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DOI: https://doi.org/10.3897/arphapreprints.e94590

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GRANT PROPOSAL

APPLICATIONS FOR ZOOSPORIC PARASITES IN AQUATIC SYSTEMS (ParAqua)

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Abstract

Zoosporic parasites (i.e. fungi and fungi-like aquatic microorganisms) constitute important drivers of natural populations, causing severe host mortality. Economic impacts of parasitic diseases are notable in the microalgae biotech industry, affecting production of food ingredients, biofuels, pharma- and nutraceuticals.
While scientific research on this topic is gaining traction by increasing studies elucidating the functional role of zoosporic parasites in natural ecosystems, we are currently lacking integrated and interdisciplinary efforts for effectively detecting and controlling parasites in the microalgae industry. To fill this gap we propose to establish an innovative, dynamic European network connecting scientists, industries and stakeholders to optimize information exchange, equalize access to resources and to develop a joint research agenda. ParAqua aims at compiling and making available all information on the occurrence of zoosporic parasites and their relationship with hosts, elucidate drivers and evaluate impacts of parasitism in natural and man-made aquatic environments. We aim to implement new tools for monitoring and prevention of infections, and to create protocols and a Decision Support Tool for detecting and controlling parasites in the microalgae biotech production. Applied knowledge on zoosporic parasites can feed back from industry to ecology, and we therefore will explore whether the developed tools can be applied for monitoring lakes and reservoirs. Short-Term Scientific Missions and Training Schools will be organised specifically for early stage scientists and managers – with a specific focus on ITC – with the aim to share and integrate both scientific and applied expertise and increase exchange between basic and applied researchers and stakeholders.

Keywords: Host-parasite interaction; Microalgal biotech; Ecosystem monitoring

1. SCIENCE AND TECHNOLOGY EXCELLENCE OF THE PROJECT

1.1 Challenge

1.1.1 DESCRIPTION OF THE STATE-OF-THE-ART

The elevator pitch to the proposal- Industrial production of microalgae for fine chemicals, pharmaceuticals and energy has a market potential estimated in the trillion-dollar range[1]. Currently, zoosporic parasites in microalgal cultures impede the quality and continuity of large-scale production (see Box I). To improve microalgal health in industrial and natural systems, the ParAqua Action will create a network of scientists, lake managers and representatives from biotechnology to unlock, interpret, deepen and disseminate our combined knowledge on zoosporic parasites in both industrial and natural systems.

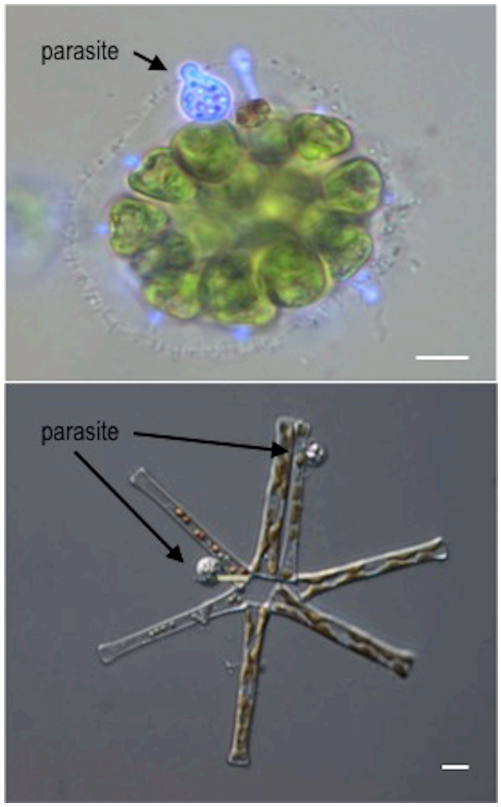
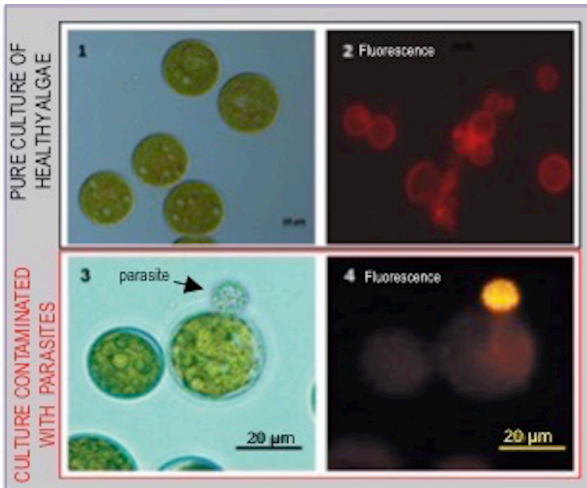


Figure 1. Microscopic images of microalgae infected with chytrid parasites. a. the chlorophyte Yamagishiella unicocca, where parasitic chytrid is stained in blue with Calcofluor White. b. the pennate diatom Asterionella formosa where arrows indicate parasitic chytrids. Scale bar 10 µm. Pictures from Silke Van den Wyngaert.

