New records of myxomycetes from high-elevation areas of Mexico and Guatemala

Rojas C[1*], Stephenson SL[1], Estrada-Torres A[2], Valverde R[3] and Morales O[4]

[1]Department of Biological Sciences, University of Arkansas, Fayetteville, Arkansas 72701 – corresponding author crojas@uark.edu, slsteph@uark.edu
[2]Centro de Investigación en Ciencias Biológicas, Universidad Autónoma de Tlaxcala, Apartado Postal 183, Tlaxcala 90,000, Tlaxcala, México – arturomixo@hotmail.com
[3]Apdo 2551-4050 Alajuela, Costa Rica – nototriton@hotmail.com
[4]Departamento de Microbiología, Facultad de Ciencias Químicas y Farmacia, Universidad de San Carlos de Guatemala, Guatemala – moresq7@gmail.com

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Surveys of four high-elevation study areas in central Mexico and northwestern Guatemala were carried out to obtain baseline information on the species of myxomycetes present. All study areas were sampled in 2006 and 2007. Both specimens that had fruited in the field and those obtained from moist chamber cultures in the laboratory were considered. The myxomycetes recorded included seven species that represented new records for Mexico and 35 species that were new for Guatemala. Five of these were new records for the Neotropics. A list of these species and information on the microhabitats in which they occurred is provided. This relatively limited study clearly demonstrates that high-elevation areas in the Neotropics are still undersampled for myxomycetes. For the majority of countries in the region, there are still information gaps relating to distribution patterns of myxomycetes. In the context of biodiversity conservation, it is important to continue studying groups of organisms such as myxomycetes in the rapidly changing Neotropical ecosystems.

Key words – Cuchumatanes – Cofre de Perote – La Malinche – myxogastria – species distribution

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*Corresponding author: Carlos Roja– e-mail – crojas@uark.edu

Introduction

The myxomycetes or myxogastrids are a group of ameboid protists (Adl et al. 2005) with the particular ability to produce fruiting bodies that resemble microscopic fungi (Stephenson et al. 2008a). These organisms are known to occur in virtually all terrestrial ecosystems (Stephenson 2003). However, most studies have been directed towards temperate forests of the Northern Hemisphere (Stephenson et al. 2004).

In spite of this situation, tropical areas of the world have received a moderate level of study. For example, the Neotropical region has been the subject of more than 550 scientific articles on myxomycetes (see Lado & Wrigley de Basanta 2008). Remarkably, as new studies continue to occur in the Neotropics, more and more species of myxomycetes continue added to the known myxobiota (e.g. Rojas & Stephenson 2007, Estrada-Torres et al. 2009). In fact, a number of new species have been recently described from understudied ecosystems in the region (e.g. Moreno et al. 2009, Wrigley de Basanta et al. 2009), and it is very likely that this trend will continue for some time.

One of the reasons why new species continue to be discovered is the nature of the Neotropical region, in which the ecological complexity of regional ecosystems provides a large number of microenvironments and high species diversity (see Kricher 1999). However, niche differentiation in myxomycetes also seems to play a role in explaining this pattern (see Rojas et al. 2009). In this way, the wide variety of conditions that allow for the existence of multiple microenvironments and the capacity of myxomycetes to use a number of different resources would favour the occurrence of different species in this type of situation. As with other groups, this pattern seems to be determined by a combination of global and local factors (Stephenson et al. 2008a).

Interestingly, in the ecosystems that occur at high elevations in the Neotropical region, myxomycetes have not been studied extensively. This is still true in spite of the baseline information that has been obtained for the myxomycete assemblages present in some of these areas, especially in countries such as Mexico, Costa Rica and Ecuador (e.g. Schnittler et al. 2002, Rodríguez-Palma et al. 2005, Rojas & Stephenson 2007). As a result of this, most high-elevation Neotropical ecosystems continue to be understudied for myxomycetes.

The lack of information on the biota of high-elevation ecosystems is an important aspect of the conservation that needs to be addressed. High-elevation ecosystems in the Neotropics are extremely important as water reservoirs and natural erosion controllers (Brown & Kappelle 2001). Moreover, these ecosystems represent biodiversity treasures and the landscapes associated with them are visually appealing (Aldrich et al. 2000). The study of microscopic organisms such as myxomycetes is important for understanding the dynamics of these forests.

