CICIMAR Oceánides
ISSN 2448-9123
https://oceanides.ipn.mx
Centro Interdisciplinario de Ciencias Marinas
https://doi.org/10.37543/oceanides.v34i1.239

Vol. 34 No. 1
Enero – Junio
2019

COLONIZATION OF FIBER-GLASS PLATES BY BENTHIC DIATOMS FROM SUBTIDAL SEDIMENT OFF THE COAST OF YUCATAN, MEXICO

Martínez, Yuriko Jocselin[1, 2 *], David Alfaro Siqueiros-Beltrones [2] & Pedro Luis Ardisson [1]

[1]Departamento de Recursos del Mar, Cinvestav. Carretera antigua a Progreso, km 6, 97310 Mérida, Yucatán, México.
[2]Departamento de Plancton y Ecología Marina, Centro Interdisciplinario de Ciencias Marinas-Instituto Politécnico Nacional. Av. IPN S/N, Col. Playa Palo de Santa Rita, La Paz, BCS. 23096, México. email: okiruy20g@gmail.com pedro.ardisson@cinvestav.mx, dsiquei@gmail.com.

RESUMEN. Las diatomeas bentónicas proliferan en diversos tipos de sustrato. Estos pueden ser naturales, o alternativos como superficies de embarcaciones grandes o pequeñas en las que la colonización por micro y macro-organismos (incrustantes) representa un problema económico y ambiental. La comprensión de este problema se dificulta dada la escasa información sobre diatomeas bentónicas, colonizadores principales de las incrustaciones. El objetivo de este estudio fue elaborar una lista florística y registrar los cambios en el proceso de colonización temprana de diatomeas bentónicas sobre sustratos alternativos, como fibra de vidrio, y aquellos que prosperan en el sedimento para probar nuestra hipótesis de que las taxocenosis de diatomeas epipélicas (sedimentos) constituyen la fuente de colonización de sustratos alternativos. El estudio se llevó a cabo en un sitio frente a la costa de Telchac, Yucatán, México, donde se colocaron placas de fibra de vidrio sobre el sedimento del fondo a una profundidad de 10 m durante cuatro meses para su colonización por diatomeas. El muestreo se realizó en puntos espaciados en el tiempo (1°, 3°, 4°, 8°, 12° y 16° semanas) posteriores a la inmersión inicial de las placas. Se identificaron 88 taxa de diatomeas bentónicas encontradas sobre las placas y en el sedimento, siendo los más abundantes *Cocconeis scutellum* var. *parva*, *Cymatosira lorenziana*, *Paralia sulcata*, *Dimeregramma australe*, *Actinoptychus senarius*, *Grammatophora marina* y *Shionodiscus oestrupii*, incluyendo dos nuevos registros para las costas mexicanas: *Cocconeis latestriata* y *Navicula uniseriata*. La composición general de las especies difiere de la de estudios previos en el área a la que se agregaron cuarenta y siete taxa, aumentando el número total a 210. Estos resultados muestran los cambios en la estructura de la taxocenosis a lo largo del tiempo, durante el período de colonización inicial, *i.e.*, periodo durante el cual no se presenta competencia intensa por espacio, detectándose un cambio en la composición de especies en la fase mensual. El alto porcentaje de especies comunes entre las placas y el sedimento soporta la hipótesis de que el sedimento es la fuente más probable de diatomeas que colonizan las placas.

Palabras clave: Bacillariophyceae; florística; microincrustaciones; sedimento; sustrato alternativo

Colonización de placas de fibra de vidrio por diatomeas bentónicas del sedimento submareal de la costa de Yucatán, México

ABSTRACT. Benthic diatoms thrive in many types of substrata, either natural or alternative such as the surfaces of large and small boats in which colonization by micro- and macro-organisms (fouling) represents an important economic and environmental problem. Addressing this issue is difficult given the scarce information on benthic diatoms one of the main micro-fouling settlers. Thus, our aim was to build a floristic list and record changes in the early colonization process of benthic diatoms that colonize alternative substrata such as fiber-glass, and those that thrive in the bottom sediment and to test our hypothesis that epipelic (sediment) diatom taxocenoses constitute the source for the colonization of alternative sustrata. The study was conducted at a coastal site off Telchac, Yucatan (Mexico), where fiber-glass plates were laid over the bottom sediment at a depth of 10 m during four months. Sampling was carried out over successive spaced points in time (1st, 3rd, 4th, 8th, 12th and 16th weeks) after the initial immersion of the plates. At the end 88 taxa growing on the plates and sediment were identified, the most abundant ones being *Cocconeis scutellum* var. *parva*, *Cymatosira lorenziana*, *Paralia sulcata*, *Dimeregramma australe*, *Actinoptychus senarius*, *Grammatophora marina* and *Shionodiscus oestrupii.* Included were two new records for the Mexican littorals: *Cocconeis latestriata* and *Navicula uniseriata.* Overall species composition differs from previous studies in the area, to which forty-seven taxa are added here, increasing their total number to 210. Our results show no changes in the species composition of the taxocenoses over time during the initial colonization period, *i.e*., the period during which there is no intense competition for space, exhibiting a change in species composition at a monthly phase.. The high percentage of common species between the plates and sediment (similarity) support the hypothesis that subtidal sediment is the most likely source for diatoms colonizing the plates.

Keywords: Bacillariophyceae; floristics; microfouling; sediment; alternative substratum

Martínez, Y. J., D. A. Siqueiros-Beltrones & P. L. Ardisson. 2019. Colonization of fiber-glass plates by benthic diatoms from subtidal sediment off the coast of Yucatan, Mexico. *CICIMAR Oceánides*, 34(1): 29-40.

INTRODUCTION

Micro- and macrofouling on large and small boats and other surfaces in the sea represent an important economic and environmental problem (López-Fuerte *et al.* , 2017). Biofouling has received considerable attention in many countries since the middle of the former century (*e.g.* Woods Hole Oceanographic Institution, 1952); however, in Mexico, its interest is still incipient. Although most of the attention on this process has focused on macrofouling biota, it is known that the initial microfouling film plays a definite successional role. At this stage, dia-

Fecha de recepción: 15 de abril de 2019

Fecha de aceptación: 13 de septiembre de 2019

toms constitute a key element, in part because of their high biomass (Cooksey & Wigglesworth-Cooksey, 1995; López-Fuerte *et al.*, 2017) and by the secreted exopolymers films that promote the ensuing macrofouling, conditioning the original surface for settling larvae of invertebrates. Hence, it is necessary to know precisely which are the primary microfouling diatom species in order to understand the ecological processes that may give an insight into treating or preventing the fouling problem.

The source of benthic diatoms as major microfoulers on alternative substrate, placed in the marine environment, maybe the water column itself and the nearby substrate such as sediments (Fernandes *et al*., 1999). However, many diatom species which turn out to be abundant on said surfaces are not considered typical from rocky substrata or other hard surfaces but are epipelic forms thriving in sediment (Siqueiros-Beltrones, 2002). Among alternative substrate, diatoms may have specific preferences (Mitbavkar & Anil, 2000), *e.g.*, a higher diatom recruitment has been observed on (hydrophobic) fiberglass than on (hydrophilic) glass surfaces (Patil & Anil, 2005a), although heavy fouling has been observed on silicon treads used as adhesive (Siqueiros-Beltrones, 2002).