Zoosporic parasites of microalgae- Microalgae provide more than half of the planet's oxygen production and net carbon fixation[2] and form the basis of most aquatic food webs[3]. Moreover, they represent promising candidates for future challenges in the bioeconomy as renewable resources for food and feed[4] refined products such as pharma- and nutraceuticals, or as fossil fuel alternatives[5,6]. Microalgal biotechnology plays an important role in the Bioeconomy Strategy and Action plan for a sustainable economy, laid out by the European Commission and focusing on an economy based upon renewable resources[1,7,8]. Like any other living organism, however, algae are vulnerable to parasitic infections. Parasitism is the most common consumer strategy[9], and a large number of biotic interactions are driven by parasites such as viruses, pathogenic bacteria and parasitic eukaryotes[10-13]. Many aquatic parasites are characterised by having two life stages, a sessile stage on the host (Fig. 1) and a motile transmission stage as zoospores that actively search for new hosts. These parasites are known as "zoosporic parasites" and include members of several phyla (e.g. Chytridiomycota, Aphelida, Heterokonta, and Cercozoa). Zoosporic parasites influence planktonic succession[14,15], regulate host genetic diversity[16] and promote the trophic transfer of organic matter locked in inedible phytoplankton species through the production of edible and nutrient-rich zoospores[12,17]. Although parasites are important drivers that modulate ecological, evolutionary and biogeochemical processes (reviewed in[18]), they are usually regarded by their negative effects due to the morbidity and mortality effects on host populations. Indeed, parasitic infections can decimate algal blooms[19,20] and lead to amphibian extinctions[21]. In the past two decades, the number of emerging virulent infectious diseases has risen, boosted by global human activities, which intensify diseases by actively dispersing parasites[19] and by modifying natural environments[22,23]. Still, little is known about the impacts of a rapidly changing environment and emerging pollutants on host-parasite relationships[22,24]. A more coordinated research approach needs to be applied to effectively project future consequences of anthropogenic environmental change on the occurrence, impact and management of aquatic zoosporic parasites.

Risks of parasites for the microalgal biotechnology industry - Microalgae and cyanobacteria produce many products that are used as food, pharma- and nutraceuticals, as well as biofuels[5]. One of the major threats for this industry (from here named "algal biotech") lies in parasite epidemics, which lead to contamination and lower quality of the final product, severe reduction, or even crashes in production[6,22,25]. Unless infections can be controlled, it is unlikely that the full potential of algal biotech can be fulfilled[26]. Algae biomass production typically relies on high density monoculture crops, which- as is the rule in agriculture - favour successful invasion and rapid spread of disease and mortality inducing parasites[27]. A number of parasites have been identified in algal mass cultures in the last few years and this number is expected to increase with the rise in commercial algae production. For comparison, oomycete infections are responsible for 10-60% productivity losses in the seaweed industry per year[28]. Contamination by chytrids has been recognized as one of the most serious hurdles for the production of astaxanthin, a carotenoid sold as antioxidant (Box 1,[29,30]).



Images of *Haematococcus pluvialis* cultures from industrial members of the network

BOX 1 - IMPACT FOR INDUSTRY

Astaxanthin-producing *Haematococcus pluvialis* (see picture) are potentially highly vulnerable to fungal parasite infections, with implications for yield and quality, thereby limiting its application scale. Indeed, the biomass produced (kg $m^{-3}d^{-1}$) can be reduced of more than 50% at double prevalence of infection and the astaxanthin yield can be reduced by up to 80% upon infection (data from industrial members of the network). Currently, as solution, biomass is harvested before the contamination spreads. However, this method is unsatisfactory as it also leads to yield loss. Many patents propose the protection of *Heamatococcus* from contamination by chytrtids using hydrogen peroxide or fungicide. Harvests are pretreated to remove the undesired compounds, prior to the extraction of the product. In addition, many studies investigated controlling methods to contain or even reduce chytrids, like testing various drivers such as pH and temperature. Similarly to the early harvest, however, also these solutions lead to a lower harvest yield and are not always feasible. Early detection methods and an improved understanding of key abiotic drivers would greatly support control of chytrids in algal production industry, thereby preventing the use of chemical treatment of infections and safeguarding high yields

Outlook- Despite the recognized vast economic potential of microalgal biotechnology and the perceived economic impacts of parasitic diseases in this field, current scientific initiatives for a better understanding of the mechanisms and consequences of parasitic infections remain fragmented across Europe. Moreover, our understanding is hindered by insufficient exchange and collaboration between fundamental ecological research, institutions and enterprises that translate scientific output into water management and economic development. We here propose to organize a highly innovative, dynamic European network, connecting academia, industry and water management authorities, aiming to combine and apply knowledge and expertise on aquatic fungi and fungi-like parasites and the relation with their hosts in natural and industrial systems. Our focus is on parasites specifically adapted to aquatic life, i.e. the zoosporic forms characterized by a lifecycle that involves motile, flagellated dissemination spores, including true fungi (such as chytrids) and other fungus-like protists (such as oomycetes, labyrinthulids, thraustochytrid), and alveolates.