However, major differences in what is known exist from place to place within the Neotropical region. In Mexico, for example, researchers have generated more than 130 publications and have used this to advance the argument that this country has the richest myxobiota in the entire Neotropics (see Lado and Wrigley de Basanta 2008). In Guatemala, on the other hand, few studies of myxomycetes have been carried out, and only two publications (Farr 1976, Estrada-Torres et al. 2000) have reported these organisms for the entire territory.

In spite of this situation, it is very likely that additional study of some of the poorly known ecosystems in both countries would continue to provide important ecological information concerning the assemblages present. For this reason, the present study was designed to generate baseline information on the myxomycetes of high-elevation areas of Mexico and Guatemala. In both cases, these data are important for setting the stage for future studies of myxomycetes, especially with respect to monitoring changes in the community dynamics of microorganisms in relation to predicted global climate change.

Methods

The study described herein was carried out between the years 2006 and 2009. All species names follow the nomeclatural treatment of Hernández-Crespo & Lado (2005) except for *Perichaena liceoides*, for which the original protologue is provided. The morphological concept of species was used in all cases.

Study areas

Four study areas in the northern section of the Neotropics were used in the surveys carried out (Fig 1). In each of the study areas, two study sites corresponding to forested and non-forested conditions were selected. On each of these study sites, two collecting plots were established. Collectively, this effort produced a total of 16 plots arranged in 8 different study sites. All sampling was confined to *high-elevation areas*, defined in this study as those areas occurring at elevations >3000 m.

In Mexico, the two study areas correspond to (A) the Matlalcueyetl (=La Malinche) Volcano (hereafter abbreviated as Malinche, collecting plots located between 19˚14'–19˚16' N and 97˚59'–98˚02' W, 3100–4050 m), which is located between the states of

Puebla and Tlaxcala and (B) the Cofre de Perote Volcano (Perote, collecting plots located between 19˚29'–19˚31' N and 97˚09'–97˚10' W, 3400–4200 m) in the state of Veracruz. In these two cases, the forests surveyed are located below the treeline (Fig. 2) and are dominated by *Pinus hartwegii* Lindl. and *Abies religiosa* (Kunth.) Schltdl. et Cham, whereas non-forested areas at the highest elevations are dominated by the tussock grasses *Festuca tolucensis* Kunth and *Calamagrostis tolucensis* (Kunth) Trin. ex Steud.

In Guatemala, the two study areas are located on the Cuchumatanes Plateau and correspond to (C) Llanos de San Miguel (Llanos, collecting plots located at 15˚30' N and 91˚29' W, 3400–3500 m) and (D) La Ventoza (Ventoza, collecting plots located at 15˚27' N and 91˚32' W, 3400–3600 m). In these areas, the forests surveyed are dominated by *Juniperus standleyi* Steyerm. or *Pinus hartwegii* Lindl. and non-forested sites are dominated by the tussock grass *Agrostis tolucensis* Kunth or *Agave hurteri* Trel.

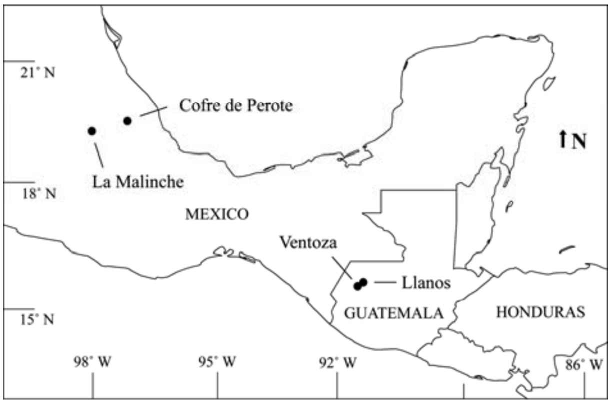

Fig. 1. – Map of central-southern Mexico and the northern section of Central America showing the geographic location of the four study areas considered in the present study. For complete names see the “study areas” section in Methods.

Sampling method

All the study areas were sampled within two consecutive periods between June and July of 2006 and 2007. Both specimens that had fruited in the field and those obtained from moist chamber cultures in the laboratory were considered.

In the latter case, a series of samples of dead plant material corresponding to ground litter, aerial litter, bark and twigs was collected from each of the plots. These samples were brought back to the laboratory, where they were used to prepare moist chamber cultures using the protocol described by Stephenson & Stempen (1994).

