar [25].

***M. fimbriata*** Gusev (Figure 2S).

This species was described from Viet Nam [74] and was found in four localities in three provinces: **PQ**, **KH**, **BT**.

Parameters: pH 4.6–7.1 (5.2 ± 0.5), specific conductance 25–112 (66 ± 18) µS cm$^{-1}$, temperature 24–31 (28 ± 1) °C.

Scales of *Mallomonas fimbriata* were also reported from one locality in Malaysia as *Mallomonas* sp. 3 ([12], Figure 49, p. 294).

***M. fragariformis*** Gusev, Kapustin, Shkurina, Martynenko (Figure 2T).

This species was described from Viet Nam [75] and was found in eight localities in six provinces: **PQ**, **CD**, **BT**, **TTH**, **PY**, **QT**.

Parameters: pH 6.0–8.7 (6.6 ± 0.5), specific conductance 37–329 (163 ± 61) µS cm$^{-1}$, temperature 30–36 (32 ± 2) °C.

Scales of *Mallomonas fragariformis* were also reported from Indonesia [22].

***M. furtiva*** Gusev, Čertnerová, Škaloudová, Škaloud (Figure 3A).

This species was described from Viet Nam [76] and was found in 24 localities in nine provinces: **PQ**, **CD**, **DN**, **LD**, **KH**, **BT**, **BD**, **PY**, **TTH**.

Parameters: pH 5.2–7.9 (6.3 ± 0.1), specific conductance 10–3000 (275 ± 138) µS cm$^{-1}$, temperature 20–38 (30 ± 1) °C.

Outside Viet Nam, it was found in the Indonesian part of New Guinea [23] and Malaysia ([12] as *M.* cf. *rasilis*, Figure 41, p. 292).

***M. grata*** E.Takahashi (Figure 3B).

This species was found in 11 localities in nine provinces: **DN**, **LD**, **KH**, **DL**, **BD**, **BV**, **NB**, **TH**, **QT**.

Parameters: pH 5.8–7.6 (7.1 ± 0.2), specific conductance 21–468 (151 ± 56) µS cm$^{-1}$, temperature 23–36 (30 ± 1) °C.

*Mallomonas grata* was described from a pond in Japan [77]. It has rare finds in India [17,18], South Korea ([78] as *Mallomonas* sp. 2, Figure 49, p. 429), China [15,16], Singapore, and Malaysia [13]. It is noted that it is a rare species and is endemic to Southeast and East Asia [13].

***M. gusakovii*** Gusev, Kapustin, Martynenko, Guseva & Kulikovskiy (Figure 3C).

This species was described from Viet Nam [79] and was found in two localities in one province: **PQ**.

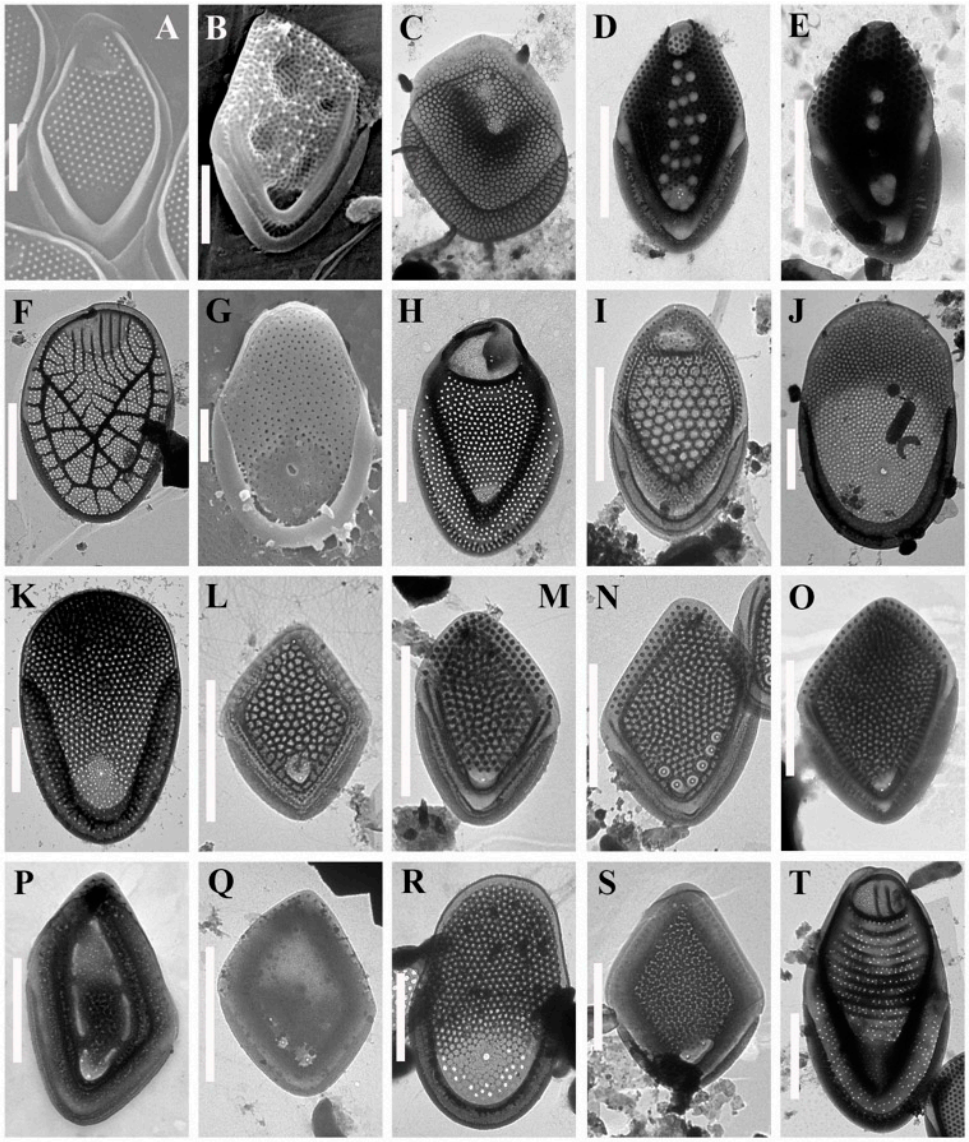


**Figure 3. Scales of *Mallomonas*.** (**A**) *M. furtiva*. (**B**) *M. grata*. (**C**) *M. gusakovii*. (**D**) *M. guttata* var. *guttata*. (**E**) *M. guttata* var. *simplex*. (**F**) *M. harrisiae*. (**G**) *M. hexareticulata*. (**H**) *M. kenyana*. (**I**) *M. korshikovii*. (**J**) *M. lamii*. (**K**) *M. loricata*. (**L**) *M. lusca*. (**M**) *M. mangofera* var. *mangofera*. (**N**) *M. mangofera* var. *foveata*. (**O**) *M.* cf. *mangofera* var. *reticulata*. (**P**) *M. mangofera* var. *sulcata*. (**Q**) *M.* cf. *mangofera* var. *gracilis*. (**R**) *M. matvienkoae* var. *siveri*. (**S**) *M. minuscula*. (**T**) *M. morrisonensis*. Scale bars: (**C**–**F**,**H**–**O**,**R**,**T**): 2 μm; (**A**,**B**,**G**,**P**,**Q**,**S**): 1 μm. TEM: (**A**,**C**–**F**,**H**–**T**); SEM: (**B**,**G**).

