Chapter 13

Myxomycetes in the 21st Century

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CONNECTION WITH THE WORLD

The myxomycetes have been formally studied since the middle part of the 17th century (Stephenson et al., 2008). Although the biology of the group has not been documented to the extent that is the case for most groups of vertebrates and plants, there is a good baseline of information relating to the fruiting body stage of myxomycetes. As noted in other chapters of this volume, this is more easily observed for taxonomic and basic ecological aspects. However, the communication of the accumulated information on myxomycetes has been conducted primarily through formal scientific and academic channels, such as articles, volumes, scientific notes, and university courses. In fact, there is a good chance that most of the readers of this volume first learned about myxomycetes directly from any of these strategies of knowledge transmission.

Recently, with the establishment of the Internet as the most important platform for global communication (Gubbia et al., 2013), there has been a fantastic development of high quality websites, blogs, social media platforms, and mobile apps for different groups of living organisms. This natural expansion of the technology-based modern lifestyle to the scientific world has created new paths for scientific communication and has changed the way our societies transfer knowledge (Cummings and Teng, 2003). Some authors have even stated that the Internet has modified the neurobiological and cognitive pathways of the human learning process (Roth and Dicke, 2005). These changes have permeated science and allowed for a rapid growth of nonscientists performing basic scientific assessments. For instance, the more prominent role of citizen science projects, most of which are based on emotional connections with nature promoted by multiscale information transfer, is highly relevant in the current structure of scientific research (Boney et al., 2014).

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In this modern context, it is understandable that effective communication seems to be a partial function of the popularity-based commercial background associated with most of the “free Internet” available to the public at large, since companies rapidly recognized the power of such a communication channel. In this manner, the more individuals promoting a specific topic, usually due to its commercial value, the more likely that such a topic would survive for longer on the Internet. We all have seen examples of the latter in the form of straightforward, short, “viral” pieces of information. Scholars have documented that most individuals do not remain focused on one webpage when “surfing the Internet” for longer than 10–20 s, unless they find something interesting (Gong et al., 2012), and this pattern has modified the way messages are communicated. However, just how easy is it to create such effective messages with information on living organisms? The average person is already very much aware of many different kinds of macroorganisms, ranging from trees to household pets. What about microorganisms to which most individuals cannot relate? Most academic communication strategists are still debating on the effectiveness of the different styles of scientific literacy approaches (MacDermott and Hand, 2015). However, there is a large consensus on the fact that Internet-based strategies should be a key element in any type of communication plan that is developed. That does not imply that communication should only take place in this platform because written works and classical human interaction would always be imperative (Raber and Richter, 2008), but it demonstrates that the Internet should be present in the desired plan of communication. Nevertheless, it is important to keep in mind that modern online-based communication is designed in short, straightforward, highly stimulating pieces. In this sense, myxomycetes have the advantage of forming beautiful fruiting bodies that when photographed or recorded with special techniques can communicate strong biophilic messages about the microscopic world around us.

The coauthors of this volume and myxomycete specialists worldwide have used their own ways to transfer accumulated knowledge in spite of their own limitations in the field of human communications. That is simply one of the shortcomings of the academic training in science. Despite that, some have even developed websites and online resources devoted to the myxomycetes and the dissemination of information around and beyond their scientific projects. In fact, most of the myxomycete specialists worldwide at some point in their lives have become teachers, either in formal academic venues or in informal ones. Also, the present volume was developed as an effort to maintain the natural process of communicating condensed information on a group of microorganisms for which a comprehensive text had not been published for almost a half century. What all this means is that very likely there has never been any point in history when such an active attempt to communicate information on myxomycetes has existed as at present. However, it is the responsibility of all science communicators, teachers, naturalists, and myxomycete professionals to understand that integrated messages are also much more effective than simple monothematic ones (Thorson and Moore, 1996). In this manner, it is not the same to provide a message on the taxonomy of myxomycetes, whether it is classical or molecular-based, by itself as opposed to integrating such a message in the context of technique development, the relevance of scientific consensus through debate, and why, in the end, for a nonscientist, taxonomy and myxomycetes ultimately matter as well.

A relevant point to consider in this discussion is that myxomycetes are an excellent gateway for individuals to enter the world of microscopic organisms (Keller and Everhart, 2010). The fruiting bodies of many species are simply beautiful, their life history intriguing, and their potential still understudied. Since research is driven by curiosity, these organisms are fantastic for integrating such elements of scholarly dissemination of information along with modern multilevel (i.e., political, social, and ecological) trends.

During the past few decades, myxomycete specialists, as well as many other biologists specializing in various other taxonomic groups, have faced a common problem. The number of individuals, particularly students, interested in classical aspects of biology has decreased, or at least that seems to be the general consensus. The traditional strategy to counterbalance such a phenomenon has been to reach out and develop different types of workshops, hands-on activities, and field-based forays. The latter has resulted in an increasing number of “amateur” groups of individuals, some of whom possess very specialized knowledge of taxonomic aspects of the more prominent groups of organisms. However, this trend is highly dependent on many socioeconomic variables that allow individuals in different regions of the world to show those levels of organization. In this manner, the relevant question is how efforts can be socioeconomically balanced out when most of the world does not have the much-needed, respective specialists or communication facilitators to “plant the seed” and mobilize such initiatives in the first place? This core issue seems to be a good stage for integrated global communication approaches, such as online courses and video-based online strategies. However, for a section of the world where the Internet is a simple fact of life, it is hard to remember that there is still a large section of the human population for which these strategies are technologically limited. These are the cases in which classical approaches still matter and the reason why educators should not give up on using traditional techniques. As we have argued, the biophilic relationships that some individuals can establish with organisms, such as the myxomycetes, may be relevant in the process of communication.

Along with the problems associated with communication channels, language barriers can impose an obstacle to the strategies of communication used to disseminate information on myxomycetes. As is the case for most groups of living organisms, English is the language most often used for scientific publications. Even though some popular works and several scientific works on myxomycetes have also been published in other languages, most of the important literature on myxomycetes is still in English. This shortcoming implies that local researchers in different parts of the world also have some responsibility in translating and communicating the mainstream information on myxomycetes in their local languages. Only with a multilanguage effort effective communication can be reached at larger geographical scales. In this regard, noteworthy achievements are represented in the works of Neubert et al. (1993, 1995, 2000), Hagiwara and Yamamoto (1995), Lado and Pando (1997), Poulain et al. (2011), and others, which in addition to being based on many decades of field research on myxomycetes, have attempted to communicate myxomycete information in languages other than English for regional populations of readers.