For the Gulf of Mexico and Caribbean Sea (Mexico), few floristic studies on benthic diatoms exist. Navarro & Hernández-Becerril (1997) compiled a check-list of diatom species that gathered both phytoplanktonic and benthic forms. Later studies have been carried out in the Yucatan Peninsula that address several issues, from species composition of epiphytic diatoms on *Thalassia testudinum* in which López-Fuerte *et al*. (2013) identified 87 taxa, to the recording of new taxa (Hernández-Almeida *et al*., 2013), including the epipelic form *Navicula lusoria* in the coast of Quintana Roo (Hernández-Almeida *et al.,* 2014). And, in particular, the study by López Fuerte *et al.* (2017) where colonization processes of diatom assemblages for monthly periods were observed. However, their results were directed toward recording the properties of antifouling paint applied to their alternative substrata. Thus, further *ex professo* research on benthic diatom floristics is still required to identify the species composition of the microfouling diatom assemblages and their source, while observing the colonization process itself. According to the above, our objective was to elaborate a floristic list of benthic diatoms that colonize alternative substrata such as fiber-glass, and those that thrive in the bottom sediment to test our hypothesis that epipelic (sediment) diatom taxocenoses constitute the source for the colonization of alternative substrata.

MATERIAL AND METHODS

The Port of Telchac is located north of the Yucatan Peninsula. The area is influenced by a Caribbean current that travels E-W along the north coast of the peninsula known as the Yucatan Current (Logan *et al.*, 1969) (Fig. 1). The littoral consists of sandy beaches with a mild slope (Contreras *et al.*, 1998; Alonzo *et al.*, 2006), where turtle-grass *Thalassia testudinum* is common and abundant, along with filamentous chlorophytes (Herrera-Silveira & Morales-Ojeda, 2009) and rhodophytes (Zubia *et al.*, 2007).

There, from November 2013 to February 2014, six fiber-glass plates (9.8×5×0.4 cm) suspended from a stainless-steel supporting structure were laid over the bottom sediment at a depth of 10 m over four

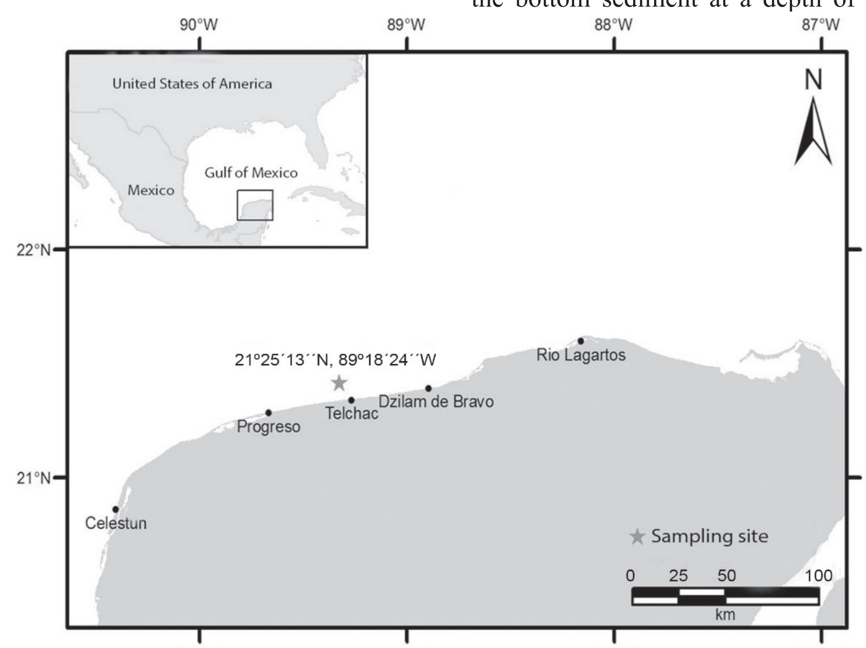


Figure 1. Location of the study area and sampling site (★) in Telchac, Yucatan, Mexico.

months to be colonized by diatoms. One plate was retrieved at intervals of 1, 3, 4, 8, 12 and 16 weeks. To compare assemblages from the distinct substrata, natural sediment was simultaneously collected around the supporting structure for the sampling of epipelic diatom taxa with the aid of a Petri dish (López-Fuerte & Siqueiros Beltrones, 2006). Diatoms were brushed off from both sides of the plates and placed into a test tube. Both the brushed off material and the sediment were processed to remove the organic matter by oxidizing the sample with a mixture of ethanol and nitric acid at a ratio of 1:3:3 (Siqueiros Beltrones, 2002). After the oxidizing reaction, the samples were rinsed with distilled water until reaching a pH>6. Cleaned diatoms were mounted on permanent slides using Pleurax (RI=1.7); two slides were mounted for each side of each plate and sediment.

Diatom species identification was carried out at 650× and 1000× under a Zeiss Primo Star optical microscope with phase contrast illumination and plan achromat optics, with a mounted Axio Cam MRc5 camera. Diatom taxa were identified following Foged (1975, 1978, 1984), Peragallo & Peragallo (1908), Siqueiros Beltrones (2002), Siqueiros Beltrones & Hernández-Almeida (2006), López-Fuerte *et al.* (2010), and Stidolph *et al.* (2012). Then, relative abundances of the taxa were estimated (N=250) for each plate and sampling weekly. Overall abundance for each species was computed by adding the number of counted valves for each week. A total of 2815 valves were counted in the samples from the fiber-glass plates (1,3,4,8,12 and 16), and 1748 valves in the sediment samples. Presence/absence similarity analysis was conducted using the Bray-Curtis index between the samples from all dates. Also, by accessing a floristic database for fouling diatoms published by López-Fuerte *et al.* (2017) the similarity between both species lists was measured (Primer 7 software).

RESULTS

Floristics. Overall, 88 benthic diatom taxa including species and varieties comprised within 42 genera were identified growing on the fiber-glass plates and sediment (Table 1). Two species are new records for the Mexican littorals, *Cocconeis latestriata* (Fig. 20) and *Navicula uniseriata* (Fig. 37), and six could not be identified to species category. The plates alone harbored 82 taxa, while in the sediment 77 taxa were recorded. On both substrata, around 70% were pennate forms. A total of 47 taxa are new additions, increasing the floristic list for the area to 210 taxa. An iconographic catalog is presented as reference taxa (Figs. 2-51).

Colonization. In the first week of colonization, the pioneer (and abundant) taxa were *Cocconeis scutellum* var. *parva* (119), *Paralia sulcata* (31), *Dimeregramma australe* (25) and *Cocconeis thalassiana* (23). While in the sediment, *Cymatosira lorenziana* (259), *Paralia sulcata* (252), *Cocconeis scutellum* var. *parva* (247), *Dimeregramma australe* (141), were the most abundant taxa. Overall, the most abundant diatom taxa found on the fiber-glass plates were: *Cocconeis scutellum* var. *parva* (538), *Cymatosira lorenziana* (448), *Paralia sulcata* (422), *Dimeregramma australe* (185), *Actinoptychus senarius* (143), *Grammatophora marina* (125) and *Shionodiscus oestrupii* (123). During the colonizing process, the abundant primary taxa from the initial phase became scarcer within a month, while less common taxa from the initial phase became abundant (Fig. 52). In general, species of *Amphora, Biddulphia, Cocconeis, Fragilaria, Grammatophora, Gyrosigma, Mastogloia, Trachyneis, Triceratum* that dominated the initial phase were outnumbered by species of *Achnanthes, Auliscus, Campylodiscus, Diploneis, Ehrenbergia, Lyrella, Navicula, Nitzschia, Terpsinoë* in the following stages. Thus, two groups were defined by the Bray-Curtis similarity test, one clustering the taxocenoses from weeks 1, 3, 4 (initial phase), and a second group that included distinct taxa from weeks 8, 12, 16 (Fig. 53). In the initial phase, 22 taxa were observed exclusively, while 18 taxa were added in the next month.