Parameters: pH 4.7–5.1, specific conductance 25–1200 μS cm–1, temperature 29–31 °C. This species is endemic to Viet Nam.

***M. guttata*** var. ***guttata*** Wujek (Figure 3D).

This species was found in 68 localities in 12 provinces: **PQ**, **CD**, **DN**, **LD**, **KH**, **BT**, **QB**, **DL**, **BD**, **PY**, **QT**, **TTH**.

Parameters: pH 4.1–8.6 (6.5 ± 0.1), specific conductance 10–3000 (216 ± 69) μS cm–1, temperature 18–39 (32 ± 0.4) °C.

It is considered a widespread taxon [1]. In the tropical region, it was recorded in most of the studied countries: Bangladesh [11], Indonesia ([24], as *M. perforata* Cronberg & Hickel, Figures 5–11, p. 108), Malaysia [12], Sri Lanka [14], Costa Rica [34], Jamaica [28], Zimbabwe [28], China [15,16], Papua New Guinea [21], India [17,18], Madagascar [25], Nigeria [19,20], Brazil [41,42], Colombia [38], and Ecuador [35].

***M. guttata*** var. ***simplex*** Nicholls (Figure 3E).

This species was found in 43 localities in 10 provinces: **PQ**, **DN**, **LD**, **KH**, **BT**, **DL**, **BD**, **PY**, **QT**, **TTH**.

Parameters: pH 4.9–8.5 (6.6 ± 0.1), specific conductance 9–3000 (120 ± 73) µS cm$^{-1}$, temperature 24–38 (30 ± 0.5) °C.

It is considered a rare species, described from Canada [80] and known from China [16,81]. *M. guttata* var. *simplex* is a dubious taxon, different from the *M. guttata* var. *guttata* in that the depressions on the central field are few and arranged in one row. In our samples, both varieties were often found together. Moreover, cells were found with scales containing both several rows and single rows of depressions [49]. A more detailed study and revision of these two taxa are needed.

***M. harrisiae*** E.Takahashi (Figure 3F).

This species was found in five localities in two provinces: **PQ** and **TTH**.

Parameters: pH 4.7–6.9 (5.8 ± 0.5), specific conductance 6–37 (28 ± 6) µS cm$^{-1}$, temperature 30–35 (32 ± 1) °C.

*Mallomonas harrisiae* is a very rare taxon that was first described from Japan [82] and was recently found in China [83]. Viet Nam is the third country where this species has been found.

***M. hexareticulata*** Jo, Shin, Kim, Siver & Andersen (Figure 3G).

This species was found in 20 localities in nine provinces: **PQ**, **KH**, **BT**, **QB**, **DL**, **BD**, **BV**, **TH**, **TTH**.

Parameters: pH 5.3–8.2 (6.9 ± 0.2), specific conductance 13–329 (116 ± 19) µS cm$^{-1}$, temperature 18–34 (30 ± 1) °C.

This species was recently described from the water bodies of South Korea [7]. We confirmed the findings of this species in Viet Nam both on the basis of both morphological and molecular approaches (unpublished).

***M. kenyana*** (Wujek & Asmund) Kapustin & Gusev (Figure 3H).

This species was found in 95 localities in 14 provinces: **DN**, **LD**, **KH**, **BT**, **BB**, **QB**, **DL**, **BD**, **PY**, **BV**, **NB**, **TH**, **QT**, **TTH**.

Parameters: pH 5.9–9.2 (7.4 ± 0.1), specific conductance 18–955 (181 ± 18) µS cm$^{-1}$, temperature 17–64 (30 ± 1) °C.

This taxon was first described as *Mallomonas cyathelata* Wujek & Asmund var. *kenyana* Wujek & Asmund [26]. It is a predominantly tropical species known from Kenya [26], Zimbabwe [28], Guatemala [28], China [15], Papua New Guinea [21], Indonesia [22], India [17,18], Madagascar [25], Nigeria [19,20], Colombia [38], Brazil [84], and the subtropics of the USA [85].

***M. korshikovii*** Gusev (Figure 3I).

This species was described from Viet Nam [45] and was found in 10 localities in seven provinces: **PQ**, **CD**, **KH**, **BT**, **BD**, **PY**, **TH**.

Parameters: pH 5.0–7.2 (6.5 ± 0.2), specific conductance 55–3000 (736 ± 377) µS cm$^{-1}$, temperature 30–36 (33 ± 1) °C.

This species is endemic to Viet Nam.

***M. lamii*** Gusev, Kulizin, Guseva, Shkurina & Kulikovskiy (Figure 3J).

This species was described from Viet Nam [86] and was found in 35 localities in 11 provinces: **CD**, **DN**, **KH**, **BT**, **DL**, **BD**, **PY**, **M**, **TH**, **QT**, **TTH**.

Parameters: pH 5.8–8.1 (6.8 ± 0.1), specific conductance 15–2370 (247 ± 83) µS cm$^{-1}$, temperature 28–39 (31 ± 0.4) °C.

Despite the fact that this species has large and conspicuous scales that are easy to detect when processing samples, it has not yet been found outside of Viet Nam. Thus, this taxon can be considered as an endemic species for this territory. However, given the fact that the species occurs quite often, it can be assumed that it should be found in neighboring regions as well.

***M. loricata*** Gusev, Shkurina & Kulikovskiy (Figure 3K).

This species was described from Viet Nam [87] and was found in 25 localities in eight provinces: **KH**, **BT**, **DL**, **BD**, **PY**, **BV**, **QT**, **TTH**.

Parameters: pH 6.0–8.3 (6.9 ± 0.1), specific conductance 32–247 (99 ± 11) μS cm$^{-1}$, temperature 27–37 (33 ± 1) °C.

*Mallomonas loricata* was also recorded in Singapore and Malaysia under the epithet *M. matvienkoae* ([13], 2007, Figure 7, p. 225). It can be assumed that this taxon has a wide distribution in the tropical region. By now, it can be considered endemic to Southeast Asia.

***M. lusca*** Gusev & Kezlya (Figure 3L).

This species was described from Viet Nam [88] and was found in six localities in three provinces: **DN**, **KH**, **BT**.

Parameters: pH 5.9–7.1 (6.6 ± 0.2), specific conductance 23–311 (95 ± 50) μS cm$^{-1}$, temperature 29–34 (31 ± 1) °C.

Scales of *Mallomonas lusca* were also reported from one locality in Malaysia [12]. This species is endemic to Southeast Asia.

***M. mangofera*** Harris & Bradley var. ***mangofera*** apud Dürrschmidt [89] (Figure 3M).

This species was found in 25 localities in 10 provinces: **CD**, **DN**, **LD**, **KH**, **QN**, **DL**, **BD**, **BV**, **NB**, **TH**.

Parameters: pH 4.8–9.0 (7.0 ± 0.2), specific conductance 10–955 (275 ± 49) μS cm$^{-1}$, temperature 20–36 (31 ± 1) °C.