Despite the different strategies of message communication, it seems that the most effective way to transfer information is with mixed approaches (Jewitt, 2012) coming from committed groups of individuals, specialists or not, and directed toward one group of organisms. In this sense, citizen-science approaches could be an effective way to develop complex networks to share information on myxomycetes, given their multiple characteristics for biophilia-based (Wilson, 1984) integration with several aspects of the human lifestyle (i.e., they are simply beautiful and we want them around). After all, myxomycetes can be observed and detected in the field by amateurs and specialists, and basic training could be accomplished with committed individuals at a comparatively low cost. Such strategies should be one of the relevant topics of conversation in professional meetings and nonacademic forums for common strategies and consensus to be reached. This is the way to capture the attention of groups of policy makers who can match the scientific and popular developments relating to one group of organisms, such as the myxomycetes, with integrated approaches to manage nature that would consider other microorganisms, as well. In this end, when popular pressure exists toward the conservation of biological resources, particularly in social media, political groups seem to respond. The latter has effectively worked for common global issues, such as climate change and management of natural resources, and it has been effective for NGO-based efforts directed toward flagship species. However, there is still much work to do to make individuals understand that nonvisible microorganisms that may not have the marketing capability of larger organisms do perform an important role and even have a high value for the dynamics of biological systems. In fact, there is still much work to do to make the public generate hedonic relationships with noneconomically important organisms. After all, not everything has to have a visible value.

In this sense, outside of classrooms and laboratories not much is known about myxomycetes. Despite this, individual efforts from professionals, naturalists, academic groups, and organized individuals have still attracted attention toward myxomycetes. Their aesthetic beauty has been an aspect of fascination for the nonspecialized public and several volumes on groups historically linked with myxomycetes have been illustrated with images of these organisms. As an example, Fig. 13.1 shows the alternative option for the cover of the present volume and demonstrates the beauty and versatility of myxomycete images, as well as their associated biophilic message with respect to the world of microscopic

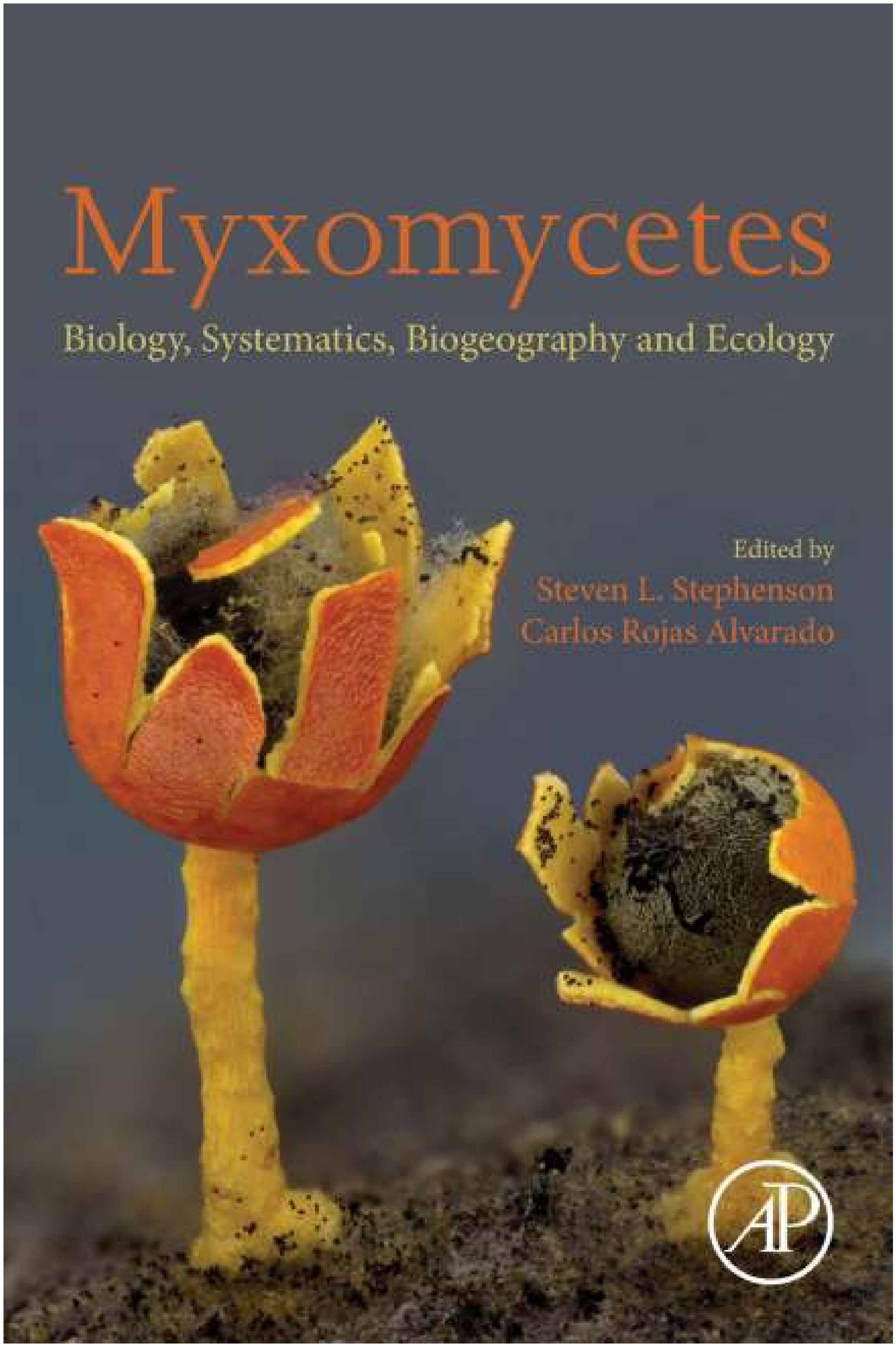

FIGURE 13.1 Alternative cover volume design evaluated for the present volume. The image corresponds to a *Diderma miniatum* collected by Dr. Carlos Lado in Peru and photographed by Carlos de Mier in the Royal Botanical Gardens of Madrid, Spain.

organisms. There is no doubt that nonspecialized eyes seeing such an image (or the selected cover of this volume) would still find it appealing and interesting.