With this method, each sample was placed in a Petri dish previously lined with filter paper and pH-neutral water was added the dish until it covered all the sample material. After approximately 24 h, the pH of the substrate was measured using a pH meter and then the excess water was poured off. The reason for measuring this parameter is that a number of previous studies have determined pH to be an important factor in determining microenvironmental preferences in myxomycetes.

After this process, all moist chamber cultures were kept at room conditions for approximately 10 weeks. During this period, they were examined for the presence of myxomycete fruiting bodies every week. Extra water was added to the culture as necessary in order to maintain a humid microenvironment.

When fruiting bodies were detected, these were extracted from the moist chamber culture and placed in a pasteboard box for identification and storage. All collections made in this manner were deposited in the mycological herbarium of the University of Arkansas (UARKM).

In addition to the specimens obtained from moist chamber cultures, collections were obtained in the field using the opportunistic protocol described by Cannon and Sutton (2004). With this method, myxomycetes were searched for in the areas corresponding to the collecting plots. When fruiting bodies were found, pH was measured in the area surrounding the fruiting body with a portable pH meter. After this, the fruiting bodies were collected, returned to the laboratory and processed in the same manner as described previously for identification and storage of specimens from moist chamber cultures.

The information represented by all of the specimens collected was used to construct a database, and this was used for the annotations of individual species.

Species list and annotations

The list of species provided in this paper includes only those taxa for which no previous records were known for the areas surveyed. As such, this list does not reflect the actual species diversity found in each study area and each country. The latter data have been summarized in a separate manuscript (Rojas et al., unpublished data).

The starting point used to compile the list was the recent review of myxomycetes for the Neotropics (Lado & Wrigley de Basanta 2008). The list of new records for the study areas considered in the present study is presented in alphabetical order by genus and then species. In all cases, the species name is followed by the authors. After this, an indication of the origin of the particular record (FC for field collections and MC for moist chamber cultures) is given, along with the number of collections and the year in which these were obtained. The country and study area (in parenthesis), forest type, substrate types and range of pH values recorded for all specimens of the species in question are provided as well. Those species that represent new records for the Neotropical region are indicated for each entry.

For the annotations, forest types were coded as following: (A) non-forested areas dominated by *Agrostis tolucencis*, (B) non-forested areas dominated by *Festuca tolucensis*, (C) *Abies religiosa*-dominated forest, (D) *Pinus hartwegii*-dominated forest and (E) *Juniperus standleyi*-dominated forest. In a similar manner, substrate types were abbreviated as following: ground litter (GL), aerial litter (AL), twigs (TW), bark (BA) and decaying wood (DW). When a particular species was associated with more than one forest and/or substrate type, the abbreviations for the latter are listed in