Scales, observed in Viet Nam, are quite similar to ones described from Chile under the name *M. mangofera* var. *mangofera* ([89], Figures 6–10, p. 181 and Figures 11–16, p. 183). Scale specimens of *M. mangofera* var. *mangofera* from the type locality in Great Britain [90], as well as the other scales from Europe (for example, [91], Figure J, p. 730; [92]), differ in the presence of the base plate pores on the posterior flange, a large window without secondary layer at the base of the V-rib, and in the peculiarities of papillae ornamentation of the shield. Further investigations are necessary for an understanding of the relationship between these two morphotypes of *Mallomonas mangofera*. Our unpublished data indicate that these are different species. However, until a revision of this group is made, we present this taxon as *M. mangofera* var. *mangofera* apud Dürrschmidt [89].

In the tropical region, this morphotype has been found in Bangladesh [11], Malaysia [12], Jamaica [28], China [15,16], Papua New Guinea [21], India [18], Madagascar [25], Brazil [41,42,85], Colombia [38], Ecuador [35], and Indonesia [23].

***M. mangofera*** var. ***foveata*** (Dürrschmidt) Kristiansen (Figure 3N).

This species was found in 35 localities in 13 provinces: **PQ**, **CD**, **DN**, **LD**, **KH**, **BT**, **BB**, **DL**, **BD**, **PY**, **TH**, **QT**, **TTH**.

Parameters: pH 4.7–8.0 (6.6 ± 0.2), specific conductance 10–740 (218 ± 44) μS cm$^{-1}$, temperature 22–39 (32 ± 1) °C.

The taxon is considered cosmopolitan [71]. Not all morphotypes in our studies had an internal reticulation formed by a secondary silica layer on the surface of the scales, while the type specimens from Chile had such a reticulation [89]. However, our studies of cultures have shown that, within the same monoclonal culture, secondary reticulation may or may not be present on scales. The taxon was found in the tropical region in Malaysia [12], Sri Lanka [14], Jamaica [28], Zimbabwe [28], Colombia [28,38], China [15,16], India [18], Madagascar [25], Brazil [41,42], Ecuador [35], and Indonesia [23].

***M.*** cf. ***mangofera*** var. ***reticulata*** (Cronberg) Kristiansen (Figure 3O).

This species was found in 26 localities in 10 provinces: **PQ**, **CD**, **DN**, **KH**, **BB**, **DL**, **BD**, **PY**, **QT**, **TTH**.

Parameters: pH 4.6–7.9 (6.2 ± 0.2), specific conductance 10–666 (147 ± 38) μS cm$^{-1}$, temperature 22–39 (31 ± 1) °C.

*Mallomonas* cf. *mangofera* var. *reticulata* is an incompletely described taxon that requires additional revision, but it can be argued with certainty that it should have species status. This taxon belongs to the group of taxa *Mallomonas mangofera* from the section Torquatae series Mangoferae, which includes many morphospecies. Several characteristics that were used for distinguishing taxa in this group have unclear taxonomic significance. In

particular, this applies to the presence or absence of reticulation and its form (triangular, polygonal, and circular). Scales of *Mallomonas mangofera* f. *reticulata*, according to the original description and holotype given by Cronberg based on material from Zimbabwe [28], have a network of triangular meshes. Scales from Viet Nam have rounded or polygonal meshes. The morphotype found in Viet Nam and the African morphotype also differ in the shape of the scales, and most likely they should be considered different species based on morphological differences. However, we present our taxon as *M.* cf. *mangofera* var. *reticulata* because the significance of such a feature as the shape of the internal reticulation is not yet clear, and further revision of this group is required. Scales identified as *Mallomonas mangofera* var. *reticulata* with polygonal or rounded meshes were recorded in China ([16], Figures 56 and 57, p. 892 and [93], Figure 47, p. 35). *Mallomonas mangofera* f. *reticulata* with a similar structure was recorded in Malaysia ([13], Figure 5, p. 253). Moreover, this morphotype was identified as *Mallomonas mangofera* var. *mangofera* in Cronberg ([28], Figure 44, p. 214), Kristiansen ([94], Figure 46), Wei & Kristiansen ([95], Figure 52), and Hansen ([25], Figure 35, p. 161). Nemcova et al. ([96], Figures 29 and 30, p. 17) presented both morphotypes from French water bodies, with triangular ([96], Figure 30, p. 17) and polygonal ([96], Figure 29, p. 17) reticulation, under the name *Mallomonas mangofera* var. *reticulata*. To date, this morphotype, in addition to the regions mentioned above, is also known from Jamaica [28], India [18], and Indonesia [23].

***M. mangofera*** var. ***sulcata*** Dürrschmidt (Figure 3P).

This species was found in six localities in five provinces: **QN**, **BD**, **PY**, **QT**, **TTH**.

Parameters: pH 5.0–7.3 (6.4 ± 0.3), specific conductance 28–119 (60 ± 16) µS cm$^{-1}$, temperature 30–37 (33 ± 1) °C.

*Mallomonas mangofera* var. *sulcata* is a very rare and not fully described variety from the *M. mangofera* complex. It was described in a Chilean water body [89]. Subsequently, it was also found in one locality in Singapore [13]. *Mallomonas mangofera* var. *sulcata* differs from other taxa of the *M. mangofera* complex by the presence of grooves (narrow long depressions) along the submarginal ribs. Although only two long depressions are indicated in the diagnosis of the species, in the accompanying illustrations, there are more of them on some scales, and they can have different shapes ([89], p. 189, Figure 37). In Singapore and Viet Nam, similar morphotypes have been found with numerous depressions, narrower than those illustrated for organisms from the type habitat. Perhaps these are scales of a different taxon than the one described from Chile. Further investigations are needed to clarify the taxonomic status of this organism and taxonomic significance of such characters as the number and shape of the depressions on the shield.

***M.*** cf. ***mangofera*** var. ***gracilis*** (Dürrschmidt) Kristiansen (Figure 3Q).

This species was found in five localities in three provinces: **BB**, **NB**, **TTH**.

Parameters: pH 5–7.9 (6.4 ± 0.6), specific conductance 28–480 (149 ± 97) µS cm$^{-1}$, temperature 22–34 (30 ± 2) °C.

*M. mangofera* var. *gracilis* is a very rare and not fully described variety from the *M. mangofera* complex. It was described from Chile [89]; subsequently, single finds were noted in Denmark [97], Finland [98], Malaysia [12], and China [16]. The diagnostic characters of this variety are rather dubious. This variety differs from the type variety of *M. mangofera* by the shield with a weakly developed pattern of papillae, which are fused together to some extent, and with a pit-like depression with a pore at the base of the posterior submarginal rib. These characteristics can also be represented by weakly silicified scales of other species of this complex. It is also unclear whether scales identified as *Mallomonas mangofera* var. *gracilis* from such distant areas represent one species. Since the ultrastructure of the scales found in Viet Nam corresponds to the description of *Mallomonas mangofera* var. *gracilis*, we present this taxon in this list. However, further studies of this morphotype are required.

***M. matvienkoae*** B. Asmund & Kristiansen var. ***siveri*** Wujek & L.C. Saha (Figure 3R).

This species was found in 3 localities in 2 provinces: **DN**, **NB**.