Qualitatively, the similarity measured between species composition growing on the fiberglass plates and that in the sediment reached 83.7%, while quantitatively they exhibited a similarity of 60%, showing that these taxa grow much alike on both substrata.

DISCUSSION

This study focused on determining the species composition of diatom assemblages that form biofilms on fiber-glass surfaces during the initial phases of colonization. Our purpose was to generate basic information to understand better and potentially overcome the problem of microfouling on surfaces of boats and industrial equipment submerged in the marine environment. Such basics imply setting objectives on knowing the species composition or floristics of the primary micro-foulers, *i.e.*, benthic diatoms and their provenance, and observing its changes over time. Floristically, our number of taxa surpasses those of similar studies elsewhere, *e.g.*, Redekar & Wagh (2000) recorded 49 species and 19 genera, while Patil & Anil (2005b) identified 71 species and 38 genera, and Mitbavkar & Anil (2007) recorded 35 diatom taxa growing on fiber-glass plates.

In contrast, our species richness is half of that recorded (170) by López-Fuerte *et al.* (2017) both for sediment and fiber-glass plates (and one third fewer genera). In sediment, they identified 115 taxa against our 77, while, on fiber-glass plates, they identified 133 taxa against our 82. These differences in the number of taxa are due likely to four factors: (1) the mooring period, that in their study it extended for 18 months and in ours for 4 months; (2) the material of the plates, that in their study was fiber-glass plates coated on one side with antifouling acrylic paint, while in ours it was untreated fiber-glass; and (3) the degree of contact of plates with sediment, because in their study the supporting structure was PVC stands whose sta-

Table 1. Floristic list of fouling diatoms growing on fiber-glass plates and surrounding sediment in Telchac beach, Yucatan, Mexico. *Taxa observed in sediment samples; Δ, taxa not recorded in López-Fuerte *et al.* (2017); NR, new records.

Bacillariophyta
Class Coscinodiscophyceae
Subclass Thalassiosirophycidae
Order Thalassiosirales
Family Thalassiosiraceae
Ehrenbergiulva granulosa (Grunow) Witkowski *
Shionodiscus oestrupii A.J. Alverson, S.H. Kang & E.C. Theriot *
Thalassiosira decipiens (Grunow) Jørgensen *
Thalassiosira eccentrica (Ehrenberg) Cleve *
Family Stephanodiscaceae
Cyclotella atomus Hustedt * Δ Fig. 9
Subclass Coscinodiscophycidae
Order Melosirales
Family Hyalodiscaceae
Podosira stelligera (Bailey) A. Mann
Order Paraliales
Family Paraliaceae
Paralia sulcata (Ehrenberg) Cleve *
Order Coscinodiscales
Family Heliopeltaceae
Actinoptychus senarius (Ehrenberg) Ehrenberg *
Subclass Biddulphiophycidae
Order Triceratiales
Family Triceratiaceae
Auliscus caelatus Bailey Δ
Auliscus sculptus (W.Smith) Brightwell *
Odontella aurita (Lyngbye) C. Agardh *
Triceratium favus Ehrenberg
Triceratium reticulum Ehrenberg
Amphipentas pentacrinus Ehrenberg
Family Plagiogrammaceae
Dimeregramma marinum (Gregory) Ralfs * Δ Fig. 8
Dimeregramma minor (Gregory) Ralfs *
Order Biddulphiales
Family Biddulphiaceae
Biddulphia biddulphiana (J.E.Smith) Boyer * Fig. 19
Zygoceros rhombus Ehrenberg* Δ Fig. 15
Subclass Cymatosirophycidae
Order Cymatosirales
Family Cymatosiraceae
Cymatosira lorenziana Grunow *
Class Fragilariophyceae
Subclass Fragilariophycidae
Order Fragilariales
Family Fragilariaceae
Fragilaria sp.
Opephora pacifica (Grunow) Petit *
Opephora schwartzii (Grunow) Petit ex Pelletan Δ
Order Rhaphoneidales
Family Rhaphoneidaceae
Dimeregramma australe (P.Petit) Boyer *
Family Psammodiscaceae
Psammodiscus nitidus (W. Gregory) Round & D.G. Mann *
Order Rhabdonematales
Family Rhabdonemataceae
Rhabdonema adriaticum Kützing
Order Striatellales
Family Striatellaceae
Grammatophora hammulifera Kützing
Grammatophora marina (Lyngbye) Kützing *
Grammatophora serpentina Ehrenberg *
Grammatophora undulata Ehrenberg
Class Bacillariophyceae
Subclass Bacillariophycidae
Order Lyrellales
Family Lyrellaceae
Lyrella clavata var. *caribaea* (Cleve) Siqueiros-Beltrones * Δ Fig. 40
Lyrella diffluens (A. Schmidt) D.G. Mann *
Lyrella hennedyi (W. Smith) Stickle & D.G. Mann * Δ
Lyrella irrorata (Greville) D.G. Mann *
Lyrella lyra (Ehrenberg) Karajeva *
Petroneis granulata (Bailey) D.G. Mann Δ Fig. 51
Petroneis plagiostoma (Grunow) D.G. Mann *
Order Mastogloiales
Family Mastogloiaceae
Mastogloia binotata (Grunow) Cleve *
Mastogloia erythraea Grunow Δ Fig. 47
Mastogloia fallax Cleve * Δ Fig. 49
Mastogloia fimbriata (T. Brightwell) Grunow * Δ Fig. 44
Mastogloia gibbosa Brun * Δ Fig. 48
Mastogloia punctatissima (Greville) Ricard Δ Fig. 45
Mastogloia varians Hustedt * Δ
Order Achnanthales
Family Achnanthaceae
Achnanthes sp. *
Family Cocconeidaceae
Cocconeis britannica Naegeli *
Cocconeis disculoides Hustedt * Δ Fig. 26
Cocconeis fluminensis var. *subimpleta* H.Peragallo & M.Peragallo * Δ
Cocconeis latestriata Hustedt * NR Δ Fig. 20
Cocconeis peltoides Hustedt *
Cocconeis scutellum var. *parva* (Grunow) Cleve * Δ
Cocconeis thalassiana Romero & López-Fuerte *
Order Naviculales
Family Scoliotropidaceae
Biremis sp.
Family Diploneidaceae
Diploneis chersonensis (Grunow) Cleve *
Diploneis didyma (Ehrenberg) Ehrenberg * Δ
Diploneis splendida (Ehrenberg) Ehrenberg * Δ Fig. 33
Diploneis papula var. *constricta* (Ehrenberg) Ehrenberg *
Diploneis litoralis (Donkin) Cleve *
Diploneis obliqua (J.-J. Brun) Hustedt * Δ
Diploneis schmidtii Cleve *Δ Fig. 35*
Diploneis smithii Cleve Δ
Diploneis sp. 1 * Δ
Diploneis sp. 2 * Δ
Family Naviculaceae
Navicula cuspidata var. *ambigua* (Ehrenberg) Cleve * Δ
Navicula (*Lyrella*) *clavata* var. *distenta* (Kuntze) Hustedt
Navicula longa (Gregory) Ralfs ex Pritchard *
Navicula sp. Bory *de* Saint-Vincent * Δ
Navicula uniseriata Østrup * NR Δ Fig. 37
Trachyneis aspera (Ehrenberg) Cleve *
Trachyneis velata A. Schmidt * Δ
Family Pleurosigmataceae
Pleurosigma formosum W. Smith *
Pleurosigma normanii Ralfs * Δ
Gyrosigma balticum (Ehrenberg) Rabenhorst Δ
Family Plagiotropidaceae
Tropidoneis pusilla (W.Gregory) Cleve*
Family Sellaphoraceae
Fallacia nummularia (Greville) D.G. Mann *
Family Amphipleuraceae
Halamphora coffeaeformis (C. Agardh) Levkov *
Family Pinnulariaceae
Oestrupia powellii (Lewis) Heiden ex Hustedt * Δ
Order Thalassiophysales
Family Catenulaceae
Amphora amoena F. Hustedt * Δ
Amphora arenaria Donkin * Δ
Amphora cingulata Cleve *
Amphora immarginata Nagumo *
Amphora obtusa W. Gregory * Δ Fig. 29
Amphora ostrearia var. *lineata* Cleve * Δ
Amphora proteus Gregory *

Table 1. Continued.