1.1.1. DESCRIPTION OF THE CHALLENGE (MAIN AIM)

The role of zoosporic parasites in aquatic ecosystems is increasingly acknowledged both in natural[18] and industrial - i.e. biotechnology – systems[25,31]. Scientific research on this topic is gaining traction by increasing efforts in elucidating zoosporic parasites diversity, occurrence, drivers, host co-evolutionary dynamics and role in food web structure. As commercial microalgae production continues to expand with a widening variety of applications, knowledge on the parasites associated with the specific host- species used in algal production, will gain in economic interest as the lack of control strategies to contain these diseases is a bottleneck in the development of a stable aquaculture economy[32]. Yet, integration of scientific efforts and merging of academic knowledge and economic interest in a joint research agenda is currently lacking. Whereas algal biotech has in depth knowledge on algal production, most of the knowledge on zoosporic parasites currently resides with aquatic ecologists. Water managers on their turn have in depth knowledge of the lakes they manage and the methods used for monitoring, but generally neglect the role of zoosporic parasites. Present research efforts are scattered across Europe and remain uncoordinated, thereby hindering progress and synergy, forcing many labs and companies to reinvent the wheel. There is, thus, an urgent need for a coordinated joint effort to build a collaborative platform linking science, industry and management, to exchange knowledge, identify and tackle pressing knowledge gaps about control strategies for aquatic parasites.

Our main aim is to uncover, harmonise and disseminate capacities for the identification and control of zoosporic parasite infections across Europe by creating a unique network of professionals from the algal biotech industry, academic research and water management. In ParAqua, we will synthesise and deepen our understanding of the complex host-parasite interactions at scales ranging from simple monocultures to complex ecosystems. ParAqua will produce an open Database, Fact Sheets, Protocols and a Decision Support Tool to the benefit of the European algal biotech industry, water management, and science. From this, we will derive parasite-control strategies that can secure sustainable algal biomass production and support monitoring and enhance a fundamental understanding of the role of zoosporic parasites in natural ecosystems. We will initiate an interactive, trans-disciplinary platform for an intensive collaborative exchange during our COST Action, which will allow us to develop and implement a full range of standardized methods and tools supporting professionals in the monitoring, control and treatment of zoosporic parasites in algal biotech and natural systems. We aim to maintain this platform in the long run, beyond the lifetime of the Action, by applying for additional funding, implementing the network in related funding schemes, and seeking connections with existing organisations. Ultimately, ParAqua aims to support European strategies to achieve several of the UN Sustainable Development Goals (SDG2-Zero Hunger; SDG6-Clean Water; SDG7-Clean Energy; SDG9-Industry, Innovation & Infrastructure; SDG14-Life below Water) by providing solutions for one of the most urgent problems in the algal biotech industry.

We identified a number of knowledge gaps, which ParAqua aims to fill by bringing together expertise from the aforementioned domains; academia, industry and water management. Identified knowledge gaps are: (i) An inventory of the possible negative and positive effects of zoosporic parasites in both industrial and natural systems; (ii) A full catalogue of observations on the occurrence of zoosporic parasites in European algal biotech and natural systems, including their phenology, prevalence of infection, and diversity; (iii) An inventory of the abiotic (e.g. temperature) and biotic (e.g. host abundance and diversity) environmental conditions under which infections occur to assess what drives parasitic development; (iv) An inventory of methods for monitoring and early detection of infection in conceptual as well as proven stages, to detect infections including at low concentration and early stage in algal biotech and natural systems; (v) A compilation of infection control methods used in algal biotech weighing their feasibility and (cost-)effectiveness.

ParAqua will help to fill the main knowledge gaps for the benefit of algal biotech and lake management across Europe while accounting for current scenarios of environmental change by developing, testing and implementing a number of Key Deliverables (for details see 4.1): (i) A database of the occurrence of zoosporic parasite infections and the environmental conditions under which they occur in algal biotech and natural ecosystems across Europe; (ii) A number of reviews, syntheses and opinion papers, jointly written by members of ParAqua that bring together data and their interpretation for a better understanding of the risks and benefits of parasites in these systems; (iii) A Decision Support Tool that will guide users through a questionnaire and advise them on the best control strategies for the timely detection and containment of parasitic infections in algal biotech without loss of valuable production; (iv) A detailed and ready-to-use protocol to detect zoosporic parasites, supporting lake monitoring and the potential for water managers to use zoosporic parasites as predictive metric for ecosystem functional diversity.

1.2 Progress beyond the state-of-the-art

1.2.1 APPROACH TO THE CHALLENGE AND PROGRESS BEYOND THE STATE-OF-THE-ART

Zoosporic parasites, although extremely abundant, have long been ignored in aquatic ecology. Yet, the knowledge on their role in nature is rapidly expanding[34]. Given the vast potential of algal biotech for a sustainable European economy, a COST Action exchanging and building knowledge on this topic is more than timely. Academic research and biotech industry regarding algal zoosporic parasites have never been brought together with the critical mass that is required to make real progress. COST Actions are the ideal framework to achieve this. Each of the sectors involved in ParAqua brings its own experience and expertise on productive algal systems (i.e. industrial or natural) and the occurrence of zoosporic parasites. We will unlock and valorise this combined knowledge and expertise.