Parameters: pH 5.2–7.8 (6.8 ± 1), specific conductance 10–480 (290 ± 175) µS cm$^{-1}$, temperature 24–34 (29 ± 4) °C.

*Mallomonas matvienkoae* var. *siveri* is a very rare taxon, described in India [18]. Findings in Viet Nam are the first outside the type habitat. Our unpublished molecular data indicate that the rank of this taxon should be raised to the species level.

***M. minuscula*** Gusev, Guseva, Kezlya & Kulikovskiy (Figure 3S).

This species was described from Viet Nam [99] and was found in 14 localities in eight provinces: **PQ**, **CD**, **LD**, **KH**, **BB**, **BD**, **PY**, **TTH**.

Parameters: pH 4.7–7.9 (6 ± 0.2), specific conductance 16–242 (94 ± 21) µS cm$^{-1}$, temperature 22–37 (32 ± 1) °C.

Based on these data, we expect a wider distribution of this species in Southeast Asia, but so far it is endemic to Viet Nam.

***M. morrisonensis*** Croome & P.A.Tyler (Figure 3T).

This species was found in 56 localities in 13 provinces: **PQ**, **DN**, **LD**, **KH**, **BT**, **DL**, **BD**, **PY**, **BV**, **NB**, **TH**, **QT**, **TTH**.

Parameters: pH 4.1–8.0 (6.3 ± 0.1), specific conductance 10–539 (104 ± 14) µS cm$^{-1}$, temperature 22–38 (31 ± 0.1) °C.

This species is distributed in tropical and subtropical regions [1]. The taxon was described from water bodies of Australia [100]. In the tropical region, it was recorded in Malaysia [12], China [15], India [17,18], Madagascar [25], and Brazil [42].

***M. multisetigera*** Dürrschmidt (Figure 4A).

It was found in 12 localities in seven provinces: **PQ**, **CD**, **KH**, **BT**, **BD**, **M**, **TTH**.

Parameters: pH 4.7–7.2 (6.4 ± 0.2), specific conductance 25–2370 (409 ± 218) µS cm$^{-1}$, temperature 29–39 (33 ± 1) °C.

This species is considered a cosmopolitan taxon [1]. In the tropical region, it is known from Jamaica [28], China [16], Madagascar [25], Nigeria [19,20], Brazil [42,101], Indonesia [23], and Ecuador [35].

***M. neoampla*** Gusev & Siver (Figure 4B).

This species was described from Viet Nam [102] and was found in 11 localities in three provinces: **KH**, **TH**, **TTH**.

Parameters: pH 5.3–7.4 (6.2 ± 0.2), specific conductance 28–263 (93 ± 21) µS cm$^{-1}$, temperature 30–35 (32 ± 1) °C.

It is a rare species also found in Malaysia [13]. This species is endemic to Southeast Asia.

***M. ocellata*** Dürrschmidt & Croome (Figure 4C).

This species was found in 14 localities in eight provinces: **LD**, **KH**, **BT**, **QB**, **DL**, **BD**, **PY**, **TTH**.

Parameters: pH 5.5–7.3 (6.5 ± 0.2), specific conductance 23–148 (62 ± 12) µS cm$^{-1}$, temperature 17–36 (29 ± 2) °C.

This is a rare species [1,13]. It is known from Malaysia, from where it was described in 1985 [12], Singapore [13], China [16], and Japan [103,104].

***M.*** cf. ***ouradion*** Harris & Bradley (Figure 4D).

This species was found in five localities in four provinces: **PQ**, **DN**, **PY**, **TTH**.

Parameters: pH 4.7–6.6 (5.5 ± 0.4), specific conductance 10–55 (36 ± 10) µS cm$^{-1}$, temperature 24–30 (28 ± 1) °C.

It is a fairly rare species with a scattered distribution [1]. It was originally described in Great Britain [105]. However, our findings in Viet Nam differ from the scales recorded in the temperate zone. In contrast to the original description of *M. ouradion*, the Vietnamese scales are smaller and have a different outline, a wide posterior border, a V-rib shifted to the center of the scales, and a poorly developed anterior submarginal rib and well-developed anterior flanges. Apparently, this morphotype is distributed in the tropical region and is a species new to science; however, there are insufficient data to describe it, so we mention it here as *M.* cf. *ouradion*.

***M. papillosa*** Harris & Bradley (Figure 4E).

This species was found in four localities in three provinces: **CD**, **DN**, **TTH**.

Parameters: pH 5.3–7.0 (6.4 ± 0.7), specific conductance 28–65 (43 ± 14) µS cm$^{-1}$, temperature 33–36 (34 ± 1) °C.