However, when talking to a layperson about locally known plants or animals, it is still much easier to relate to what they already know than with such cryptic topics as microorganisms. In fact, personal accumulated knowledge on microscopic organisms is likely very low for most the world population. This is ironic, since microbial systems are essential for the existence of specific ecosystems (Pointing and Belnap, 2012), commercial products (Velivelli et al., 2014), and lifestyles (Kramer et al., 2013). For example, myxomycetes have been recently reported to absorb heavy metals (Rea-Maminta et al., 2015) and thus have been proposed as bioremediators, but most individuals ignore this information. The widespread low level of microbial literacy is a constraint for the true integrated development of applied strategies, and in developing countries the valuation of microbial-based ecosystem services seems to be a black box still waiting for attention. We are not proposing a commercially based approach to address myxomycetes since their real value, as with several other groups of organisms on the planet, may simply be related to their very existence. However, such an applied field of knowledge is still in a very basic stage.

Such a constraint has been detected by both economists and biologists and even though some individuals would not agree on a quantified economic strategy based on the concept of natural capital, this concept has allowed economic theory to enrich the models used by natural science and particularly conservation specialists. In this way, biological systems are conceptualized as organizations of sinks, sources, and flows or quantifiable energy that permit human social systems to utilize both goods and services from nature. Of course, the key element is the maximization of the human-nature interaction in terms of sustainability and intelligent, responsible use of resources. However, how accurate such models can be in systems where microbial ecosystem functions are poorly documented? What about myxomycetes, whose trophic stages are extremely poorly studied (Chapter 9)? To cope with such limitations, the elaboration of interesting ideas for human development toward balancing conservation and utilization or resources has been an active task of policy makers in the past few decades.

For instance, the economic strategy for more equal development known as the triple helix (Leydesdorff, 2013), which calls for three sectors of society—academia, government and industry—to be engines of development has gained recent popularity in some countries. Most developed countries in the northern hemisphere have understood such a concept for decades and even though the system has weakened due to globalization and free-market dynamics, it still somehow works in these areas. The problem in developing regions is that the lack of long-term political, economic, and social stability has not permitted a true development of academy-based research, social outreach, and scientific empowerment in political spheres. In these areas, more than in developed countries, private industries are disconnected with universities and local governments. The latter are expected to perform an auditing role on the former while universities are expected to do the same on both governments and industries.

Of course, the true development of a scientific path moves forward more rapidly when teams of organized individuals, independent of their origin and approaches, share common interests and work together toward achieving a goal. The accumulation of information presented in this volume is an example of the latter, since during the last 50 years or so, many individuals from different parts of the world have permitted the fastest rate of accumulation ever documented. However, as mentioned before, such a community of active researchers and individuals interested in myxomycetes still lacks the political leverage to introduce this taxonomic group of microorganisms in agendas outside the scientific environment. This is not surprising, taking into consideration that a larger and much more involved group of organisms in human development, such as the fungi, are also ignored for the most part. In this sense, it is imperative for everybody dealing with myxomycetes to use as many communication channels as possible and incorporate the group into as many different agendas as possible. For a true integrated strategy of natural resources management, sustainability and economic development, it is necessary to understand that microbial communities perform a unique role on the earth and that even though undocumented roles such as the ones performed by myxomycetes do exist, that does not imply that those organisms lack importance for ecosystem functioning.

RESEARCH PERSPECTIVES

Most of the research directed toward myxomycetes has been carried out in universities and research centers associated with academic institutions. However, extremely valuable input has been provided for a number of years by individuals who have not been affiliated with academia and yet have devoted their time to collecting, identifying, and understanding myxomycete relationships with the environment. Over time, very important contributions have been provided by both groups, and most myxomycete collections contain several records from both, as well. In this sense, it is important to acknowledge the role of nonacademically affiliated myxomycete researchers for the construction of hypotheses and generation of information about the group.

The modern constraint associated with the prominent role of researchers who are not affiliated with academic institutions is that they usually cannot apply for public funds and thus are limited to generating smaller scale datasets; they are more inclined to continue their research within a specific field of action (i.e., taxonomy) and they are usually not encouraged to train younger researchers. This is particularly relevant in areas of the world where myxomycete research is absent or slow since the process of generational change would reach only those younger researchers geographically close to these potential mentors. In contrast, when researchers from academic institutions obtain funds, usually through a network of collaborators, some money can be invested in training newer generations of researchers from different parts of the world and in connecting several disciplines outside the biological sciences. Given the reduced number of funding opportunities in the current global context, most academic myxomycete researchers tend to form strong international networks that extend by default their scale of action and influence. One of the most prominent examples of the latter has taken place in the past decade at the University of Arkansas in the United States, where a generation of researchers from North and South America, Africa, Southeast Asia, and Europe has been completely or partially trained. In this sense, the role of academically affiliated researchers may be more important for developing standard methodologies and continuing the existence of international networks. Either way, all valuable inputs for the generation of myxomycete information should be recognized, understanding the limitations of contextual elements.

What is interesting in the historical development of the generation of information on myxomycetes is that the internationalization of research seems to have been present for a long time. As has been the case for many groups of living organisms, the first documented processes of myxomycete study took place in Europe and rapidly transferred to North America (Lado and Wrigley de Basanta, 2008). After that, both European and American researchers started carrying projects in areas of the world that had been undocumented at the time; these included Africa and Latin America. Later, the Far East, particularly Japan, became an important source of information on myxomycetes and more recently, individuals in Southeast Asia have activated research in that part of the world. At this point, most of the ecological systems on Earth have been documented in one way or another and even though there are still geographical gaps to fill in, there is a "good" idea of the distribution of myxomycetes, based on the occurrence of fruiting bodies throughout the world (Fig. 13.2).