Occurrence- Timely detection and identification of zoosporic parasites remains a major challenge, particularly in algal biotech industrial systems, while this is essential to avoid significant production losses. Addressing harmful infections starts with knowing “who is there” in time for taking appropriate action. ParAqua will develop an extensive catalogue of parasite and host occurrence, including - where possible - information on environmental conditions, physiological characterization, sequencing, ecology and biogeography. This will integrate the assessment of best practices isolating and maintaining strains of host and parasites, including optimized long-term preservation by cryoconservation and of barcoding of host-parasite systems. Members of each country from the ParAqua Management Committee will be responsible for contributing to the “occurrence database” with data from their respective countries on infections in industrial and natural systems. In accordance with the principle of open cooperation, our industrial partners already acknowledged that the data provided for the Action activities will be publicly available. By setting up an ongoing occurrence database and facilitating the inclusion of zoosporic parasites in existing culture collections, we will harmonise and standardise species identification and quantification, including strains and sequences currently available within the consortium and extended network, thereby linking fundamental and applied research. Moreover, the database will provide sequence and reference information and facilitate characterization of parasites, including their diversity and specificity, both in natural lake ecosystems and industrial production cultures. Lastly, the database will support studies on the complex relationships of co-occurrence and co-evolution of host and parasites and the importance of overlooked biotic interactions (such as parasitism) in guaranteeing ecosystem functional processes in natural ecosystems.

Early detection- Early detection and timely treatment of infections in aquaculture is critical to minimize the economic losses caused by infection. Collaborative compilation and testing of standardized procedures and rapid detection methods (molecular, real-time automated monitoring) will greatly improve the design of monitoring and early-warning systems for infections by zoosporic parasites. The use of DNA-based methods is still limited by primer biases and their specificity for understudied taxonomic groups. While DNA-barcodes for terrestrial oomycetes are available and widely used (e.g.[34]) and genome regions for potential fungal barcodes have been identified[35], DNA-barcodes for most other zoosporic parasites are missing or inconclusive. Existing DNA-barcodes rarely allow identification even to the genus level (e.g.[36]). Hence, ParAqua aims to develop a curated sequence database to correctly identify parasites and link information to host species and host range specificity. The sequence database will allow the design of adapted molecular tools to meet the urgent requirement for methodologies capable of specific and sensitive detection of infections in industrial systems. Automated sensors

are promising tools for real-time monitoring and to develop reliable methods and predictive tools for early detection. Broadening the network of collaborators both within and beyond the ParAqua consortium will help in defining the role of zoosporic parasites in natural ecosystems, change our current concepts of plankton diversity, and support commercial cultivation of algae in industrial settings.

Environmental drivers- Zoosporic parasites can lead natural populations to collapse by infecting more than 90% of a host[14]. Likewise, infections in industrial cultivation settings were shown to crash host biomass production (Box I;[25]). When and under which environmental conditions zoosporic parasites can successfully invade a host population and develop into an epidemic remains unresolved[37]. Compiling the available information on environmental drivers of infections and sources of contamination from natural and industrial systems will be an important step towards understanding and eventually predicting which environmental conditions will be conducive or unfavourable to infection by zoosporic parasites.

Economic losses through parasites- Once production systems are infected, most control strategies consist of premature harvest or stopping production, with subsequent disinfection of the cultivation system. These are costly procedures, leading to economic losses due to reduced yields and shut-down of production. Moreover, disinfection may be problematic in open production systems prone to invasion such as raceway ponds. But also in closed systems, such as tubular photobioreactor, disinfection may fail as zoosporic parasites produce thick-walled cysts and resting spores resistant to disinfection[38]. Compiling and cross-referencing control strategies, including innovative approaches we can summarize as “learning from nature”, such as biological control, crop rotation systems and genetic diversity of the inoculum, will produce a reference manual of best practices under different production systems to prevent, control or mitigate infections by zoosporic parasites. This knowledge base will be openly shared via the ParAqua Action with the scientific community, stakeholders and end-users and facilitate stable production of microalgae and hence contribute to European society and economy.

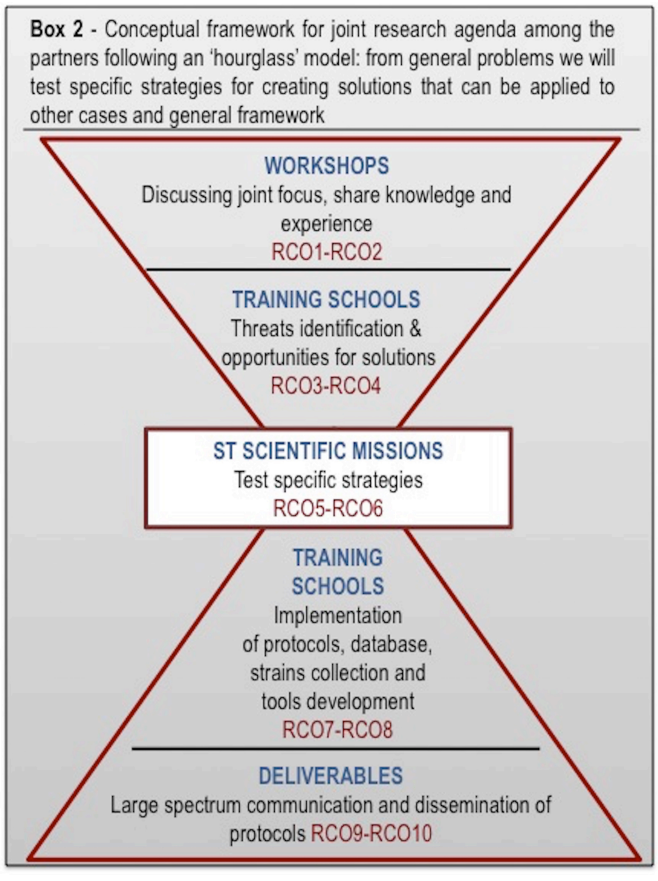
1.2.2 OBJECTIVES

1.2.2.1 Research Coordination Objectives

We built our research coordination objectives in a consequent conceptual framework detailing the different appointments between the partners following an “hourglass” model (Box 2): from general problems we will test selected strategies for creating solutions that can be applied to other cases and general frameworks. Specific efforts will be dedicated to develop control mechanisms and tools for monitoring and disease prevention (RCO 4 and 6).