Order Bacillariales
Family Bacillariaceae
Bacillaria socialis (Gregory) Ralfs * Δ Fig. 16
Nitzschia acicularis (Kützing) W. Smith * Δ
Nitzschia fluminensis Grunow * Δ Fig. 38
Order Rhopalodiales
Family Rhopalodiaceae
Rhopalodia gibberula (Ehrenberg) Otto Müller * Δ
Order Surirellales
Family Surirellaceae
Campylodiscus cf. *angularis* Ehrenberg ex Kützing * Δ
Psammodictyon constrictum (Gregory) D.G. Mann * Δ
Psammodictyon panduriforme (W. Gregory) D.G. Mann *
Surirella armoricana H. Peragallo & M. Peragallo * Δ
Surirella fastuosa Ehrenberg *
Surirella fastuosa var. *recedens* (A. Schmidt) Cleve * Δ

bility did not guarantee the permanent separation of plates and the bottom sediment, while in our study the plates were hanged on a stable stainless steel supporting structure, not in direct contact with bottom sediment; (4) season, inasmuch their sampling comprised Spring and Summer, while ours was in the Autumn and Winter period. In accordance with this last factor, our floristics has to be considered complementary.

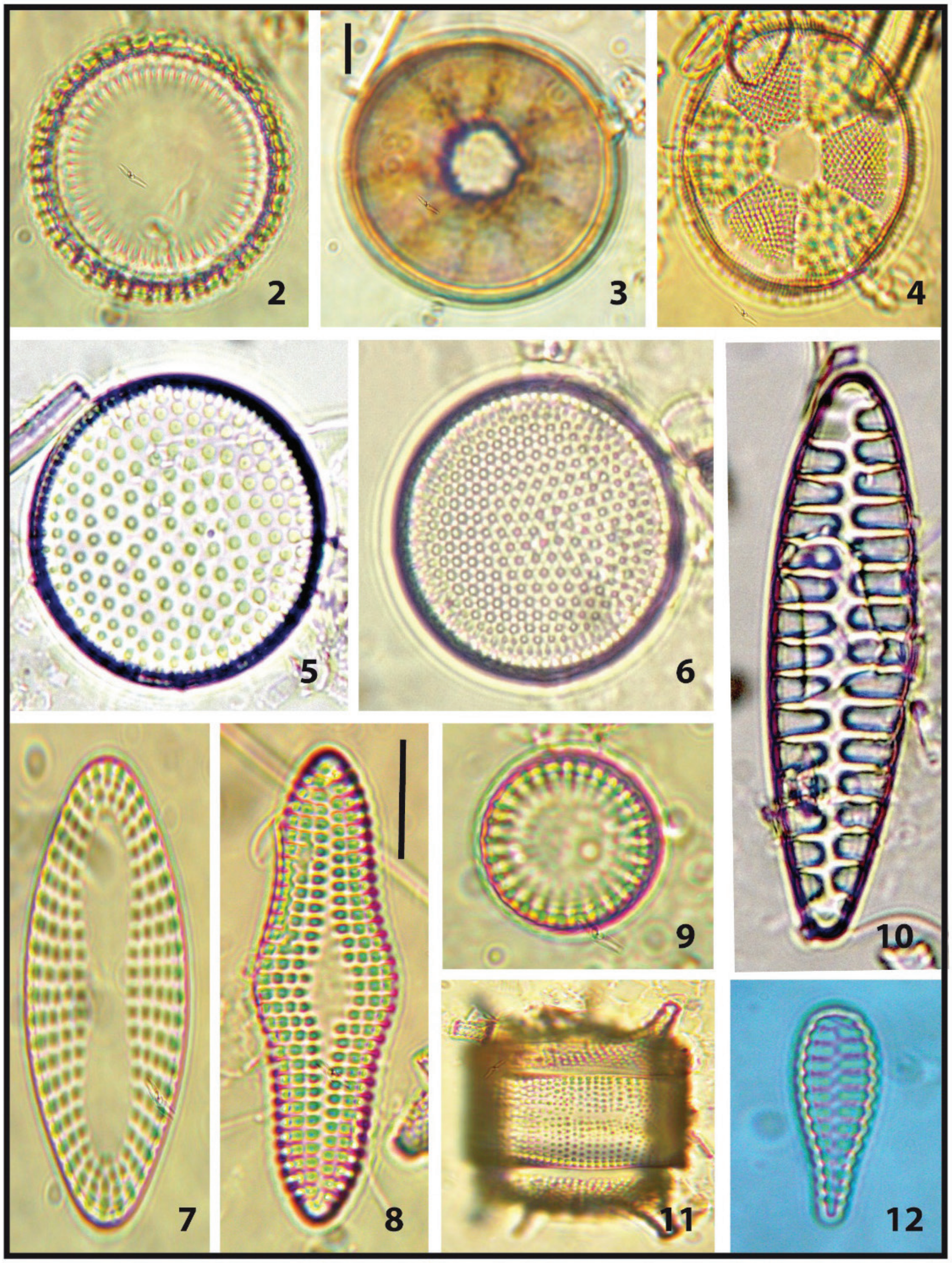
In any case, the 47 taxa added in our study that had not been listed previously, indicate that much floristic work is still required for this area. Notwithstanding, the joint lists reach 210 taxa of fouling diatoms: 158 epipelic forms, and 173 on the alternative substratum. This study and the one by López-Fuerte *et al.* (2017) have recorded more taxa than earlier studies in the Gulf of Mexico, the Caribbean Sea, and the Yucatan Peninsula (Licea *et al.* , 2011; Navarro & Hernández-Becerril, 1997; Stidolph *et al.* , 2012; Siqueiros Beltrones & Martínez, 2017).

Only seven taxa from the sediment were not observed on the plates backing our assumption that sediment diatom assemblages are the main source of colonizing taxa for this alternative substratum. This is evidenced by the fact that the taxa recorded as abundant on the fiber-glass plates were also abundant on the sediment (*Paralia sulcata*, *Cocconeis scutellum* var. *parva* and *Dimeregramma australe*).