The internationalization of myxomycete research has taken a different shape in the last decades and turned into a collaborative effort directed toward the goal of understanding the phylogenetic position and molecular relationships among groups within the myxomycetes. This has been very important for the development of new hypotheses relating to the group but has created a modern technological and infrastructural gap between researchers based in developed and developing areas of the world. Since this phenomenon does not apply only to myxomycetes but to many other groups of organisms, some governments have created legislation to protect their own intracellular diversity, the potential use of the information contained at that level, and the intellectual property rights of local researchers.

Developing countries have been particularly active in regulating "access to biodiversity." This is a concept understood in an international legal framework as "access to biochemical, molecular, and genetic information," based on claiming moral rights associated with geographical location. The Nagoya protocol, sponsored by the Convention on Biological Diversity (UNEP, 2011),

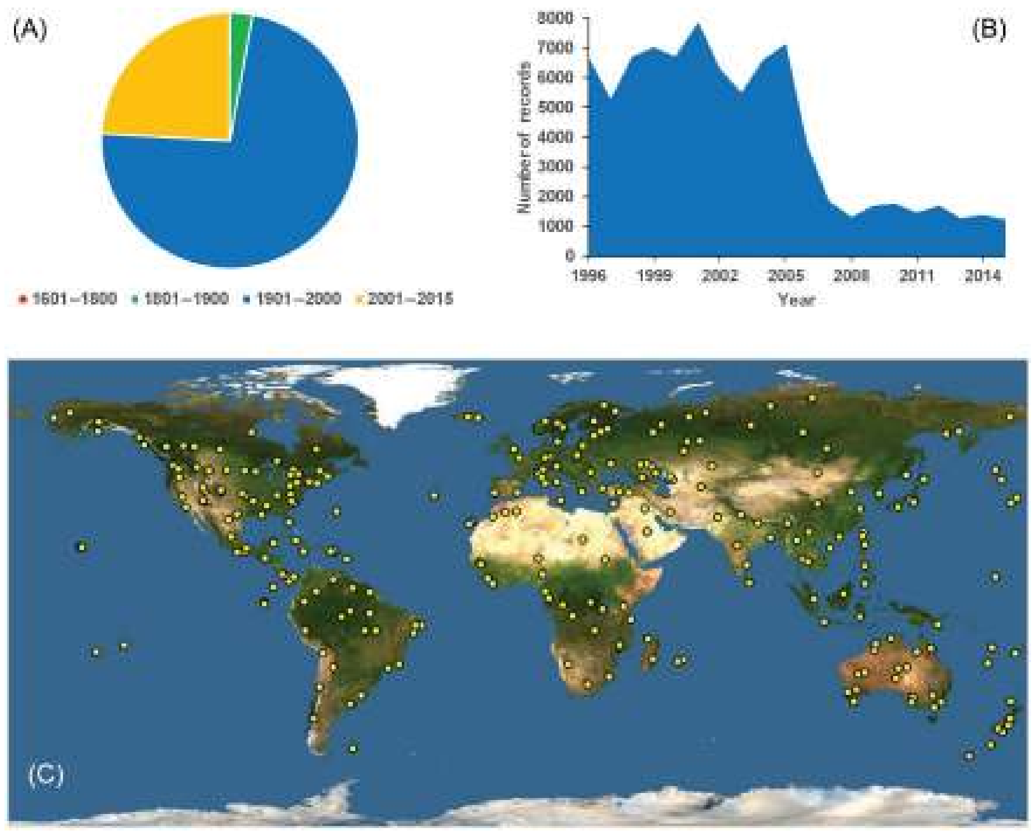

FIGURE 13.2 Myxomycetes have been studied since the middle of the 17th century, but most of the records included in the GBIF platform (A; www.gbif.org) were collected in the 1901–2000 period. During the most recent years, there has been a decline in the number of records in GBIF (B) even though the research activity has not declined. The distribution of genera, such as *Physarum* (C), clearly shows a cosmopolitan range even though several species, such as *P. echinosporum* (Chapter 8), have limited distribution (www.discoverlife.org).

which started in 2014, is one example of the latter. Up to now, this protocol has been signed by over 80 countries in the world, mainly in Latin America, Africa, Europe, Australia, and the Asian continent, and it has created a legal framework for the sharing of economic benefits product of bioprospecting and marketing of biodiversity. The issue observed by some individuals (Richerzhagen, 2014) is that this protocol also limits the capacity of foreign researchers to operate projects in signatory countries, since it does establish that local counterparts should be part of the project.

Modern myxomycete research should take place in this specific environment, which differs dramatically from the setting of any other time in history. Only a few years ago, the regulatory framework for biological research, particularly examples focusing on the generation of molecular information, was more loosely established in most countries. However, even for basic routine tasks, such as movement of collections from one country to another, most internal regulations establish the signing of bi- or multiparty research agreements, material transfer agreements, and the previous signing of informed consents between researchers and the owners, public or private, of the areas where research has taken place. The reality is that, in a similar manner to other types of researchers for other groups or organisms, most myxomycete scientists operate behind legal operative international regulations. This is one aspect that obviously must change in the development of research projects on myxomycetes worldwide, not only for moral reasons, but more importantly because the limited funding agencies that can still provide grants for myxomycete research have already complied, or will likely do so, with such international guidelines. However, it is important to critically analyze the role of such international agreements in terms of hindering or promoting research in the first place. In this manner, the responsibility of the younger generations of myxomycete researchers is to understand the current stage of international research to practice and transmit to their students/apprentices good practices for the implementation of international team–based research and the development of critical thinking skills.

In addition to such legal international limitations, one aspect that has been prominent in the history of myxomycete research is the classical monothematic approach taken by most researchers. There are limited numbers of scientific articles and notes on myxomycete research from any other perspective than the biological one. With the notable exception of some modern investigators who have developed applied research using myxomycetes in the fields of civil engineering, computer sciences, medicine, pharmacy, and alternative energy strategies, there are limited historical examples of myxomycete applications. This volume contains a complete chapter (Chapter 11) devoted to such topics, but alternative approaches on myxomycetes are traditionally not considered by most researchers due to their classical biological background. In this sense, there is a whole field of work for the future in these directions if different groups of individuals receive information on myxomycetes and learn about their fascinating life cycles, system relationships, and potential for various applications. At least for some parts of the world, the basic surveying and accumulated knowledge on the myxomycete biota present within political or natural boundaries already exists, and more applied projects for human development using myxomycetes could be designed. Even though this is not the case for most of the world, given the technological gaps between developed and developing countries already discussed, the latter research path may represent an alternative for some groups of researchers based in developing countries and for multidisciplinary approaches to be executed in these areas. It is important to mention that all or most of the currently integrated ecological methodologies can be applied to the study of myxomycetes.