- RCO1. Compile and integrate a database on zoosporic parasites across Europe and inventorize parasite effects on algal hosts in algal biotech and natural systems.
- RCO2. List and integrate information on environmental drivers of parasite epidemic development - and contrast with the role of host abundance in setting up infections. Work towards a risk assessment tool for the likelihood of parasite occurrence, as a first step towards prediction of infection risks and dynamics.
- RCO3. From the analysis of assembled data in RCOs 1 and 2, identify the most pressing knowledge gaps and needs. Focus on research that leads to solutions and best control strategies aimed at minimising the damaging impacts of infections in algal biotech systems. Build a knowledge hub, which will act as a catalyst for innovation in finding and implementing practical solutions to overcome economic losses in algal biotech systems.
- RCO4. Collect, assess and organise early detection methods such as DNA testing and real time automated monitoring systems. Produce fact-sheets, compiled as a handbook made available through a web page for the guidance of the algal biotech industry and lake management.
- RCO5. During the Action specific monitoring campaigns will be designed to follow parasites and

Box 2 - Conceptual framework for joint research agenda among the partners following an ‘hourglass’ model: from general problems we will test specific strategies for creating solutions that can be applied to other cases and general framework



their hosts in algal biotech as well as natural systems. Short Term Scientific Missions (STSM) will play a crucial role in setting up and carrying out these monitoring campaigns.

- RCO6. Develop specific protocols for monitoring and control strategies for disease prevention, weighing their feasibility and (cost-)effectiveness. We will bring together existing models of host-parasite systems already elaborated in various European laboratoria, and develop new ones based on the monitored parameters (e.g. fluorescence, nutrients uptake). This will allow us to develop scripts for models to predict production losses and allow for early warning alerts.
- RCO7. Jointly develop a Decision Support Tool that guides users from the scientific community and algal biotech industry to the best possible solutions to prevent or contain infections in algal biotech systems at the earliest possible stage, minimising production losses and maximising enterprise profits.
- RCO8. Encourage submission of zoosporic parasites in European culture collections to strengthen their presence and ensure long-term preservation for the benefit of fundamental and applied research on these parasites.
- RCO9 In a collaborative effort between academia, industry and lake managers, explore the potential of considering naturally occurring parasites as metrics for novel monitoring strategy in lakes and reservoirs. Formulate a white paper giving advice on the assessment of ecosystem properties (e.g. such as food web activity, recycling, connectance, and trophic transfer efficiency) that can be directly affected by the interactions of parasites with other aquatic organisms.
- RCO10. By using the knowledge as assembled and disseminated in the Action, expand our expertise on the occurrence of zoosporic parasites under a changing climate. Advocate the importance of maintaining healthy aquatic ecosystems by supporting biodiversity and emphasizing the importance of overlooked biotic interactions (such as parasitism) in guaranteeing ecosystem functional processes.

Although this is an ambitious list of RCOs we are confident we can achieve these objectives, having experienced the phenomenal energy and productivity that comes out of a well managed COST Action, and the benefit from COST Action mechanisms like Training Schools (TS) and STSM.

1.2.2.2 Capacity-building Objectives

- CBO1. Establish an active network of representatives from academic research, biotech and water management, each sector brings their own experience and expertise. To build up from the existing network and reach strong representation across Europe, including most of the COST Countries.
- CBO2. Stimulate innovative solutions in algal biotech and lake management for the losses incurred through parasite infections. Ideally create new or enhanced business opportunities for European Small and Medium Enterprises (SMEs) in these sectors.
- CBO3. Actively promote and guard diversity in all of the Action`s activities, diversity in terms of geographic origin, gender and career stage.
- CBO4. Actively create opportunities for Early Career Investigators (ECI) in leading the Action, e.g. through leadership roles in Working and Project Groups. To provide opportunities for ECIs to broaden and deepen their skills through TS and STSM.
- CBO5. Equally provide opportunities for scientists and professionals from biotech and water management. The STSM committee will oversee that reciprocal - academia vs industry - STSM are organized, with a particular focus on appointing ITC as host, so that they can disseminate knowledge in their respective countries.
- CBO6. Set-up and maintain an active communication strategy, through the use of various social media, press-releases or public presentations to raise public awareness about the topics of interest in ParAqua.
- CBO7. Aiming for the long-term maintenance of the ParAqua network after finishing the Action. Reach out and seek connection with existing relevant networks like European Algae Biomass Association, EABA, https://www.eaba-association.org/en or Global Lake Ecological Observatory Network, GLEON, http://gleon.org/.
- CBO8.Create and maintain an expert panel with representatives recruited from the Action that supports industry and lake management with making science informed choices in managing parasites.
- CBO9. Engage with existing European culture collections to deposit strains of zoosporic parasites like chytrid fungi which are typically underrepresented in collections like at the Westerdijk institute, http://www.westerdijkinstitute.nl or the German collection of microorganisms (DSMZ), https://www.dsmz.de/. The presence of chytrids and others parasites will be a stimulus for basic research and applied sciences in Europe.
- CBO10 Inform and educate stakeholders that are not already in the heart of the Action (see CBO1) and the public at large with factsheets, handbooks, databases, public events and scientific papers etc. Increase awareness about the importance of biodiversity for healthy ecosystem functioning and biotechnology.