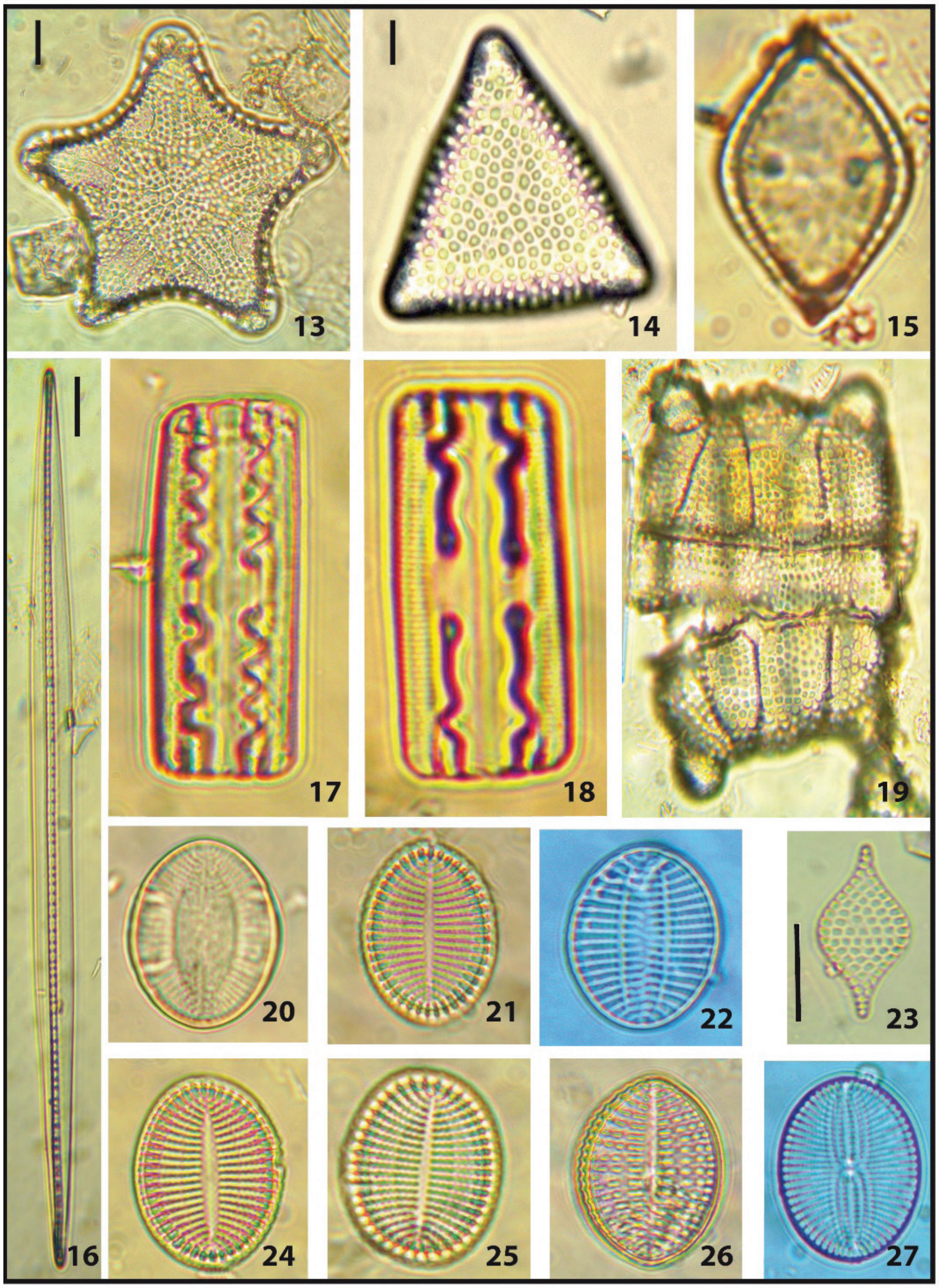
Although our two new records for the study area were previously reported by Hustedt (1955) for North Carolina (*Cocconeis latestriata*) and by Foged (1975) for the Caribbean (*Navicula uniseriata*), they are new for the overall Mexican littorals. Also, the former is listed for the Mexican NW (López-Fuerte & Siqueiros Beltrones, 2016). However, the record is unconfirmed. These newly recorded taxa underline the need for continuing studies on benthic diatom floristics in this and other areas of the Mexican coasts. Previously Hernández-Almeida *et al.* (2013) reported 9 new records for the Yucatan shores, of which *Petroneis plagiostoma*, *Oestrupia powelllii* and several species of *Cocconeis* were commonly observed in the present study, both in sediment and on fiberglass plates.

The primary phase of colonization was characterized by pioneer diatom forms such as *Paralia sulcata*, *Dimeregramma australe*, *Actinoptychus senarius*, and "adnate" forms such as *Cocconeis scutellum*, *C. scutellum* var. *parva* and *C. dirupta* (Korte & Blinn 1983, Siqueiros-Beltrones & Ibarra-Obando, 1985). Species of *Cocconeis* exhibit an adequate morphology for the initial colonization of submerged surfaces (Siqueiros-Beltrones, 2002) which renders them among the main microfouling biota against the shear stress occurring on the exposed surfaces of boats (Molino & Wetherbee, 2008). Also, taxa such as *Paralia sulcata* have been recorded during the early stages of colonization along with other centric forms in moderate frequencies in the first six days (Patil & Anil 2005a, 2005b). Thus these taxa may be considered as pioneer species of the microfouling process.

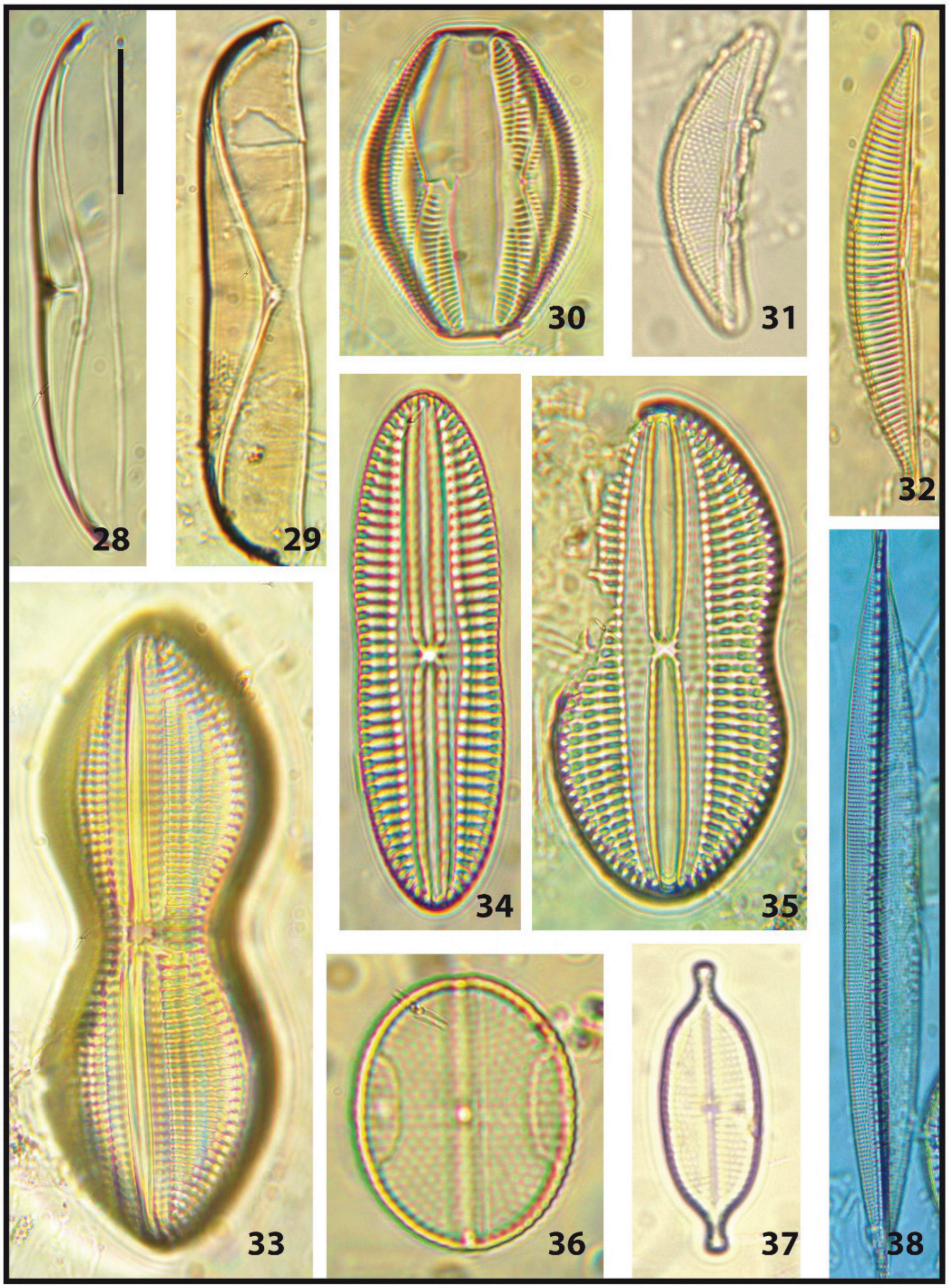
The most conspicuous diatom taxa in López-Fuerte *et al.* (2017) for the same study area were *Cocconeis thalassiana*, *Delphineis surirella*, *Mastogloia corsicana*, *M. crucicula* and *Rhopalodia musculus*. The taxa already do differ from those reported in this study. These differences somehow enhance the heterogeneity detected by López-Fuerte *et al.* (2017) in the sense that conspicuous taxa are replaced by others in time and space within the same area, changing the structure of the taxocenoses, These authors recorded dissimilarities in species composition between months 2, 4 and 18, whereas we detected a similar species composition during the first four weeks (initial phase) that differed from the one observed during the beginning of the eight weeks, indicating that species composition by diatoms begins to change after the first four weeks. It has to be considered that the colonizing process and changes in species composition are rapid events during the initial (days-weeks) stages (Patil & Anil, 2005b). During the eight weeks of sampling and the following, colonization by mollusks, polychaetes, and macroalgae occurred. The marked dissimilarity between the diatom assemblages of these dates with the previous samplings may be related to the presence of these organisms that may have enhanced the proliferation of epizoic and epiphytic diatom forms. It is expected that availability of live substrata will provide an