However, the development of intraacademic merging and collaboration should be promoted in the first place for this type of proposal to be maturely designed and academically supported. The reality is that within academic institutions, particularly those of a comparatively large size, most scholars are disconnected from the research efforts of other individuals within the same institution. Similarly, it is very hard for most individuals to keep up with scientific developments with all of the multiangled social stimulation provided by the modern lifestyle. It would be very difficult to produce a general communication channel that could keep individuals interested in myxomycetes for long periods of time, but it is probably not so difficult to generate such channels for specific social subgroups. In this sense, a multidisciplinary approach integrating specialists in other disciplines of human knowledge could help the more classical myxomycete scientists disseminate their work in more creative and effective ways. Whether or not such a strategy could create a local "snowball" effect would be determined by the context, but most myxomycete specialists, academic or not, are recognized in their particular workplace, regardless of the general interest that other colleagues may have on myxomycetes.

Whatever strategies for the development of future research lines may be generated, in the modern context myxomycete specialists have recently been and will likely continue to reach out to colleagues in other disciplines to design more creative projects as well. This type of skill for a multidisciplinary approach is important to transmit to the younger generation of myxomycete specialists, in a manner that would give equal importance to the transfer of knowledge at both the information and the disciplinary formation level. For a group of organisms, such as the myxomycetes, which will likely continue attracting much less attention than their vertebrate or botanical counterparts, it is imperative to provide a much more integrated conceptual framework for research to take place. For example, it may be very attractive for younger researchers to begin using modern techniques to generate data and produce popular articles in spite the fact that there are still many basic questions on myxomycetes that have not been answered. In this way, a balance between the two fields of action is necessary, since the key to biological comprehensiveness is the integration of results through theoretical elements. In the end, science is the activity responsible for the identification of patterns in nature, and this can be substantiated only from many different angles when researchers work from several different perspectives.

In this sense, it is important to understand that the advancements, both theoretical and experimental, generated for a group of organisms are a byproduct of the intensity and effort of work over time. Since myxomycetes have not been studied with the intensity of other groups of organisms, there are still several basic questions to address, and there are still many possibilities to readdress questions with modern techniques and higher resolution datasets, particularly with the extremely understudied tropic stages. This is currently an active approach in the taxonomic and phylogenetic areas of myxomycete research, but it could easily be applied to ecological and biogeographical fields, for example. For some very well studied parts of the world, perhaps this approach is the next logical step.

The effective execution of myxomycete research projects depends heavily upon two main aspects: namely, human expertise and infrastructural/equipment capabilities. We have addressed the fact that a large gap between developed and developing areas may exist due to intrinsic modern characteristics of both areas. However, for those developing regions, countries, for example, that may lack a high level of human expertise on myxomycetes, it is crucial for researchers to develop plans for the improvement of conditions and learn from the lessons of colleagues. It is understandable that not all developing regions have the same capacities, but there are always opportunities to address issues and improve research conditions. This does not mean that everybody should carry out the same tasks or do the same work in different geographical regions, and points more toward understanding in which directions the local capability may grow and improve and which directions may not be feasible for future growth. For the latter, it is the establishment of relationships with other complementary groups that could determine the success of the global research endeavors.

In either case, one aspect that is important to remember is that, due to the modern constraints of the research environments, most individual efforts should become local team strategies. Contrary to past research, the modern paradigm of research calls for teams rather than for individuals. In this sense, research networks are essential, and whether they are national or regional, they are very important. However, local-based teams, within the institutions or the organized groups where the effort to study myxomycetes arise, are a key element for the execution of modern comprehensive projects. These teams not only provide an increased effort to generate more robust datasets but an internal leverage that can boost the support to the research initiatives. In this sense, some scholars have pointed out that the formation of a critical intellectual mass on one topic of human knowledge is a key for the correct implementation of plans and ideas (Guest, 1997). When this is implemented at the local level, it may provide the necessary boost for the lead local researchers to move on with their plans for research.

An example of the latter is the well-documented advancement of techniques and protocols for molecular analyses of myxomycetes. Only 2 decades ago, when other living organisms already had baseline work in place, most of the work on myxomycetes was in a very early stage of development. However, the modern trend to look at molecular data for different types of biological analyses created a need to move research in that direction, fostered teams to work together and helped these individuals generate the much-needed ground work that determined the protocols used today. Even though this field of action is still ongoing and new developments are generated every year by different teams of researchers, it took a longer time for myxomycetes to be documented at a level equivalent to the levels of many other groups of organisms. These types of technical challenges, better addressed in other chapters of this volume, have created important limitations for the generation of information on the group. Moreover, as already mentioned, it has also indicated that more applied lines of investigation are still in very early stages of implementation.

CONSERVATION AND MANAGEMENT

Most areas in the world have not yet been well documented with respect to the diversity of myxomycetes (as represented by fruiting bodies) present, the functional diversity of the group is still understudied, and survey efforts are currently not normalized using appropriate standards. In this situation, it is very hard to determine the management status of the different species or groups within the myxomycetes and thus design appropriate methods for their management. In recent years, there have been initiatives to create groups of researchers that can propose guidelines for the management and conservation of myxomycetes. An innovative example was the effort of Schnittler et al. (2011), who put together a red list analysis using a threat and conservation approach for German myxomycetes. In this work, the authors tried to cover the dissemination of knowledge about myxomycete ecology and natural history in Germany, they compiled a checklist of myxomycetes for that country, and attempted to assess multiorigin threats to the existence of the group. However, the current baseline information associated with most biological systems in the world is so basic that it seems impossible to accomplish a similar task for most other regions at the present time. When only the biodiversity aspect is considered, it is still hard to determine for most species of myxomycete whether they are becoming rare, are simply uncommon or are strongly associated with specific biological systems (or geographical zones) and thus not present in most others.