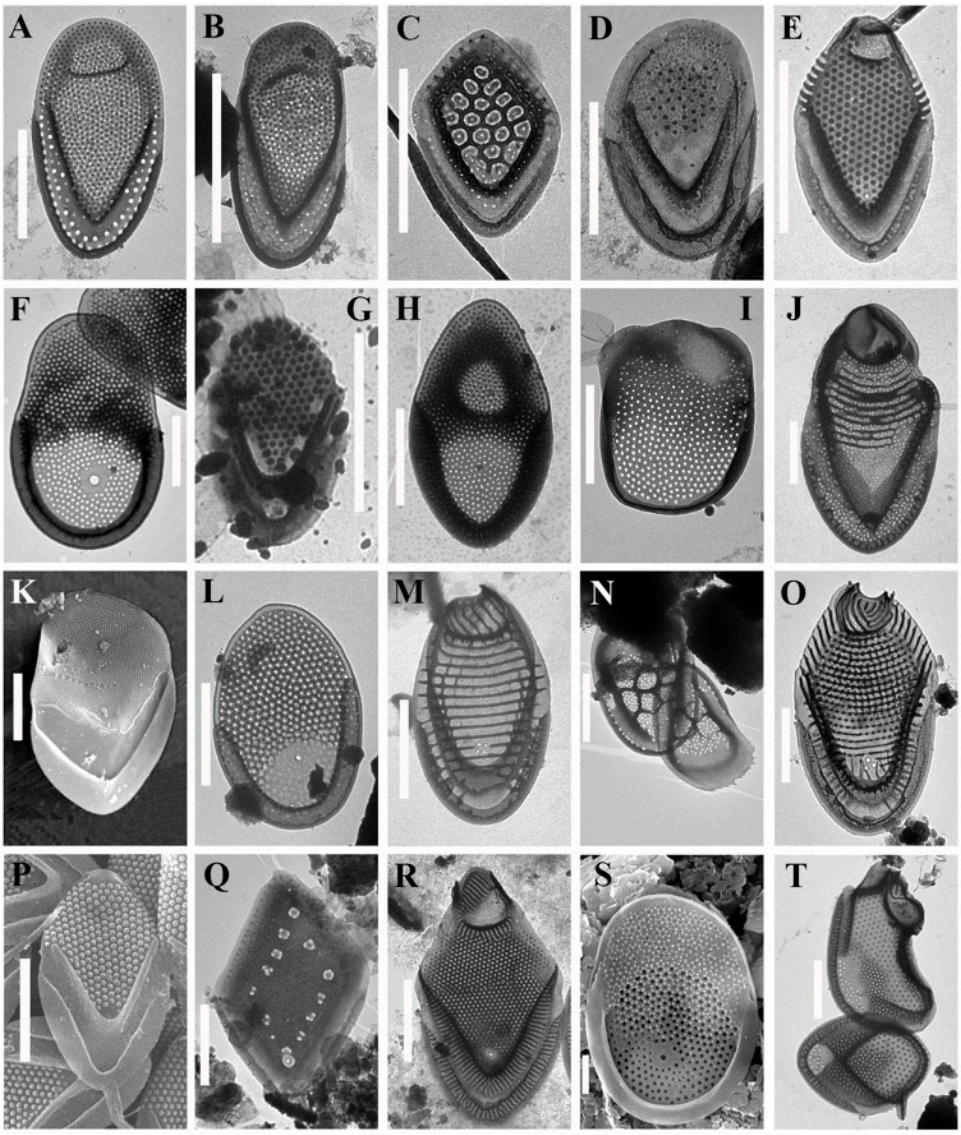


**Figure 4. Scales of *Mallomonas*.** (**A**) *M. multisetigera*. (**B**) *M. neoampla*. (**C**) *M. ocellata*. (**D**) *M.* cf. *ouradion*. (**E**) *M. papillosa*. (**F**) *M. paragrandis*. (**G**) *M. parvula* [43]. (**H**) *M. peronoides*. (**I**) *M. plumosa*. (**J**) *M. portae-ferreae*. (**K**) *M. pseudobronchartiana*. (**L**) *M. pseudomatvienkoae*. (**M**) *M. pseudocratis*. (**N**) *M. punctifera*. (**O**) *M. punctostriata*. (**P**) *M. rasilis*. (**Q**) *M. siderea*. (**R**) *M. skvortsovii*. (**S**) *M. sorohexareticulata*. (**T**) *M. spinosa*. Scale bars: (**B**): 5 µm; (**K**): 3 µm; (**A**,**C**–**J**,**L**–**N**,**P**,**R**–**T**): 2 µm; (**O**,**Q**,**S**): 1 µm. TEM: (**A**–**J**,**L**–**O**,**Q**,**R**,**T**); SEM: (**K**,**P**,**S**).

This species is considered cosmopolitan and is often found in the temperate zone [1]. However, in the tropical region, it is quite rare. Single finds are known from Malaysia [12], the highlands of Colombia [28], China [15,16], Papua New Guinea [21], India [18], Madagascar [25], Brazil [42], Indonesia [23], and Ecuador [35].

***M. paragrandis*** Gusev (Figure 4F).

This species was described from Viet Nam [106] and was found in 95 localities in 13 provinces: **PQ**, **CD**, **DN**, **KH**, **BT**, **DL**, **BD**, **PY**, **M**, **NB**, **TH**, **QT**, **TTH**.

Parameters: pH 4.8–8.5 (6.8 ± 0.1), specific conductance 10–3000 (199 ± 54) µS cm$^{-1}$, temperature 25–39 (32 ± 0.1) °C.

It is one of the most common species of the genus in Viet Nam. It has also been found in Indonesia [22] and Madagascar ([25] as *M. matvienkoae* f. *matvienkoae*, Figure 15, p. 154).

***M. parvula*** Dürrschmidt (Figure 4G).

This species was found in one locality in one province: **NB**.

Parameters: pH 7.4, specific conductance 480 µS cm$^{-1}$, temperature 34 °C.

It belongs to common species of temperate latitudes [1]. It is rare in the tropical region, recorded in China [15], Nigeria [19,20], and Ecuador [35].

***M. peronoides*** (K.Harris) Momeu & L.S.Péterfi (Figure 4H).

This species was found in 50 localities in 14 provinces: **CD**, **DN**, **KH**, **BT**, **BB**, **DL**, **BD**, **PY**, **M**, **BV**, **NB**, **TH**, **QT**, **TTH**.

Parameters: pH 5.7–8.6 (7.2 ± 0.1), specific conductance 10–2370 (318 ± 56) µS cm$^{-1}$, temperature 22–39 (32 ± 0.1) °C.

It is considered a widespread species, but it is more common in tropical areas [1], where it is known from Sri Lanka [14], Zimbabwe [28], China [15,16], India [17,18], Madagascar [25], Nigeria [19,20], Brazil [40–42], and Indonesia [22].

***M. plumosa*** Croome & P.A. Tyler (Figure 4I).

This species was found in 31 localities in nine provinces: **CD**, **DN**, **LD**, **KH**, **BT**, **DL**, **PY**, **QT**, **TTH**.

Parameters: pH 4.8–8.6 (6.4 ± 0.2), specific conductance 10–293 (88 ± 14) µS cm$^{-1}$, temperature 24–36 (30 ± 1) °C.

*Mallomonas plumosa* is a rare species described from Australia, in Tasmania [99]. The species was also found in New Zealand and South and Southeast Asia [1]. It is known from the tropical region in China [16], India [17,18], and Indonesia [22].

***M. portae-ferreae*** Péterfi & Asmund (Figure 4J).

This species was found in 11 localities in eight provinces: **KH**, **BT**, **DL**, **BD**, **M**, **BV**, **NB**, **TH**.

Parameters: pH 6.8–9.2 (7.5 ± 0.2), specific conductance 65–2370 (433 ± 206) µS cm$^{-1}$, temperature 28–34 (31 ± 1) °C.

The species is considered a cosmopolitan taxon, but it is distributed mainly in regions with a warm climate [1]. It was found in the tropics in Bangladesh [11], Sri Lanka [14], Republic of Chad [107], Zimbabwe [28], tropical China [15,16], India [17,18], Indonesia [22,23], South Africa [33], and Brazil [28].

***M. pseudobronchartiana*** Gusev, Siver & Shin (Figure 4K).

This species was described from Viet Nam [57] and was found in two localities in two provinces: **DN**, **DL**.

Parameters: pH 5.9–6.1, specific conductance 22–119 µS cm$^{-1}$, temperature 28–29 (29 ± 1) °C.

Outside Viet Nam, this species has been observed in South Korea ([73] as *M. bronchartiana*, Figures 4 and 5, p. 211; [9] as *M.* sp. 1, Figure 11, p. 939) and multiple regions in the United States ([108–110] as *M. bronchartiana*).

***M. pseudomatvienkoae*** Jo, Shin, Kim, Siver & Andersen (Figure 4L).

This species was found in 79 localities in 15 provinces: **PQ**, **CD**, **DN**, **LD**, **KH**, **BT**, **DL**, **BD**, **PY**, **M**, **BV**, **NB**, **TH**, **QT**, **TTH**.

Parameters: pH 4.1–8.2 (6.4 ± 0.1), specific conductance 6–2370 (155 ± 36) µS cm$^{-1}$, temperature 23–39 (31 ± 0.1) °C.