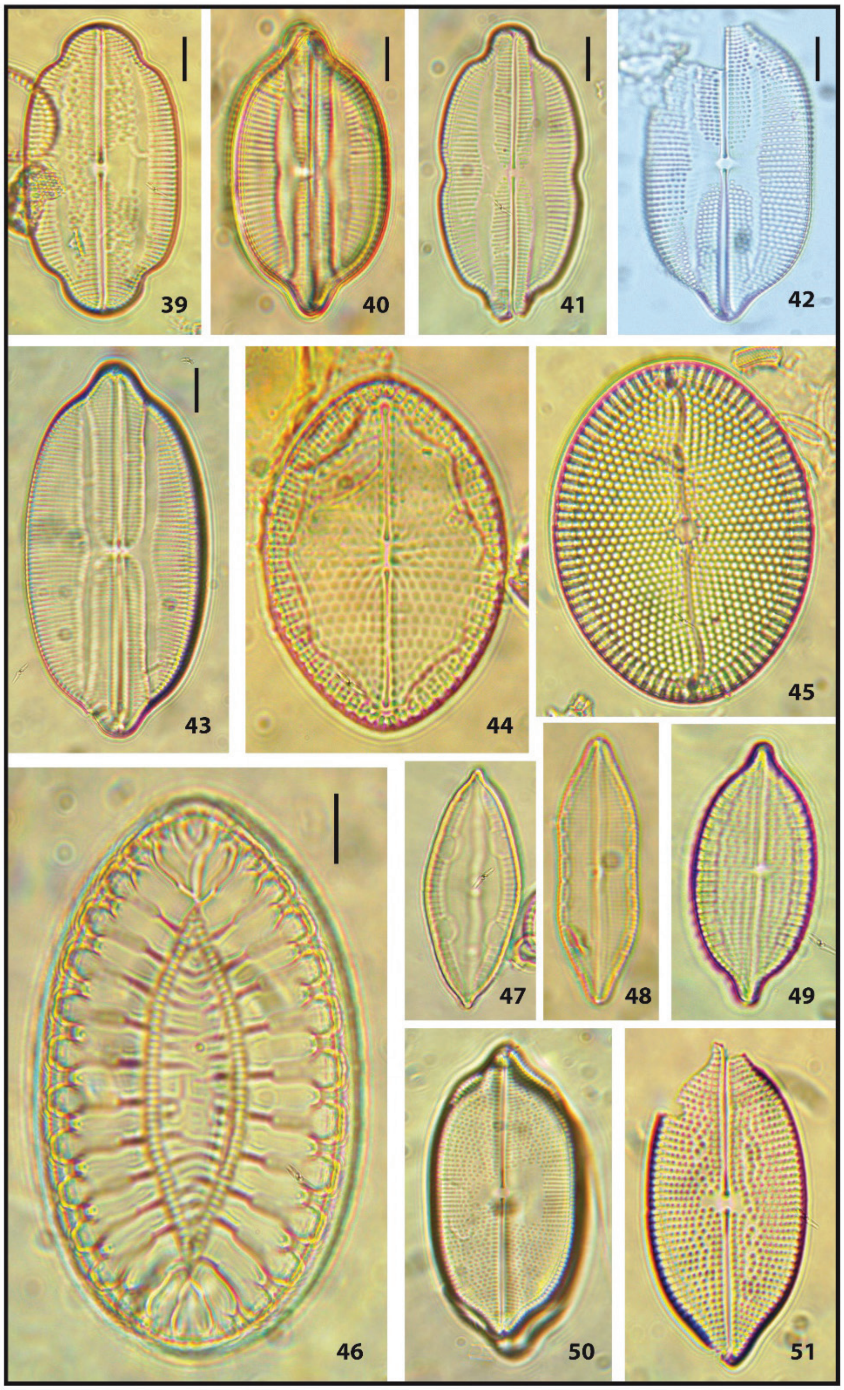
Figures 2-12. At 1000×. 2) *Paralia sulcata*; 3) *Podosira stelligera*; 4) *Actinoptychus senarius*; 5) *Psammodiscus nitidus*; 6) *Shionodiscus oestrupii*; 7) *Dimeregramma australe*; 8) *Dimerogramma marinum*; 9) *Cyclotella atomus*; 10) *Opephora schwartzii*; 11) *Odontella aurita*; 12) *Opephora pacifica*. Bar = 10 µm.



Figures 13-27. At 630×. 16) *Bacillaria socialis*. At 1000×. 13) *Amphipentas pentacrinus*; 14) *Triceratium reticulum*; 15) *Zygoceros rhombus*; 17) *Grammatophora serpentina*; 18) *Grammatophora marina*; 19) *Biddulphia biddulphiana*; 20) *Cocconeis latestriata*; 21, 25) *Cocconeis britanica*; 22) *Cocconeis peltoides*; 23) *Cymatosira lorenziana*; 24) *Cocconeis thalassiana*; 26) *Cocconeis disculoides*; 27) *Fallacia nummularia*. Bar = 10 μm.



Figures 28-38. At 1000×. 28) *Amphora cingulata*; 29) *Amphora obtusa*; 30) *Amphora proteus*; 31) *Amphora immarginata*; 32) *Halamphora coffeaeformis*; 33) *Diploneis splendida*; 34) *Diploneis papula* var. *constricta*; 35) *Diploneis schmidtii*; 36) *Mastogloia binotata*; 37) *Navicula uniseriata*; 38) *Nitzschia fluminensis*. Bar = 10 µm.