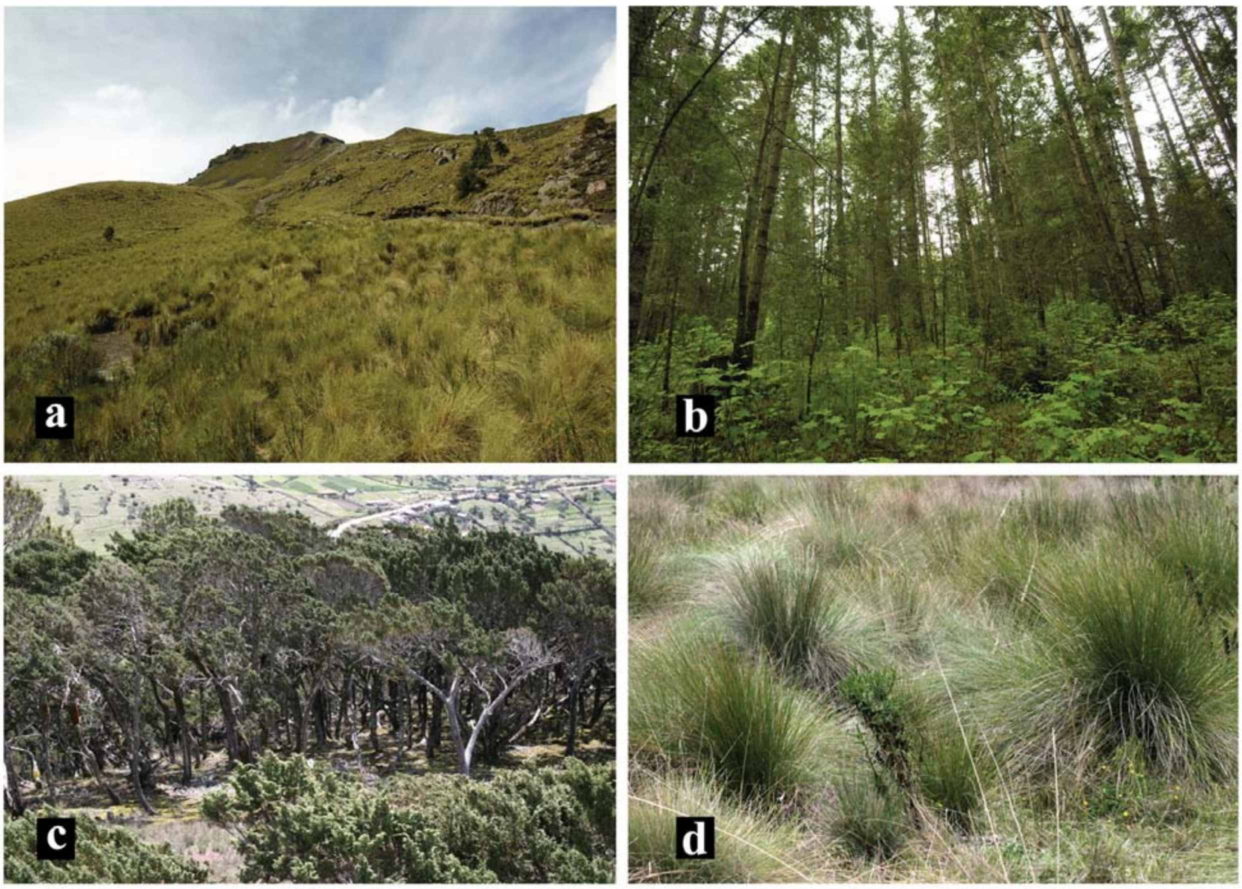

Fig. 2. – Some of the study areas surveyed in the investigation presented herein: (**a**) non-forested area dominated by *Festuca tolucensis* close to the summit in the La Malinche Volcano; (**b**) *Abies religiosa*-dominated forest in the Cofre de Perote volcano; (**c**) *Juniperus standleyi*-dominated forest in the Ventoza study area and (**d**) detail of the tussock grass *Agrostis tolucencis* dominating the landscape in the Llanos de San Miguel

order of their frequency for that particular species.

In countries where the species was previously observed, study areas where specimens were collected are only mentioned and no detailed data are provided. The number of specimens recorded and the other data given in each instance corresponds only to the country for which the species is a new record. All new records from Mexico are denoted with one asterisk before the name, two asterisks are used for new records for Guatemala, and new records for the two countries by three asterisks.

Results

A total of 82 species were recorded from the various study areas. Seven of these represented new records for Mexico and 35 were new records for Guatemala. In addition, five new records for the Neotropical region were found. For Mexico, one specimen that could only be identified to the genus level also represented a new record.

Approximately 55% of the records of species new to the areas studied were collected in forested plots, whereas the remaining 45% were collected in non-forested plots. Interestingly, about 27% of the total number of collections was recorded from the *Pinus hartwegii*-dominated forests, whereas about 24% and 5% were from the *Juniperus standleyi* and the *Abies religiosa*-dominated forests, respectively. When the substrates of the new records were evaluated, approximately 48% were associated with aerial litter, 21% with twigs, 17% with ground litter and 14% with bark.

The annotated list of all new species documented from the study areas is provided below.

List of new myxomycetes for Mexico and Guatemala

* *Amaurochaete* Rostaf. (a specimen that could be identified only to genus)
MC, 1 collection, 2007. Mexico (Malinche), in C, on TW, pH = 4.6.

** *Arcyria afroalpina* Rammeloo
MC, 3 collections, 2006. Guatemala (Llanos), in D, on AL and BA, pH range = 5.8–6.2.

* *Arcyria occidentalis* (T.Macbr.) G.Lister
FC, 1 collection, 2007. Mexico (Malinche), in C, on DW, pH = 4.6. New record for the Neotropics.

** *Badhamia melanospora* Speg.
MC, 1 collection, 2006. Mexico (Malinche and Perote) and Guatemala (Ventoza), in E, on AL, pH = 5.7.

** *Ceratiomyxa fruticulosa* (O.F.Müll.) T.Macbr.
FC, 11 collections, 2007. Guatemala (Llanos and Ventoza), in D, E and A, on DW, pH range = 3.2–8.1.