2. NETWORKING EXCELLENCE

Algal biotech has a large potential to contribute to sustainable economic growth in Europe, but given the young age of this industry, the opportunities and risks need to be better explored. Intensive interactions between experts from different fields and disciplines offer critical mass to find the best solutions that minimize economic losses. The

COST Action provides us with the best possible opportunity to overcome the current fragmentation of knowledge and exchange in the field. Moreover, by harmonisation of methods and dissemination of results, ParAqua will keep European research and R&D on zoosporic parasites at the forefront of science. A COST Action on these virulent parasites is timely. Timely, given the rapidly expanding scientific knowledge. Timely, given the highly promising usability of algae in a sustainable economy, as a renewable source of energy, food and pharmaceuticals. Timely, given the uncertainty of possible risks of climate change, e.g. for the spread of parasites and disease. Timely, given the multiple business opportunities it offers for SMEs in Europe.

2.1. Added value of networking in S&T Excellence

2.1.1. ADDED VALUE IN RELATION TO EXISTING EFFORTS AT EUROPEAN AND/OR INTERNATIONAL LEVEL

ParAqua evolved from a group of researchers and other professionals who frequently come together and already organised three open workshops. These are grassroots organised meetings, without any formal organisation hosting them. In the workshops, progress in fundamental and applied research on chytrids and the diseases they cause was being discussed. Given the nascent state of the field this is not an area with already a large number of past or present European projects. Rather, ParAqua will act as a catalyst to open and expand this field for the benefit of research and industry. Nevertheless, ParAqua will take advantage of the results of previous and ongoing projects at the national level, integrate their outcomes and ensure their further use to add maximum value to researchers, end-users and stakeholders in the European context. Most academics at the heart of ParAqua have ongoing research projects, funded by the national science foundations in their respective countries, thus rapidly expanding our knowledge base on the biology of zoosporic parasites. Furthermore, ParAqua will coordinate efforts towards future research projects focused on research gaps and stakeholder needs, for example in the form of a Doctoral Network (MSCA-DN) to actively involve early stage researchers in future research of aquatic parasites. There are currently initiatives to explore the global occurrence of fungi and to better understand their role in ecosystem functioning, such as the whole genome sequencing, the 1000 fungal genome project (http://1000.fungalgenomes.org/home/), and the FunAqua project (Estonian University of Life Sciences), but these initiatives lack the connection between genomics and ecology of the sequenced fungi and the links with algal biotech and stakeholders. In addition, algal biotechnology companies have started in all European countries and constitute a promising investment for the ITC economy. ParAqua will offer the unique opportunity to bring together the experience of these companies in a safe environment with a collaborative spirit and to the benefit of the participating ITC countries.

Although green algae are the favourite group of microalgae used in biotechnology, there seems to be a growing interest in cyanobacteria who produce a wide array of bioactive compounds which are of interest given antimicrobial or anticancer properties[4]. For this cyanobacteria part of ParAqua it clearly connects to the earlier COST Action CyanoCOST (ES1105; https://cyanocost.wordpress.com/) through exploring the role of fungal parasites as important driving forces in eco-evolutionary dynamics (i.e. toxin production in particular strains of cyanobacteria), or for the production of essential biomolecules (e.g. fatty acids and sterols). There are strong ties between scientists in ParAqua and GLEON, the Global Lake Ecological Observatory Network and NETLAKE (https://www.dkit.ie/netlake), another successful COST Action, now continued as GLEON-Europe. Finally, there are strong existing links with the EU-projects AQUACOSM and AQUACOSM-PLUS (ES1201; https://www.aquacosm.eu/), which bring together a large range of freshwater and marine mesocosm facilities in Europe. In all of these facilities parasites of plankton occur. By sharing our protocols for detection of zoosporic parasites there are mutual benefits: for the ParAqua community by gaining data on parasite occurrence, for the AQUACOSM community by learning more of the crucial role of parasites in aquatic food webs, and last but not least for SMEs and lake managers to better project dynamics and system feedback by these key parasites.

2.2. ADDED VALUE OF NETWORKING IN IMPACT

Given the pioneering role of ParAqua in collecting, unlocking, harmonising, deepening and disseminating knowledge on the role of zoosporic parasites in natural and artificial aquatic systems, it is essential that all relevant disciplines are represented in the network. Right from the start the three key sectors are involved and have provided input to the proposal: (i) academic research, (ii) algal biotech industry (SMEs from various countries), and (iii) lake management (public institutes and water consultants). Building such a broad basis from the beginning of the network will strengthen the capacity across Europe for the risk assessment of these infections in natural and industrial systems through the establishment of strong and synergistic cooperation between fundamental and applied research, authorities and industry. Whereas the academic world may have the best overview of the current scientific understanding, the algae biotech industry has broader hands-on experience on how and when these infections interfere with their production processes. Lake managers offer in-depth knowledge of the functioning of aquatic ecosystems across Europe and are experts in monitoring these, for instance in the context of the EU-WFD. They can in turn use the knowledge developed in the Action to better develop monitoring measures and strategies to optimize lake management policies based on a full understanding of ecosystem functioning including the

overlooked functional group of parasites. This knowledge will be expanded during the Action through Research Coordination Obj. 5.