This species from the *M. matvienkoae* complex was recently described based on combined morphological and molecular studies of strains isolated from South Korea [7]. This morphotype was also found in India ([17] as *M. matvienkoae* var. *matvienkoae*, Figure 15, p. 350), Colombia ([38] as *M. matvienkoae* var. *matvienkoae*, Figure 21, p. 159), and Indonesia [22]. This taxon is widespread in Viet Nam, and, therefore, it should also be a common species in other regions of tropical and subtropical Asia. It is possible that this morphotype was not previously illustrated separately, as it was considered to belong to *M. matvienkoae*.

***M. pseudocratis*** Dürrschmidt (Figure 4M).

This species was found in four localities in two provinces: **QB** and **NB**.

Parameters: pH 7.1–7.8 (7.5 ± 0.2), specific conductance 104–480 (315 ± 92) µS cm$^{-1}$, temperature 17–34 (24 ± 5) °C.

*M. pseudocratis* is a widespread species, but it has a scattered distribution [1]. In the tropics, it is known from China [15] and India [18].

***M. punctifera*** Korshikov (Figure 4N).

This species was found in two localities in one province: **LD**.

Parameters: pH 6.5–6.6, specific conductance 16–164 μS $cm^{-1}$, temperature 20–23 °C.

*Mallomonas punctifera* is a common species in northern temperate latitudes [1]. In the tropics, it has been reported only from Malaysia [12] and China [15,16].

***M. punctostriata*** Gusev & Kulikovskiy (Figure 4O).

This species was described from Viet Nam [60] and was found in two localities in two provinces: **PQ**, **KH**.

Parameters: pH 5.0–7.0, specific conductance 1200–3000 μS $cm^{-1}$, temperature 31–34 °C.

*M. punctostriata* was found only in Viet Nam. Both habitats are located near the sea coast and have high mineralization.

***M. rasilis*** Dürrschmidt (Figure 4P).

This species was found in 32 localities in 14 provinces: **PQ**, **CD**, **DN**, **LD**, **KH**, **BT**, **BB**, **DL**, **BD**, **PY**, **BV**, **NB**, **TH**, **TTH**.

Parameters: pH 4.7–9 (6.9 ± 0.2), specific conductance 22–711 (169 ± 34) μS $cm^{-1}$, temperature 19–64 (32 ± 1) °C.

*M. rasilis* is considered a widespread species [1], but the finds of this species require verification, and the taxon needs revision [77]. *M. rasilis* was described from Chile [89]. In the tropics and subtropics, the species was found in Korea ([73] as *M.* sp. 4, Figures 52 and 53), Sri Lanka [14], China [16,84], Madagascar [25], and Indonesia [24].

***M. siderea*** Gusev & Kulikovskiy (Figure 4Q).

This species was described from Viet Nam [111] and was found in six localities in six provinces: **QB**, **PY**, **NB**, **TH**, **QT**, **TTH**.

Parameters: pH 4.7–9.0 (6.9 ± 0.2), specific conductance 22–711 (169 ± 34) μS $cm^{-1}$, temperature 19–64 (32 ± 1) °C.

It is a rare species in Viet Nam. One collar scale of this species has also been recorded in Malaysia under the name *M. grata* ([13], Figure 4, p. 253). Thus, this species can be considered endemic to Southeast Asia.

***M. skvortsovii*** Gusev, Doan-Nhu, Nguyen-Ngoc & Kapustin (Figure 4R).

This species was described from Viet Nam [68] and was found in two localities in two provinces: **PQ**, **DN**.

Parameters: pH 5.2–6.4, specific conductance 10–119 μS $cm^{-1}$, temperature 24–30 °C.

It is a very rare species endemic to Viet Nam.

***M. sorohexareticulata*** Jo, Shin, Kim, Siver & Andersen (Figure 4S).

This species was found in 35 localities in 10 provinces: **PQ**, **DN**, **LD**, **KH**, **BT**, **QB**, **DL**, **BD**, **QT**, **TTH**.

Parameters: pH 4.6–8.0 (6.4 ± 0.1), specific conductance 9–104 (44 ± 4) μS $cm^{-1}$, temperature 17–36 (31 ± 1) °C.

This species from the *M. matvienkoae* complex was recently described based on combined morphological and molecular studies of strains isolated from South Korea [7]. Scales with a similar ultrastructure under the name *Mallomonas matvienkoae* were reported from tropical China ([15], Figure 14, p. 175; [16], Figure 21, p. 887), Madagascar ([25], Figure 13, p. 154), and Nigeria ([19], Figure 5, p. 101). It can be assumed that this species should also be common in other regions of tropical and subtropical Asia.

***M. spinosa*** Gusev emend. Wei & Kristiansen (Figure 4T).

This species was described from Viet Nam [112] and was found in 28 localities in 12 provinces: **PQ**, **CD**, **DN**, **KH**, **BT**, **DL**, **BD**, **PY**, **M**, **TH**, **QT**, **TTH**.

Parameters: pH 4.7–8.0 (6.7 ± 0.1), specific conductance 25–1591 (198 ± 68) μS $cm^{-1}$, temperature 28–36 (32 ± 0.1) °C.

The scale of this species was first found in Malaysia, but due to insufficient material, the authors did not describe this species and referred it as *Mallomonas* sp. 1 [12]. This taxon was also recorded in China, in the province of Hainan [16], and in Indonesia [22].