Figures 39-51. At 1000×. 39) *Lyrella diffluens*; 40) *Lyrella clavata* var. *caribaea*; 41) *Navicula* (*Lyrella*) *clavata* var. *distenta;* 42) *Lyrella irrorata*; 43) *Lyrella lyra*; 44) *Mastogloia fimbriata*; 45) *Mastogloia splendida*; 46) *Surirella fastuosa*; 47) *Mastogloia erythraea*; 48) *Mastogloia gibbosa*; 49) *Mastogloia fallax*; 50) *Petroneis plagiostoma*; 51) *Petroneis granulata*. Bar = 10 µm.

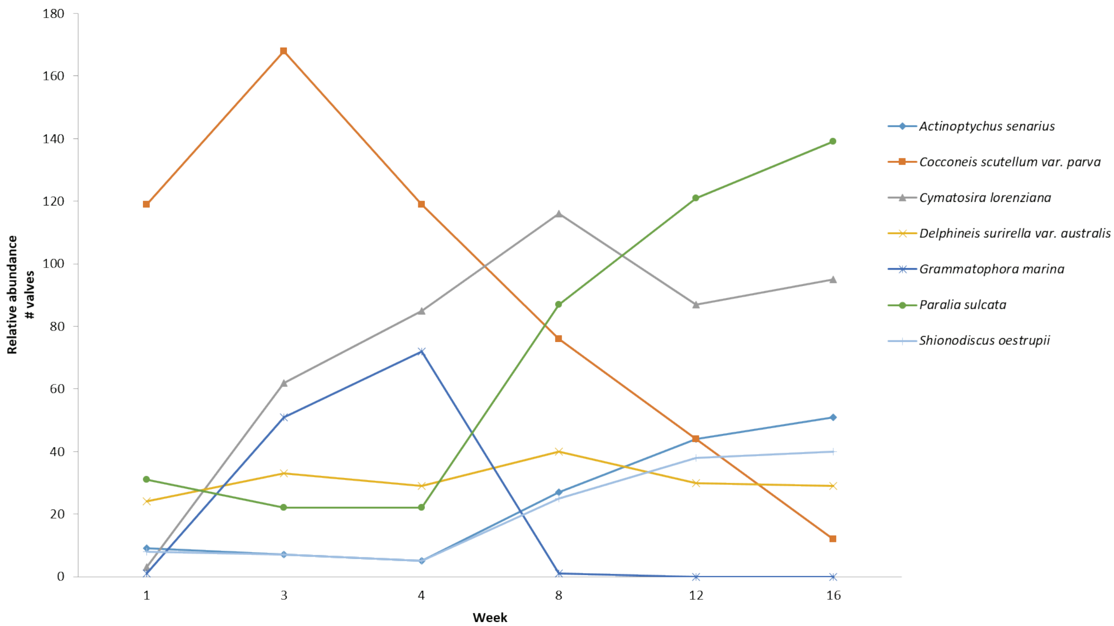


Figure 52. Variation of the most abundant taxa during the immersion period.

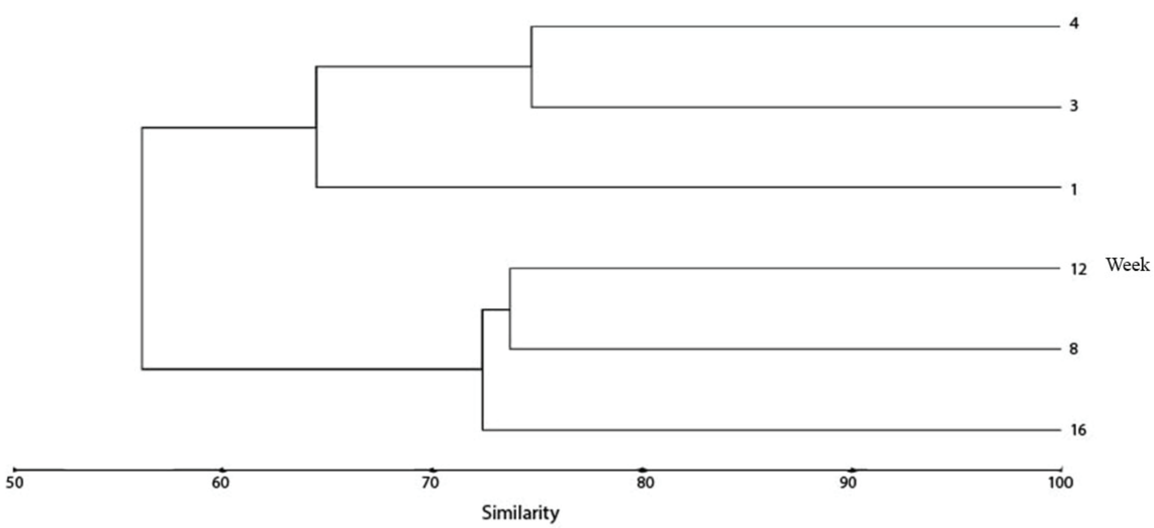


Figure 53. Similarity of diatom assemblages settled on the fiberglass (FG) plates, based on the Bray-Curtis qualitative similarity index. Number, weeks.

opportunity for the settlement of more diatom taxa which prefer a natural alternative, albeit to prove this an *ex professo* analysis is required.

This study complements and brings up to date the diatom floristics for the study area. However, it is evident that much more floristics research is required in this and other Mexican littorals to eventually provide the taxonomic certainty for conservation and management decision concerning the fouling nature of diatoms.

The above results back our hypothesis that epipelic diatoms are an important source for the colonization of an alternative substrate. On the other hand, the similarity between the diatom taxocenoses recorded by López-Fuerte *et al.* (2017) and those from this study was relatively low. Only 25% similarity for sediment samples, and 39% for the fiber-glass plates.

The examination of the sediment adjacent to the structure holding the fiberglass plates rendered an accurate reference on the origin of the diatoms found on the plates, in agreement with our hypothesis, inasmuch as many of the diatom taxa were recorded from sediment. Moreover, the identification of pioneer species in colonization processes, mainly adnate forms, and those that secrete exopolymers that favor the settlement of other life forms provide a basis for other studies related to the control of biofouling.

ACKNOWLEDGEMENTS

We thank Sandra Patiño and Emmanuel Mimila for their aid during field-work, and Omar López-Fuerte for his advice on taxonomic identification and providing the diatom database used for comparison. Monse Landero composed the map of the study area; María Teresa Herrera-Dorantes provided laboratory support and in the design and construction of the sampling device. We acknowledge the financial support through project CONACYT 179110 at Cinvestav-Merida, supervised by Lucien Veleva. DASB is fellow of Comisión de Operación y Fomento de Actividades Académicas (COFAA) and Estímulos al Desempeño de los Investigadores (EDI) of the Instituto Politécnico Nacional.

REFERENCES

Alonzo, S.L., R.C. Vinajera & R.G. Rodríguez. 2006. Granulometría de dos tipos predominantes de suelo del estado de Yucatán. *Ing.*, 10(3): 61-68.

Cooksey, K.E. & B. Wigglesworth-Cooksey. 1995. Adhesion of bacteria and diatoms to surfaces in the sea: a review. *Aquat. Microb. Ecol.,* 9(1): 87-96. https://doi.org/10.3354/ame009087

Contreras, F., M. Herzing & A. Botello. 1998. *Atlas del Golfo y Caribe Mexicano. Centro de eco desarrollo*. Secretaria de pesca.

Fernandes, L.F., F.P. Brandini, K.S. Gutzeit, A.L. Fonseca & F.M. Pellizzari. 1999. Benthic diatoms growing on glass slides in the Paranagua Bay, southern Brazil: Taxonomic structure and seasonal variation. *Insula,* 28: 53-100.

Foged, N. 1975. *Some littoral diatoms from the coast of Tanzania*. Bibliotheca Phycologica. J. Cramer, Odense.