Although some species of myxomycete are currently included in several regional Red Lists, there are several methodological and terminological problems in the evaluation of their conservation status with respect to IUCN criteria (International Union for Conservation of Nature and Natural Resources). The IUCN Red List criteria assign species to categories of extinction risk, using quantitative rules based on population sizes, population decline rates, range areas, and range declines. The IUCN quantitative analyses estimate the extinction probability of a taxon based on its known life history, habitat requirements, threats, and any specified management options. The analysis of population viability is an example of such approach, and it is expected that quantitative analyses make full use of all relevant available data. In a situation in which there is limited information, whatever data are available can be used to provide an estimate of extinction risk. However, the application of the IUCN criteria to myxomycetes in fact generates more questions that the actual applicability of the current methodology, due to the life history and characteristics of the group. For example, how is an "individual" defined for myxomycetes? Can changes in population size be assessed in myxomycetes? How can population growth rates be determined for myxomycetes? What is a "population" in myxomycetes? Is it possible to determine the dispersal ability of species within the group? What is "endemic" and "rare" for myxomycetes?

As we can observe, it is not easy to identify what constitutes an "individual organism" for myxomycetes because their life cycle includes partially documented life cycles, one reproductive stage and two vegetative ones, several morphologies at all different levels and limited documentation of population-based parameters. Should single fruiting bodies or groups of crowded fruiting bodies be counted as one individual? Despite the obvious constraints of such methodology, IUCN approaches require practical protocols as well. Also, spores, plasmodia (except perhaps for protoplasmodia and those that give rise to aethalia and pseudoaethalia), and amoeboflagellates provide evidence of the occurrence of myxomycetes in a specific microsite or locality, but they cannot be counted as individuals. There is no feasible way of assessing either the absolute or relative abundance of each of these stages in myxomycetes, even on a limited spatial scale. The absence of such data makes it impossible to evaluate population sizes following IUCN criteria (Kryvomaz and Stephenson, 2016).

Moreover, appreciable changes in species composition, overall abundance, and diversity are observed for myxomycetes from 1 year to the next at the locality level. In theory, it might well be possible to assess changes in at least some microhabitats (e.g., soil) with the use of direct environmental sampling with some of the molecular techniques now in use, but such sampling would be limited to relatively small microsites, and it is highly questionable that these would be of any value in assessing population changes for the entire habitat. A population, as defined by IUCN, is the total number of mature individuals of the taxon. It is the fundamental basis for the determination of the critically endangered (CR), endangered (EN), or vulnerable (VU) categories. Such determination is performed by calculating the reduction in population size in the past and predicting what the size of the group of individuals will be in the future. However, quantitative studies of myxomycetes have not yet produced data of this type. Records of myxomycetes are based almost exclusively upon fruiting bodies collected in nature or recovered in moist chamber cultures, but there is no way of knowing what the numbers generated in this approach represent. The typical number of functional individuals at an average site could be interpreted for myxomycetes as the total number of functional individuals over multiple years. It is important to consider both known localities and an estimate of the likely number of unrecorded localities to obtain an estimate of the total number of localities and hence the total population size. There are relatively little data on the variation in abundance displayed by species of myxomycetes during a single season or over several years. Most studies are carried out during a single expedition, and this type of effort does not yield data about phenology. As we can see, the knowledge of the spatial and temporal distribution of myxomycetes in the various microhabitats in which they occur is still far too limited.

Given that scenario, an interesting proposal to consider for the conservation of myxomycetes is the "microhabitat approach" proposed by Schnittler et al. (2011), in which the target of conservation is the microhabitat used by microorganisms rather than the species. This is similar to the idea of targeting ecosystems rather than individual species of macroscopic organisms due to the added value of ecological networks, ecosystem functioning, and the maintenance of important biological processes (Cadotte et al., 2011). Using this approach, the determination of the species of myxomycetes involved could be carried out by consolidated specialists, the modern research approaches could be the responsibility of highly trained students, and the basic ecological quantification could easily be determined by conservationists and/or laypersons. Such a division of labor has the potential of increasing the quality and quantity of data in several important selected biological systems worldwide.

Despite the lack of a consolidated strategy for the conservation of myxomycetes, the role of different actors in the successful inclusion of myxomycetes in the lists of managed groups is a key for the development of standard guidelines. Since several other groups of living organisms have already been included in regional and international management systems, the different stakeholders in the field of the conservation have already accumulated experience in the creation, implementation, and control of such systems (i.e., NGOs, government branches dealing with conservation, universities, and communities of individuals surrounding protected areas). In this way, there is no reason to think that most of these management models would not work on myxomycetes, particularly those created to apply to microscopic groups (like the "microhabitat approach"). In fact, such consideration might even represent an interesting option for some myxomycete specialists to engage efforts in an integrated field that makes use, but not exclusively, of biological information.

The concepts of management and conservation require more integrated, ideally holistic strategies and multidisciplinary teams than most classical biological topics. However, it still seems that most myxomycete specialists are disconnected with these types of initiatives and, as mentioned earlier, most projects designed in the past decade target intrinsic aspects of the biology of myxomycetes, such as their evolutionary path, phylogeny, and molecular taxonomy. The latter does make sense considering the limited available information about myxomycetes using modern techniques during the period when those protocols have been used. However, it still points out the fact that most myxomycete research is limited in its applicability for other disciplines, multidisciplinary design, and conceptualization in the context of management and conservation.

Most individuals involved in wildlife or nature management understand that when it comes to nature there are two main discursive approaches in the field. The first one is the classical scientific path that attempts to manage nature based on empirical data collected independently by groups of researchers. Advocates of this approach tend to use primarily "hard" data to make conclusions that can be used for the rational management of the biological group or system under scrutiny. The second approach is the politically supported path in which decisions are made based on contextual elements taking place at a larger scale within national or international political agendas. With this strategy, the management of biological groups or systems is primarily seen as a function of current international pressures, legislation in place, and even popularity of jurisdiction-level decisions. In practice, most universities and research institutions tend to favor the first approach, whereas NGOs and governments primarily use the second one.

The goal of any stakeholder in the management and conservation field is the implementation of sustainable practices associated with the preservation of either a group of organisms or the biological systems sustaining such a group.