** *Cribraria languescens* Rex
FC, 1 collection, 2007. Guatemala (Llanos), in D, on DW, pH = 3.7.

** *Cribraria minutissima* Schwein.
FC, 1 collection, 2007. Guatemala (Llanos), D, on DW, pH = 3.7.

** *Cribraria oregana* H.C.Gilbert
FC, 6 collections, 2007. Guatemala (Llanos and Ventoza), in D, on DW, pH range = 3.9–4.5.

** *Cribraria vulgaris* Schrad.
FC, 2 collections, 2007. Guatemala (Llanos), in D, on DW, pH range = 3.7–3.8.

** *Comatricha nigra* (Pers. ex J.F.Gmel.) J.Schröt.
MC, 10 collections, 2006 and 2007. Mexico (Malinche and Perote) and Guatemala (Llanos and Ventoza), in E, D and A, on TW and BA, pH range = 4.0–5.2.

* *Comatricha rigidireta* Nann.-Bremek.
MC, 1 collection, 2006. Mexico (Perote), in D, on BA, pH = 4.8. New record for the Neotropics.

** *Didymium anellus* Morgan
MC, 21 collections, 2006 and 2007. Mexico (Malinche and Perote) and Guatemala (Llanos and Ventoza), in E, D and A, on AL and GL, pH range = 4.1–6.2.

** *Didymium bahiense* Gottsb.

MC, 18 collections, 2006 and 2007. Mexico (Malinche and Perote) and Guatemala (Llanos and Ventoza), in E, D and A, on AL, GL and TW, pH range = 3.9–6.8.

** *Didymium clavus* (Alb. & Schwein.) Rabenh.
MC, 5 collections, 2006. Mexico (Malinche and Perote) and Guatemala (Llanos and Ventoza), in E and A, on AL, pH range = 3.5–6.1.

** *Didymium difforme* (Pers.) Gray
MC, 28 collections, 2006 and 2007. Mexico (Malinche and Cofre) and Guatemala (Llanos and Ventoza), in E, D and A, on AL, GL and TW, pH range = 4.8–7.5

** *Didymium dubium* Rostaf.
MC, 5 collections, 2006 and 2007. Mexico (Perote) and Guatemala (Llanos and Ventoza), in A, on GL and AL, pH range = 5.2–5.8.

** *Didymium iridis* (Ditmar) Fr.
MC, 43 collections, 2006 and 2007. Mexico (Malinche and Cofre) and Guatemala (Llanos and Ventoza), in E, D and A, on AL, GL, TW and BA, pH range = 3.8–6.8.

** *Didymium minus* (Lister) Morgan
MC, 9 collections, 2006 and 2007. Mexico (Malinche and Perote) and Guatemala (Llanos and Ventoza), in E and A, on AL, pH range = 4.4–6.2.

** *Didymium squamulosum* (Alb. & Schwein.) Fr.
MC, 29 collections, 2006 and 2007. Mexico (Malinche and Perote) and Guatemala (Llanos and Ventoza), in both E, D and A, on AL and GL, pH range = 4.5–6.6.

** *Diachea leucopodia* (Alb. & Schwein.) Fr.
MC, 1 collection, 2006. Mexico (Perote) and Guatemala (Llanos), in A, on AL, pH = 5.0.

** *Echinostelium minutum* de Bary
MC, 6 collections, 2006 and 2007. Mexico (Malinche and Perote) and Guatemala (Llanos and Ventoza), in E and D, on BA and TW, pH range = 3.3–4.8.

** *Fuligo septica* (L.) F.H.Wigg.
FC, 4 collections, 2007. Guatemala (Llanos), in D and A, on DW, pH range = 3.5–6.6.

** *Lamproderma scintillans* (Berk. & Broome) Morgan
MC, 2 collections, 2006. Mexico (Perote) and Guatemala (Llanos and Ventoza), in A, on AL, pH range = 4.6–6.1.

** *Licea belmontiana* Nann.-Bremek.
MC, 5 collections, 2006. Guatemala (Llanos and Ventoza), in E, D and A, on TW and BA, pH range = 3.7–4.9.

* *Licea deplanata* Kowalski
MC, 2 collections, 2006. Mexico (Perote), in B, on TW, pH range = 4.5–5.8. New record for the Neotropics.