***M. splendens*** (G.S. West) Playfair emend. Croome, Dürrschmidt & P.A. Tyler (Figure 5A).

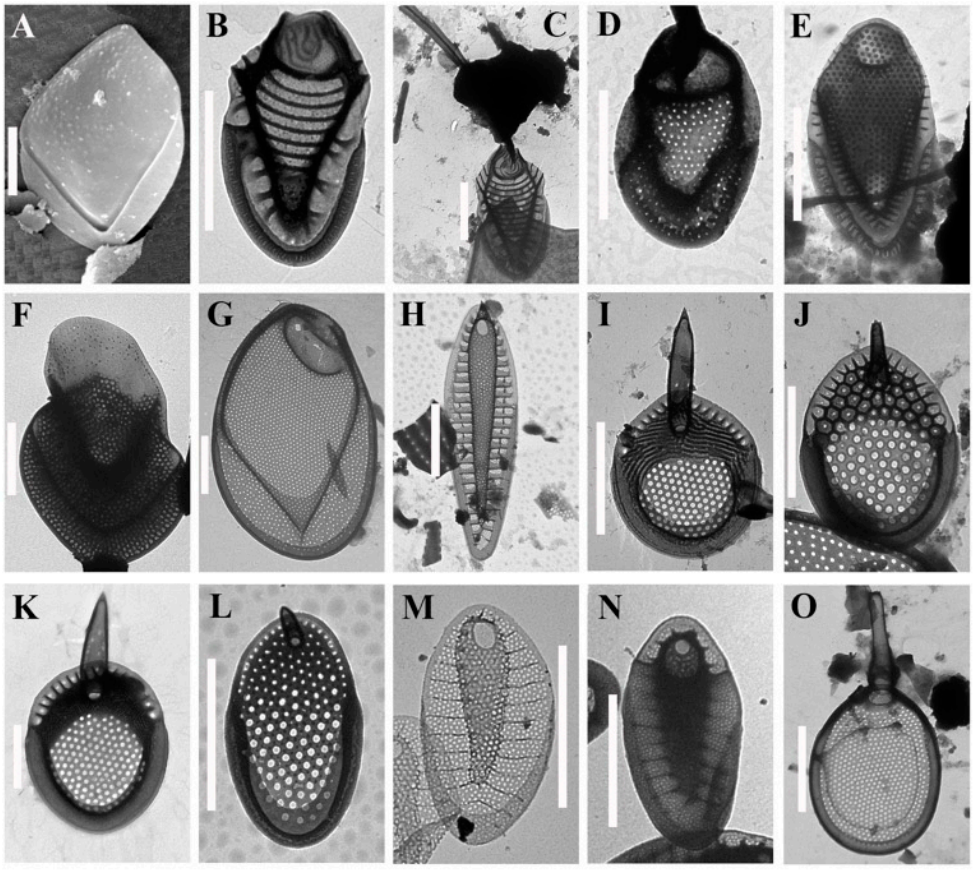


**Figure 5. Scales of *Mallomonas* and *Synura*.** (**A**) *M. splendens*. (**B**) *M. striata sensu lato* [48]. (**C**) *M. striata* var. *serrata*. (**D**) *M. tonsurata*. (**E**) *M. tropica*. (**F**) *M. velari*. (**G**) *M. vietnamica*. (**H**) *Synura australiensis*. (**I**) *S. echinulata*. (**J**) *S.* cf. *longitubularis*. (**K**) *S. mammillosa*. (**L**) *S. papillosa*. (**M**,**N**) *S. petersenii sensu lato* (*S.* spp. from *S. petersenii* complex). (**O**) *S. sphagnicola*. Scale bars: (**A**–**J**,**L**–**O**): 2 µm; (**K**): 1 µm. TEM: (**B**–**O**); SEM: (**A**).

This species was found in 40 localities in nine provinces: **PQ**, **CD**, **DN**, **LD**, **KH**, **BT**, **PY**, **QT**, **TTH**.

Parameters: pH 4.6–7.2 (6.0 ± 0.1), specific conductance 10–1240 (123 ± 45) µS cm$^{-1}$, temperature 20–36 (30 ± 1) °C.

This species has a limited distribution, primarily in Asia and Australia [1]. The modern diagnosis is based on the study of material using electron microscopy from Australia [113]. It has the form of *M. splendens* f. *arnhemensis*, which is distinguished by a depression in the central field at the angle of a V-shaped rib [113], which was also found in Viet Nam and Indonesia. Since it is difficult to distinguish this feature in the TEM images, we do not consider this form separately in this work. Based on electron microscopy data, *M. splendens* has been recorded from Australia [12], Malaysia [12], China [16], Indonesia [22], and Papua New Guinea [21].

***M. striata*** Asmund *sensu lato* (Figure 5B).

It was found in one locality in one province: **TTH**.

Parameters: pH 6.5, specific conductance 51 µS cm$^{-1}$, temperature 30 °C.

*Mallomonas striata* is considered a cosmopolitan taxon [1,114]. However, recently it has been shown that *M. striata* is a complex of species that can be morphologically distinguished by the structure of bristles, the shape of scales, and the number and arrangement of structural elements on the surface of scales [66,67,115,116]. Only one scale was found, in general, corresponding to the type of *Mallomonas striata* in ultrastructure, so we reported it as *M. striata sensu lato*. This species is rare in the tropics and has been recorded in Costa Rica [34], Colombia [38], and Jamaica [28].

***M. striata*** var. ***serrata*** Harris & Bradley (Figure 5C).

It was found in one locality in one province: **LD**.

Parameters: pH 7.1, specific conductance 38 µS cm$^{-1}$, temperature 20 °C.

This taxon is considered cosmopolitan [1]. It differs from the type variety in the structure of the bristles and the shape of the scales [115]. In the tropical region, it was recorded in Malaysia [12], Brazil [28,41,42], Jamaica [28], Zimbabwe [28], Papua New Guinea [21], Madagascar [25], Ecuador [35], and Indonesia [23].

***M. tonsurata*** Teiling (Figure 5D).

This species was found in 102 localities in 16 provinces: **PQ, CD, DN, LD, KH, QN, BT, QB, DL, BD, PY, M, BV, TH, QT, TTH**.

Parameters: pH 4.8–8.6 (7.0 ± 0.1), specific conductance 9–2370 (126 ± 26) µS cm$^{-1}$, temperature 17–39 (31 ± 0.1) °C.

It is a cosmopolitan species [1,71]. It was found in the tropics in most of the studied countries: Malaysia [12,13], Singapore [13], Sri Lanka [14], Republic of Chad [27], Zimbabwe [28], highlands of Colombia [28], Guatemala [28], tropical China [15,16], India [18], Nigeria [19,20], Indonesia [22], and Brazil [28,40].

***M. tropica*** Dürrschmidt & Croome (Figure 5E).

This species was found in eight localities in four provinces: **CD**, **KH**, **BD**, **TTH**.

Parameters: pH 4.1–7.0 (5.9 ± 0.4), specific conductance 28–286 (125 ± 37) µS cm$^{-1}$, temperature 31–36 (33 ± 1) °C.

It is a very rare species and was found in Viet Nam for the first time after the description from a water body in Malaysia [12].

***M. velari*** Gusev, Siver & Shin (Figure 5F).

This species was described from Viet Nam [57] and was found in two localities in two provinces: **PQ**, **DN**.

Parameters: pH 4.7–5.2, specific conductance 10–25 µS cm$^{-1}$, temperature 24–29 °C.

It is a very rare species endemic to Viet Nam.

***M. vietnamica*** Gusev, Kezlya & Tran (Figure 5G).

This species was described from Viet Nam [117] and was found in one locality in one province: **BV**.

Parameters: pH 7.8, specific conductance 153 µS cm$^{-1}$, temperature 25 °C.

It is a very rare species endemic to Viet Nam.

***Synura australiensis*** Playfair (Figure 5H).

This species was found in 19 localities in six provinces: **DN**, **LD**, **KH**, **BT**, **DL**, **TTH**.

Parameters: pH 4.8–7.5 (6.1 ± 0.2), specific conductance 10–133 (56 ± 10) µS cm$^{-1}$, temperature 22–35 (28 ± 1) °C.

It is a widespread species in the tropical region [1]. In particular, it is known from Australia [12], Brazil [28,39], Zimbabwe [28], Papua New Guinea [21], India [17,18], and Madagascar [25].

***S. echinulata*** Korshikov (Figure 5I).

This species was found in 36 localities in nine provinces: **PQ**, **CD**, **DN**, **LD**, **KH**, **BT**, **DL**, **PY**, **TTH**.

Parameters: pH 4.6–8.0 (6.1 ± 0.1), specific conductance 10–96 (42 ± 4) µS cm$^{-1}$, temperature 22–38 (30 ± 1) °C.

It is a widespread taxon in various climatic zones [1]. In the tropics, this morphotype was found in most of the studied countries.

***S.*** cf. ***longitubularis*** Jo, Shin, Kim & Siver (Figure 5J).

This species was found in 174 localities in 17 provinces: PQ, CD, DN, LD, KH, BT, BB, QB, DL, BD, PY, M, BV, NB, TH, QT, TTH.