Foged, N. 1978. *Diatoms in Eastern Australia*. Bibliotheca Phycologica, 41. J. Cramer, Odense. 148 p. https://doi.org/10.1111/j.1502-3885.1978.tb00049.x

Foged, N. 1984. *Freshwater and littoral diatoms from Cuba*. Bibliotheca Diatomologica. J. Cramer, Odense.

Herrera-Silveira, J.A. & S.M. Morales-Ojeda. 2009. Evaluation of the health status of a coastal ecosystem in southeast Mexico: Assessment of water quality, phytoplankton, and submerged aquatic vegetation. *Mar. Pollut. Bull.*, 59(1-3): 72–86. https://doi.org/10.1016/j.marpolbul.2008.11.017

Hernández-Almeida, O.U., J.A. Herrera-Silveira & F. Merino-Virgilio. 2013. Nueve nuevos registros de diatomeas bentónicas de los géneros *Climaconeis*, *Cocconeis*, *Licmophora*, *Talaroneis*, *Oestrupia*, *Petroneis* y *Synedrosphenia* en la costa norte de la Península de Yucatán, México. *Hidrobiológica*, 23(2): 154-168.

Hernández-Almeida, O.U., F.O. López-Fuerte, J.A. Herrera-Silveira & D. Aldana-Aranda. 2014. Primer registro de la diatomea *Navicula lusoria* Giffen 1975 para México y el Mar Caribe. *Hidrobiológica*, 24(3): 281–286.

Hustedt, F. 1955. Marine littoral diatoms of Beaufort North Carolina. *Bull. Duke Univ. Mar. Stn.*, 6: 1-67.

Korte V.L. & D.W. Blinn. 1983. Diatom colonization on artificial substrata in pool and riffle zones studied by light and scanning electron microscopy. *J. Phycol.*, 19(3): 332- 341. https://doi.org/10.1111/j.0022-3646.1983.00332.x

Licea, S., M.E. Zamudio, J.L. Moreno-Ruíz & R. Luna. 2011. A suggested local regions in the Southern Gulf of Mexico using a diatom database (1979-2002) and oceanic hydrographic features. *J. Environ. Biol.*, 32(4): 443-453.

Logan, B.W., J.L. Harding, W.M. Ahr, J.D. Williams & R.S. Snead. 1969. Carbonate sediments and reefs of the Yucatan Shelf Mexico. Part 1: Late Quaternary carbonate sediments of Yucatan Shelf, Mexico. *Am. Assoc. Petr. Geol. B.*, 11: 1-128.

López-Fuerte, F.O. & D.A. Siqueiros Beltrones. 2006. Distribución y estructura de comunidades de diatomeas en sedimentos de un sistema de manglar. *Hidrobiológica*, 16(1): 23-33.

López-Fuerte, F.O., D.A. Siqueiros Beltrones, & N. Navarro. 2010. *Benthic diatoms associated with mangrove environments in the northwest region of Mexico*, CONABIO–UABCS–IPN.

López-Fuerte, F.O., D.A. Siqueiros Beltrones & O.U. Hernández-Almeida. 2013. Epiphytic diatoms of *Thalassia testudinum* in Yalahau lagoon, Quintana Roo, Mexico. *Mar. Biodivers. Rec.,* 6:6; e107. https://doi.org/10.1017/S1755267213000857

López-Fuerte, F.O. & D.A. Siqueiros Beltrones. 2016. A checklist of marine benthic diatoms (Bacillariophyta) from México. *Phytotaxa*, 283(3): 201-258. https://doi.org/10.11646/phytotaxa.283.3.1

López-Fuerte, F.O., D.A. Siqueiros Beltrones, L. Veleva & D.A. Huerta-Quintanilla. 2017. Species composition and assemblage structure of microfouling diatoms growing on fiberglass plates off the coast of Yucatán, Mexico. *Hidrobiológica*, 27(1): 23-37. https://doi.org/10.24275/uam/izt/dcbs/hidro/2017v27n1/Siqueiros

Mitbavkar, S. & A.C. Anil. 2000. Diatom colonization on stainless steel panels in estuarine waters of Goa, west coast of India. *Indian J. Mar. Sci.*, 29(3): 273-276.

Mitbavkar, S. & A.C. Anil. 2007. Species interactions within a fouling diatom community: roles of nutrients, initial inoculum, and competitive strategies. *Biofouling*, 23(1-2): 99-112. https://doi.org/10.1080/08927010701191753

Molino P. & R. Wetherbee. 2008. The biology of biofouling diatoms and their role in the development of microbial slimes. *Biofouling*, 24(5): 365-379. https://doi.org/10.1080/08927010802254583

Navarro, J.N. & D.U. Hernández-Becerril. 1997. *Check-list of marine diatoms from the Caribbean Sea*. In: Listados florísticos de Mexico. XV. Universidad Nacional Autónoma de Mexico. Mexico, D.F.

Patil, J.S. & A.C. Anil. 2005a. Quantification of diatoms in biofilms: standardization of methods. *Biofouling*, 21(3-4): 181–188. https://doi.org/10.1080/08927010500241726

Patil, J.S. & A.C. Anil. 2005b. Biofilm diatom community structure: Influence of temporal and substratum variability. *Biofouling*, 21(3-4): 189-206. https://doi.org/10.1080/08927010500256757

Peragallo, H. & M. Peragallo. 1908. *Diatomées marines de France et des districs maritimes voisins*. M.J. Tempere, Fontainebleau.

Redekar, P.D. & A.B. Wagh. 2000. Studies on fouling diatoms from the Zuari estuary Goa (West coast of India). *Seaweed Research and Utilization*, 22(1-2): 113-119.

Siqueiros-Beltrones D.A. & S.E. Ibarra-Obando. 1985. Lista Florística de las diatomeas epifitas de *Zostera marina* en Bahía Falsa, San Quintín B. C. *Cienc. Mar.*, 11(3): 21-67. https://doi.org/10.7773/cm.v11i3.480

Siqueiros Beltrones, D.A. 2002. *Diatomeas bentónicas de la península de Baja California; diversidad y potencial ecológico*. Centro Interdisciplinario de Ciencias Marinas-Instituto Politécnico Nacional / Universidad Autónoma de Baja California Sur, México. 119p.

Siqueiros Beltrones, D.A. & O.U. Hernández-Almeida. 2006. Florística de diatomeas epifitas en un manchón de macroalgas subtropicales. *CICIMAR Oceánides*, 21(1): 11-61. https://doi.org/10.37543/oceanides.v21i1-2.25

Siqueiros Beltrones, D.A. & Y.J. Martínez. 2017. Prospective floristics of epiphytic diatoms on Rhodophyta from the Southern Gulf of Mexico. *CICIMAR Oceánides*, 32(2): 35-49. https://doi.org/10.37543/oceanides.v32i2.207

Stidolph, S.R., F.A.S. Sterrenburg, K.E.L. Smith. & A. Kraberg. 2012. *Diatom Atlas: U.S. Geological Survey Open-File Report 2012–1163*, accessed on February, 2018, available online at https://pubs.usgs.gov/of/2012/1163/

Woods Hole Oceanographic Institution, United Sta-tes. Navy Dept. Bureau of Ships. 1952. *Marine fouling and its prevention; prepared for Bu-reau of Ships, Navy Dept., https://hdl.handle.net/1912/191. accessed on September 2019. https://doi.org/10.1575/1912/191*

Zubia, M., D. Robledo & Y. Freile-Pelegrin. 2007. Antioxidant activities in tropical marine macroalgae from the Yucatan Peninsula, Mexico. *J. Appl. Phycol.* 19 (5): 449–458. https://doi.org/10.1007/s10811-006-9152-5