** *Licea minima* Fr.
MC, 8 collections, 2006 and 2007. Mexico (Malinche) and Guatemala (Llanos and Ventoza), in E, D and A, on BA and TW, pH range = 3.6–4.7.

** *Licea pusilla* Schrad.
MC, 1 collection, 2007. Guatemala (Llanos), in D, on GL, pH = 4.8.

*** *Licea testudinacea* Nann.-Bremek.
MC, 6 collections, 2007. Mexico (Malinche) and Guatemala (Ventoza), in C, D and A, on BA and TW, pH range = 3.7–6.0. New record for the Neotropics.

** *Lycogala epidendrum* (L.) Fr.
FC, 4 collections, 2007. Guatemala (Llanos and Ventoza), in E and A, on DW, pH range = 4.7–7.0.

* *Paradiacheopsis solitaria* (Nann.-Bremek.) Nann.-Bremek.
MC, 1 collection, 2006. Mexico (Malinche), in D, on BA, pH = 4.9. New record for the Neotropics.

** *Perichaena chrysosperma* (Curr.) Lister
MC, 2 collections, 2006. Mexico (Malinche and Perote) and Guatemala (Llanos), in A, on GL, pH range = 4.5–5.6.

** *Perichaena corticalis* (Batsch) Rostaf.
MC, 2 collections, 2006. Mexico (Malinche and Perote) and Guatemala (Llanos), in A, on GL, pH = 5.6.

** *Perichaena depressa* Lib.
MC, 21 collections, 2006 and 2007. Mexico (Malinche and Perote) and Guatemala (Llanos and Ventoza), in E, D and A, on AL, GL, TW and BA, pH range = 3.5–7.1.

* *Perichaena dictyonema* Rammeloo
MC, 2 collections, 2006. Mexico (Malinche), in C, on AL, pH range = 6.6–7.3.

* *Perichaena liceoides* Rostaf., Sluzowce Monogr. 295 (1875)
MC, 12 collections, 2006 and 2007. Mexico (Malinche and Perote), in C, D and B, on AL and GL, pH range = 4.8–7.9.

** *Physarum bivalve* Pers.
MC, 4 collections, 2007. Mexico (Malinche and Perote) and Guatemala (Llanos and Ventoza), in D and A, on AL and BA, pH range = 4.8–5.8.

** *Physarum echinosporum* Lister
MC, 5 collections, 2006 and 2007. Mexico (Malinche and Perote) and Guatemala (Llanos), in D and A, on AL, BA, TW and GL, pH range = 4.1–6.1.

** *Physarum pusillum* (Berk. & M.A.Curtis) G.Lister
MC, 1 collection, 2006. Mexico (Malinche and Perote) and Guatemala (Ventoza), in D, on AL, pH = 5.5.

** *Stemonitis fusca* Roth
MC, 94 collections, 2006 and 2007. Mexico (Malinche and Perote) and Guatemala (Llanos and Ventoza), in E, D and A, on TW, AL, BA and GL, pH range = 3.7–6.0.

** *Trichia botrytis (*J.F.Gmel.) Pers.
MC, 2 collections, 2006. Mexico (Malinche) and Guatemala (Llanos and Ventoza), in E and D, on GL, pH range = 4.9–5.3.

** *Trichia contorta* (Ditmar) Rostaf.
MC, 3 collections, 2006. Mexico (Malinche) and Guatemala (Llanos and Ventoza), in A, on GL and TW, pH range = 4.0–5.3.

** *Trichia subfusca* Rex
MC, 3 collections, 2006 and 2007. Mexico (Malinche) and Guatemala (Llanos and Ventoza), in E and D, on GL, pH range = 4.2–4.4.

Discussion

The number of new records of myxomycetes obtained in the present study is probably not surprising. This is especially true when it is considered that the myxobiota of Guatemala is very much understudied. It is interesting to note, however, that even though there have been a number of investigations in Mexico, the present study reports seven new myxomycete species for that country.

The latter is not an unimportant result. As is true for many other countries, high-elevation areas in Mexico have not received as much attention as lowland areas (see Lado & Wrigley de Basanta 2008). Both La Malinche and Cofre de Perote are exceptions to the latter and have been studied in the past (e.g. Guzmán & Villareal 1984, Rodríguez-Palma et al. 2005). However, in both cases the effort was centered on forested areas, leaving the grass-dominated communities that occur beyond the treeline understudied. In the case of La Malinche, for example, most previous studies have been carried out in the *Abies religiosa* forest (Rodríguez-Palma et al. 2005).