In this manner, since such preservation should theoretically be as strong as possible, it seems illogical to believe that only one of the approaches mentioned earlier would be enough to provide the requirements for a realistic implementation of a management program. Most successful conservation stakeholders have learned over time that a series of social, cultural, economic, political, historical, and spiritual variables play an important role in the successful implementation of the initiatives and that strongly biased approaches usually fail.

In this sense, most individuals would not understand why some conservation teams are performing "perceptional" or "conceptual" studies in relation to the management of nature. However, it is easy to understand that one of the keys of sustainability is the promotion of local actions in favor of local communities. As such, it seems highly unrealistic to determine large geographical-scale guidelines for the management of biological systems without considering the homogeneity of perceptional social systems within the same geographical unit. Such a mistake has been documented to undermine the value of some visions of life, usually practiced by small, nonpowerful social groups, and conceptually empower those already with power. For myxomycetes, for example, it is very interesting to see the historical empowerment and current semiindependence of some geographical areas where myxomycete specialists have worked. This is not surprising given the local natural extensionist action of researchers, but it shows that there are simply not enough researchers of myxomycetes worldwide to cover a large extent of the planet. However, the observed normal evolution of myxomycete research has not only enriched the field through healthy competition and different project designs but also favored much needed research synergies, training of young researchers, and institutional collaborations. Such a legacy should be maintained by the current and the next generation of myxomycete specialists and even boosted through more integrated approaches that also consider the multiperspective considerations mentioned earlier in this chapter.

Given all of these considerations, does it make sense to generate strategies for the conservation of myxomycetes? To what extent are these organisms really threatened (certainly a difficult question to address)? Or should they be simply included in conservation agendas targeting microbial diversity? It would have been easy to justify either path if myxomycetes were documented to affect in any way our human lifestyle, but it probably does makes more sense to include them in general microbial conservation programs given their relative innocuity. The reasons may come from two different directions. On one hand, most microbial communities beyond the myxomycetes are also poorly documented in most biological systems worldwide, and on the other hand, the case of most discrete nonpathogenic microbial communities is hard to make due to the cognitive distance between mildly innocuous microbes and human societies.

For instance, it is reasonable to think that only some groups of microscopic organisms have a positive health effect on societies; however, due to the poor documentation of across-group microbial relationships, there is a current trend to generalize the concept of microbial conservation for collective health (Berg et al., 2014; O'Doherty et al., 2016; Panizzon et al., 2015). In that scenario, it seems reasonable to include myxomycetes in the groups of organisms to be managed, but such a trend also shows one more fields of work where myxomycete specialists could potentially engage with public health researchers. There has been some research directed toward the potential health interactions of myxomycetes and humans, particularly with respect to allergies (Lierl, 2013), but the documentation of a more complete scenario has not as yet been carried out in a comprehensive manner.

In terms of ecological relevance, the topic of management and conservation of myxomycetes is also limited in extent, scope, and design. As mentioned earlier in this chapter and more thoroughly in other chapters of this volume, most of the historical research on myxomycetes has been primarily taxonomic and most of the ecologically meaningful relationships studied by researchers comprise only a basic glimpse of the interactions of the group and the surrounding biotic and abiotic elements. It is perhaps safe to say that most of the conceptual advancements in the ecological study of myxomycetes were developed in the first part of the 20th century and that most modern researchers have supported the "gap filling" problem at this point. Most ecological research has either taken a basic approach or considered the ecological relationships as a byproduct of the taxonomic goals pursued. In that way, the ecology of myxomycetes as we know it today is a compendium of natural history and biology of the particular species or assemblages of species and not necessarily a more complex depiction of network interactions, energy flows, and life cycle–integrated analyses entangled in theoretical biological elements.

Interestingly, myxomycetes have several particularities that can be explored in depth from different perspectives in the future to develop such theoretical connections and strengthen the working vision of research teams. For this reason, and also given the recent advancements in the techniques and approaches followed by researchers, it seems logical that the near future may witness many interesting ecological elements relating to myxomycetes that are as yet undocumented in the published literature.

Such potential advances would be more relevant if conceptual elements of the management and conservation approaches were considered. As mentioned earlier, integrated stories tend to be favored, particularly at the granting agency level, over simple ones. For instance, the topics of microbial trophic networks, gene flow, forest fragmentation, and ecosystem services could be adapted to construct an integrated project intended to document the landscape-mediated gene flow capacity of microbes in the framework of management and conservation of ecosystem services. Such a comprehensive project sounds different from simply focusing on the different parts, and it may provide more data on the contextual interactions that affect the biology of the group with the advantage that it can also generate information for those researchers working on the conservation strategies of myxomycetes.

It is understandable that at the local level there should still be efforts to document taxonomic assemblages associated with different forest types, substrates, and other ecological compartments. However, at the regional and higher levels, efforts should target the integrated approach recently mentioned while also including elements for the development of new lines of research. This is the reason why teams of researchers are necessary for larger geographical scales and the reason why extensionism and training, either through technology-based strategies or other techniques of communication, should still take place.

Despite the latter, it is important to remember that myxomycetes, as is the case for any other group of organisms living on the planet, do interact with our species and that there are several other issues for which there may only be limited documentation that could be studied in the future. In particular, the negative effects on myxomycete populations facilitated by global phenomena, such as climate change, land use change, and human-mediated dispersal (i.e., myxomycetes as invasive species) are good areas for future study within the field of conservation. For instance, since temperature and moisture are thought to be the main factors limiting the occurrence of myxomycetes, the anticipated changes in climate regimes are almost certainly going to have a significant impact upon their distribution and ecology. This will likely be true for those species of myxomycetes restricted to specific types of microhabitats (e.g., alpine snowbanks), for those which are confined to geographical areas that are limited in extent (e.g., small oceanic islands), and for assemblages of species associated with deserts and the polar regions of the world, which are highly sensitive ecological systems. But any evaluation of the impact of climate change on myxomycetes is extremely difficult. The main question is whether myxomycetes react to climate change at all? If they do react, in what way is such effect expressed? Are there any species of myxomycetes that might be threatened by climate change? Is it even possible to assess a cause–effect relationship for organisms that are ephemeral and usually so hidden in nature? In future research, at least two possible effects of climate change should be clearly distinguished.