2.2.1. SECURING THE CRITICAL MASS AND EXPERTISE

The broad range of expertise involved in ParAqua ensures securing the critical mass, and includes a range of disciplines and expertise: (i) Partners from universities and research institutes, each bringing in their own network and expertise, (ii) Researchers from diverse disciplines, e.g. biochemists, biologists, ecologists, phyto- and zoo-pathologists, taxonomists, evolutionary biologists, (iii) Algal biotech enterprise managers, (iv) Engineers and companies of algal bioreactors development, technology and consumables suppliers, (v) Environmental laboratories, both public and private, (vi) Local and regional authorities, and (vii) Water managers. The formation of a community that interacts via a pan-European network will greatly facilitate the development and sharing of new techniques to boost innovations. Importantly, the broad range of researchers and close connections to several international initiatives (GLEON, AQUACOSM, etc.) will greatly support promoting implementation of chytrids in sampling schemes. Whereas we have taken care to include the aforementioned three crucial sectors into the network from the get-go we will work during the lifetime of the Action to achieve an even better balance between the three sectors. Presently we have two partners from public health institutes (both from ITC), two private water consultants (one from an ITC), two partners from lake management, eight from industry (two from ITC) and 23 from public sector research (13 from ITC). Balancing this Action, with a critical mass in each sector to achieve the proposed goals is one of our major aims.

2.2.2. INVOLVEMENT OF STAKEHOLDERS

In year 1 of the Action during the first general meeting (see Gantt chart), we will host a special Stakeholder meeting where all industrial partners and Stakeholders from water management will be involved. With this Stakeholder Platform we will discuss the needs they see for their sector for expanding knowledge and expertise on algal parasites. We intend that for each country one of the two seats on the Management Committee is appointed by a representative from either industry or water management, and one from academia. This will be prioritised during the Action and we will actively seek leadership roles for professionals from industry and lake management in all aspects of the Action (see CBO6). We will also reach out to European Algae Biomass Association (EABA), an existing platform where algal experts from academic research and industry interact. We will try to establish ParAqua as an EABA working group on the risks and management of parasites.

2.2.3. MUTUAL BENEFITS OF THE INVOLVEMENT OF SECONDARY PROPOSERS FROM NEAR NEIGHBOUR OR INTERNATIONAL PARTNER COUNTRIES OR INTERNATIONAL ORGANISATIONS

Together with 55 proposers from 26 COST Countries, researchers from three COST International Partners (US, Japan and New Zealand) will also contribute to the achievements of the Action's objectives. This synergy of international collaborators will ensure that relevant trends and strategies being developed in other non-European countries can be quickly incorporated. Cross comparisons will facilitate establishing standard protocols that are validated worldwide. Global connections will moreover enable fast dissemination of findings and methods through the respective national experts and allow promoting the Action activities in non-European countries. Further opportunities will be explored also after the inauguration of the Action through existing partnerships and newly established collaborations that will arise from the Action`s activities.

3. IMPACT

3.1. IMPACT TO SCIENCE, SOCIETY AND COMPETITIVENESS, AND POTENTIAL FOR INNOVATION/BREAK-THROUGHS

3.1.1. SCIENTIFIC, TECHNOLOGICAL, AND/OR SOCIOECONOMIC IMPACTS (INCLUDING POTENTIAL INNOVATIONS AND/OR BREAKTHROUGHS)

ParAqua will build capacity in the European Research community by increasing scientific knowledge and facilitate its translation for application in algal biotechnology industries. The formation of a network of scientists, engineers, water managers and entrepreneurs is an important step forward to stimulate the inclusion of parasites in ecological research and explore possibilities to provide innovative solutions for the control of infections in algal biotech industry. Together, this will benefit not only academic understanding of the role of zoosporic parasites in aquatic ecosystems, but more importantly has real applications in the rapidly emerging algal biotech industry in Europe.

Scientific impact- Zoosporic parasites are thus far too often neglected by aquatic ecologists. This has hampered a better understanding of the factors that determine the degree of parasitism, such as the roles of the hosts vs the abiotic environmental conditions like temperature. With ParAqua we aim to stimulate applied zoosporic parasite

research across Europe and lay the foundations for future European and multinational projects. Apart from building a multifaceted network, ParAqua will develop standardized operating protocols for the study of these parasites in aquatic ecosystems and the laboratory. These will be made openly available through the website, and will be promoted during sessions at international aquatic science or microbial ecology meetings, which are regularly organized and attended by consortium members, e.g. ASLO (Association for the Sciences of Limnology and Oceanography), SIL (International Society of Limnology), EPC (European Phycological Congress), ICHA (International Conference on Harmful Algae), SAME (Symposium of Aquatic Microbial Ecology) etc.. Moreover, we will stimulate the inclusion of host-parasite systems in existing culture collections, allowing greater access for scientists interested to investigate zoosporic parasites. By writing synthesis, opinion and meta-analysis publications on our current understanding of zoosporic parasites, as well as their application for industry and water management (see also 3.1.1.2), we will attain further outreach in the scientific community.