For Guatemala, the situation is very different. It is clear that the 26 species of myxomycetes known for this country before the present study (see Lado & Wrigley de Basanta 2008) do not reflect the diversity of forms that would be expected to occur in this area. However, no studies have been carried out in most parts of this country. In this sense it is not surprising that the present study increased by 135% the number of known species for Guatemala. Curiously, both the investigation carried out by Estrada-Torres et al. (2000) and the study presented herein were centered on the Cuchumatanes Plateau, the highest mountain range in the country. For this reason, it is very likely that future studies will increase the number of myxomycetes known for Guatemala, especially those directed towards areas that still remain unexplored.

It is interesting to note that about half of the collections that represent new records for both countries were obtained from the less studied non-forested areas. This result certainly suggests that such areas could potentially provide a number of new records for other countries in the Neotropics. A comprehensive examination of the species present in high-elevation non-forested areas of Costa Rica (Rojas et al., unpublished data) provides evidence for such a hypothesis. In the present study, non-forested ecosystems had not been sampled in any of the study areas (see Guzmán & Villareal 1984, Estrada-Torres et al. 2000, Rodríguez-Palma et al. 2005)

The fact that the forest type accounting for the lowest number of new records is the *Abies religiosa* forest lends support for the hypothesis that most myxomycetes in understudied ecosystems have not yet been documented. This is due in part to the fact that most myxomycetes seem to display patterns of occurrence that can be related to macro- and microenvironmental characteristics of the habitat (see Stephenson et al. 2008a), which accounts for the particular species assemblages associated with different types of forest. This phenomenon undoubtedly accounts for the fact that about half of the new records were recovered from the less studied *Juniperus standleyi* and *Pinus hartwegii* forests.

For the moist chamber culture component of the present study, it seems apparent that most of the new records were associated with either aerial litter or woody twigs. The presence of certain myxomycetes for these substrates is not surprising, since both have been previously documented as supporting distinctive assemblages of species (see Stephenson et al. 2004, Stephenson et al. 2008b). As such, it is interesting to observe that such substrates yielded a large number of new records during the present study. At least for aerial litter, the results seem to support the hypothesis that this is an important substrate for myxomycetes in tropical forests (see Black et al 2004).

In the present study, aerial litter also yielded all of the species of *Didymium*. This is not surprising since this genus is frequently encountered in myxomycete surveys carried out in tropical areas (e.g. Schnittler and Stephenson 2000, Tran et al. 2006). In contrast, the presence of species of the genus *Licea* primarily on bark and twigs seems to indicate an apparent specificity of members of that genus for those substrates. This phenomenon has been reported previously (see Ing 1994). Evidently, both vegetative and reproductive structures in myxomycetes can reach and grow on virtually any surface in the forest. However, the presence of a number of species primarily associated with or even restricted solely to particular substrates seems to be an indication of the specificity that some myxomycetes apparently show for particular food resources and/or substrate features as well as the importance of those factors on the dynamics of myxomycete communities.

In any case, most of the species reported herein are common and have broad distribution ranges within the Neotropical region (see Lado and Wrigley de Basanta 2008). However, some species such as *Arcyria occidentalis*, *Comatricha rigidireta*, *Licea deplanata*, *Licea testudinacea* and *Paradiacheopsis solitaria*, all of which are new records for the Neotropics, are obviously still not yet documented for other countries in the region. It is perhaps noteworthy that all of these species produce small fruiting bodies and thus may have been overlooked in previous studies that did not use the moist chamber culture method. It is important to mention that the use of this technique usually yields species that are not found under natural conditions. Since most records of myxomycetes from Latin America have been obtained in the field, it is still impossible to say whether or not the new records truly represent rare taxa in the Neotropics or simply reflect the relatively few studies that have been carried out in suitable habitats or have used both collecting techniques.

One obvious result from the present study and other recent investigations carried out in the high-elevation areas of the Neotropics (e.g. Rojas & Stephenson 2007) is that myxomycetes do occur, sometimes in abundance, in these areas. Within the context of conservation, it is important to know the composition of species present in different areas of similar characteristics in order to assess the effect of possible changes in the dynamics of these assemblages. Rapid-assessment projects such as the one described herein are relevant in this sense, since they provide baseline information that can be used for the monitoring of species assemblages in threatened ecosystems.

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