First, the effect of climate change on the composition of myxomycete assemblages, which does not necessarily consider the threat to individual species, must be assessed. Second, the effects of climate change on a particular species of myxomycete, which may well be threatened and thus would warrant inclusion on Red Lists, needs to be evaluated. Using species distribution models, modeling metapopulation dynamics and various other methods are difficult to apply to myxomycetes, in part because there are limited (and rather fragmentary) data available from studies of their distribution around the world. Moreover, distribution data are based on the visible stage in the life cycle—the fruiting body—which is possible to find and identify but only reveals limited information regarding the abundance of the species. Truly definitive confirmation of species occurrences at a specific locality would require a DNA-based analysis of soil, organic matter, living plants, atmosphere, and water—essentially any place where it is possible to find myxomycetes in one of the cryptic but active stages of their life cycle (i.e., amoeboflagellates and plasmodia). Most of the data about the occurrence of myxomycetes in many areas of the world is based on the results obtained in single expeditions. To truly determine the impact of climate change on the distribution of myxomycetes, there needs to be regular monitoring of myxomycete habitats in several study sites, where all possible climatic parameters (e.g., amount and type of precipitation, humidity, and temperature) would be recorded daily, weekly, monthly, seasonally, and on a yearly basis. Only then would it be possible in that way to determine the ecological resilience of myxomycete populations and the role of biological systems to modulate such resilience. All these future directions of study around the concept of climate change may provide much needed information on myxomycetes, contribute to the multidisciplinary approach and collaborative efforts to study the group, and construct the basis for more complex research projects involving the myxomycetes as a group, or of a particular species of interest within the group.

The management and conservation of myxomycetes should not be a discrete field of action within the community of myxomycete researchers and specialists, but a common horizontal element embedded in any project on myxomycetes. The likelihood of microbial groups to be integrated in more formal conservation efforts depends heavily on the activity of the research community and their interaction with other individuals, agencies, government offices, NGOs and the public. The strategy should probably look to integrate myxomycetes in more general efforts to manage and conserve microbial communities, taking into consideration their important participation toward ecosystem functioning and, by default, the goods and services provided. In this sense, it is also imperative to begin integrating this element in professional meetings and in extension programs more strongly than in the past, to generate other types of support from the academic and the general public communities as well.

PUTTING THE PIECES TOGETHER

Modern researchers, specialists, and individuals interested in myxomycetes face a common shortcoming, the poor geographical documentation of the group (although better than for most other groups of protists) and the limited availability of integrated information have not moved myxomycetes higher up in social agendas. Except for some myxomycetes that have been studied as model organisms, the biology of most species and the two tropic stages in the life cycle are poorly documented. Most of the work on the group has been strictly scientific, and specialists have not looked to include this in their environmental plans. The range of action by myxomycete specialists has been limited by their number and their monothematic vision of work. Language barriers, training centers for newer generations of specialists, and a large infrastructural/technical gap between developed and developing institutions are still present worldwide.

Despite these challenges and obstacles for the generation of information in myxomycetes around the world, this is the most active moment in history for the documentation of the biology or myxomycetes. A very tangible proof of the latter is the present volume, which summarizes through the eyes of world-class researchers and specialists, the accumulated knowledge on myxomycetes during the last half century or so. Since a multidisciplinary approach, including elements from applied sciences, education, and communication has been pursued herein, it is expected that this volume will represent a major contribution to the development of myxomycete activity in the foreseeable future.

However, it is still the responsibility of all the individuals involved one or way or another with myxomycetes to promote the inclusion of the group in other fields of research. Topics, such as management and conservation, climate change monitoring, and applicability of myxomycetes in new areas of science, should be transversal elements in the development of research in the future. A mixed-channel, multilanguage approach to disseminating data and more modern communication strategies should be used by teams of researchers looking to sustain integrated lines of research (Fig. 13.3).

Given the accumulation of information on myxomycetes facilitated by researchers in the past and the newer developments generated by modern teams, it is necessary to give credit to the comparatively smaller number of individuals that have engaged in the generation of information about the group. It is understandable that a deeper disconnection between the nonspecialized public

FIGURE 13.3 Word map showing the concept relationships among communication strategies, research, and conservation/management of myxomycetes proposed in the present chapter. This is intended to serve a basis for debate in different spaces and to promote the discussion of nonbiological elements in biological venues. As observed in other chapters of this volume, the community of myxomycete researchers also use the word "myxos" to refer to them.

and myxomycetes has always existed than is the case for other groups of living organisms, such as vertebrates and plants. However, it seems about time for myxomycetes to be included in general microbial conservation agendas and other types of social efforts with the objective of managing more responsibly the natural resources of the planet. Biological systems and important energy transfer networks relying on bottom-up dynamics could use integrated information on myxomycetes to quantify more accurately their own organization and, with that, provide policy makers with arguments to create guidelines for microbial conservation.

The natural paths taken by researchers at different moments in history are logical and contextual, and they should be embraced by the community of myxomycete specialists rather than criticized. At least in recent decades, the former has been the trend observed by the research community, and such a legacy of professional respect and tolerance should be maintained by the younger generations of specialists. Given the fact that more complex research designs, including transversal elements and deeper theoretical considerations, should be expected in the future, it is important for specialists to address their contextual limiting factors and understand their real capacities. This relevant task is key for the establishment of research groups that can work together, share capacities, and push the research goals ahead, particularly for a group of microorganisms for which there is still only a very limited number of specialists around the world.

Overall, myxomycetes represent a very interesting assemblage of microorganisms with many characteristics that are unique to the group. Although their formal study, as documented in Chapter 2 of the present volume, has accumulated over 350 years of work and a substantial body of information on the biology of myxomycetes is currently available, there is still plenty of room for new research to be carried out. The higher resolution capacity of modern techniques and the possibilities of multidisciplinary integration provided by the current research pressures, represent both challenges and opportunities for the community of specialists on the group. In the 21st century, myxomycetes are far from being well documented from most of the different perspectives from which the group can be studied, and creative team-based work is necessary to move forward common goals intended to continue the documentation of the group. Several current researchers have understood this, but it is the task of the younger generation of individuals interested in the group to continue promoting the study of myxomycetes all over the world.

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