Parameters: pH 4.9–10.0 (6.9 ± 0.1), specific conductance 9–2370 (160 ± 18) µS cm$^{-1}$, temperature 17–34 (31 ± 0.1) °C.

*Synura* cf. *longitubularis* is one of the most widespread taxa of synuralean algae in Viet Nam. However, the identification of this taxon based on morphological data is problematic [8]. *Synura longitubularis* was recently described in South Korea based on

molecular data [8] and is almost indistinguishable from *S. curtispina* Petersen & Hansen in terms of the scale ultrastructure. Our unpublished data on 15 strains from 12 water bodies of four provinces of Viet Nam, using the ITS rDNA marker, indicate that only *S. longitubularis* was found in water bodies of Viet Nam; however, more research is needed on the distribution of this taxon. Since *S. longitubularis* is morphologically indistinguishable from *S. curtispina*, a correct analysis of the previous finds in the tropics is not possible. It can only be noted that this morphotype was found in almost all studied tropical countries.

***S. mammillosa*** E.Takahashi (Figure 5K).

This species was found in 10 localities in six provinces: **PQ**, **LD**, **QB**, **BD**, **PY**, **TTH**. Parameters: pH 4.6–7.4 (6.4 ± 0.3), specific conductance 16–1200 (167 ± 121) µS cm$^{-1}$, temperature 17–34 (25 ± 2) °C.

It is considered a widespread species [1]. It was found in the tropics in Brazil [28,40,42], China [15], Madagascar [25], Nigeria [19,20], Ecuador [35], Colombia [38], and Indonesia [23].

***S. papillosa*** Kapustin, Gusev & Siver (Figure 5L).

This species was described from Viet Nam [118] and was found in 45 localities in 10 provinces: **PQ**, **CD**, **DN**, **KH**, **BT**, **DL**, **BD**, **PY**, **QT**, **TTH**.

Parameters: pH 4.6–8.0 (6.2 ± 0.1), specific conductance 10–3000 (187 ± 76) µS cm$^{-1}$, temperature 24–39 (31 ± 1) °C.

*Synura papillosa* is quite widespread and is found both in warm climates and in temperate regions of North America [118].

***S. petersenii*** Korshikov *sensu lato* (Figure 5M,N).

It was found in nine localities in four provinces: **DN**, **LD**, **KH**, **BT**.

Parameters: pH 5.7–7.6 (6.6 ± 0.2), specific conductance 14–740 (205 ± 96) µS cm$^{-1}$, temperature 20–32 (27 ± 1) °C.

*Synura petersenii* is a complex of closely related cryptic and pseudocryptic taxa that requires molecular methods for correct identification [4,5,8,119,120]. Therefore, the correct identification of the scales found in Viet Nam is impossible. In the tropical region, they were noted in most of the countries studied, but since it is not possible to correctly identify them, a detailed distribution analysis is not given here.

***S. sphagnicola*** (Korshikov) Korshikov (Figure 5O).

This species was found in 12 localities in four provinces: **PQ**, **LD**, **QT**, **TTH**.

Parameters: pH 4.7–7.3 (6.3 ± 0.3), specific conductance 9–66 (38 ± 5) µS cm$^{-1}$, temperature 24–37 (33 ± 1) °C.

*Synura sphagnicola* is a widespread taxon that prefers acidic conditions [1]. In the tropics, this species was found in Malaysia [12], China [15], Nigeria [19,20], Brazil [41,42,85], and Ecuador [35].

## 4. Discussion

Our investigations of algae from the order Synurales have revealed an exceptionally high diversity in Viet Nam. There are now 67 *Mallomonas* taxa and 7 *Synura* taxa that have been reported from Viet Nam. Among them, 21 species of the genus *Mallomonas* [45,57,59,60,68,74–76,79,86–88,99,102,106,111,112,117] and one species of the genus *Synura* were described from Vietnam [118]. Moreover, 18 unidentified morphotypes of *Mallomonas* scales and one of *Synura* have also been reported in freshwaters of the country [43,46,48,50–52]. All of these taxa are presumably new species for science, which require more detailed morphological and molecular studies for description. The number of described new species of the genus *Mallomonas* from Viet Nam is approximately 10% of the known species of the genus. About one-third of the known species of this genus have now been found in Viet Nam. Many *Mallomonas* species found in the country are known only from Viet Nam or have a limited distribution in Southeast Asia.

Among the synuralean algae found in Vietnam, cosmopolitan and widespread species accounted for one third of the total number of taxa while species restricted to tropical and subtropical latitudes accounted for more than half (Figure 6).

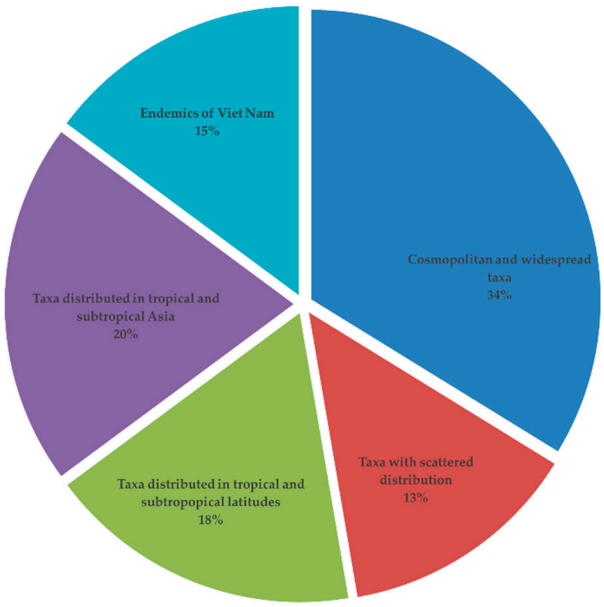


**Figure 6.** Diagram showing the proportions of taxa with cosmopolitan, widespread, scattered, and tropical and subtropical distributions. Cosmopolitan, widespread taxa were identified based on [1,71], other categories—on the basis of literature analysis.

This taxonomic diversity of synuralean algae (74 taxa) exceeds values for other studied tropical countries. For example, 55 taxa of synuralean algae in the Asian tropics were recorded in subtropical and tropical areas of China [15,16], 38 were found in Indonesia [22–24,121], 37 in Malaysia [12,13], 35 in India [17,18], 14 in Sri Lanka [14], and 11 in Bangladesh [11]. In other tropical areas, quite high diversity has been recorded in Madagascar—29 taxa of synuralean algae [25]. In other tropical countries, the number of recorded taxa was lower than 20.

The highest taxonomic diversity of synuralean algae in our studies was observed in natural water bodies, most of which were located in protected areas with reduced anthropogenic impact [43,48,49,51]. Most endemic and rare species were found in such habitats. Most eutrophic and hypereutrophic artificial water bodies (reservoirs and ponds) have a reduced number of synuralean species [43,48]. Most of the territory of Viet Nam is under serious anthropogenic pressure, especially lowland areas [122–124]. Additional efforts are needed for the development of protected natural areas. They should include entire landscape complexes of unique terrestrial and aquatic habitats. Algae of the order Synurales can be good marker taxa for identifying such unique aquatic ecosystems.

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