Technological impact- We will have technological impact through the development and support of automated methods for monitoring and control mechanisms for disease prevention (see RCO4 & 6) and standardized decision-making protocols for cost effective solutions to end-users, notably for industry and water management. This will be achieved by the design, testing and dissemination of an online Decision Support Tool, where various existing and novel strategies for the detection, monitoring and control of zoosporic infections are carefully structured to achieve tailor-made advice.

Socio-economic impact- To provide a better description of the economic impacts of the network and the potential benefits for the algal biotech industry, we organised preliminary meetings with our industrial partners to discuss their profitable gain from participating in the network. Tangible economic impact will be more controlled production due to the understanding of infections and higher reliability of the yield due to a more constant production. We will explore the opportunity to develop production lines of high-quality products (such as nutraceuticals and advanced bionutritionals). We will achieve further societal impact by building an online open platform with factsheets and general background information highlighting the importance of parasites for ecosystem functioning. This will also include a searchable database with available expertise per country. Moreover, we will produce a white paper in which aquatic parasites (such as fungi) will be highlighted from different perspectives, including for example for the production of bioactive compounds (e.g. antimicrobial) or essential biomolecules (e.g. fatty acids and sterols), or as important driving forces in eco-evolutionary dynamics (i.e. toxin production in particular strains of cyanobacteria), opening avenues for collaborations, and include other different aspects not necessarily related to parasites as an issue. By exploring new possibilities for application of zoosporic parasites in aquatic systems, we will benefit the maintenance of ecosystem services to society and economic benefits to local and regional commercial industries.

3.2 MEASURES TO MAXIMISE IMPACT

3.1.2. KNOWLEDGE CREATION, TRANSFER OF KNOWLEDGE AND CAREER DEVELOPMENT

ParAqua will enhance awareness about the impacts of parasites in algal biotech industry, and the role of parasites in aquatic food webs through the development of simple standardized protocols for zoosporic parasite detection and counting. This way, zoosporic parasites may become more easily a part of sampling schemes, supporting both algal biotech and aquatic ecological research. Importantly, we will provide an online open platform to disseminate cost-effective monitoring methods, which can be used by the industrial stakeholders as well as by public environmental agencies. All currently existing protocols will be shared and harmonized throughout Europe, mutually benefitting science and industry. Other initiatives we have listed in our RCOs and CBOs are aimed at maximising output. Activities like a central database on zoosporic parasite occurrence (RCO1), organising monitoring campaigns and provide up-to-date tools (RCO5 & 6), a Decision Support Tool for algal biotechnology (RCO7), a permanent expert panel (CBO9) and the collaboration with European culture collections (CBO10) and organisations like EABA all will help to ensure a lasting impact of ParAqua in Europe.

ParAqua will greatly contribute to the prevention of production losses caused by parasites in algal biotech systems, through the interdisciplinary network from science, industry and water management. Importantly, ParAqua will allow knowledge sharing across European countries, bring in international experts, and allow effective cross-disciplinary exchange. By interdisciplinary network building, the identification of research gaps, and defining focus areas in order to achieve breakthroughs in the field, we will keep the European scientific community (both fundamental and applied) at the forefront of zoosporic parasite research. Extending with new members our established network, we will enable laboratories with little previous experience and from less research-intensive countries to rapidly come up to par with the state of the art knowledge and undertake innovative research. Linking academia with partners form industry and water management will allow the profitable impact of the acquired know-how on detection, identification, quantification and management of zoosporic infections. We will connect to the international community through the development of a handbook on methods, web-based activities (see also 3.2.2) and through the publication or methods, reviews and synthesis papers in international scientific journals. For continuation of the established network, exchange of expertise, and safeguard future efforts, ParAqua will invest in early career professionals and prioritize exchange between early career investigators and young managers from industry for

STSM and Training Schools. Importantly, they will be involved in leading positions in the WG organization and management. Similarly, for all leadership positions within ParAqua, the utmost care will be taken for equal distribution of leadership tasks, involving gender equality and ITC countries. ECI and young managers preferentially from IPC and NNC will be also invited to partake in COST Action meeting and Training Schools as Invited Speakers.

3.2.2 PLAN FOR DISSEMINATION AND/OR EXPLOITATION AND DIALOGUE WITH THE GENERAL PUBLIC OR POLICY

We will connect to the general public through the development of an interactive webpage with fact sheets, regular blogs and the direct opening of ParAqua social media accounts (including Facebook, Twitter). Moreover, we will engage with regular media by bringing out press releases, organizing (sessions in) public conferences, and facilitating visibility of zoosporic parasites in public events, such as open institute days, field site excursions, etc. A working group (WG4) will be dedicated to the dissemination and communication plan of the Action. By creating an European consortium with internationally renowned experts as well as fully integrated industrial partners, we have the ideal network to influence policy-making. Current European regulations do not allow the use of multiple algal strains or species in biotechnology, even though we know from ecological principles that a higher diversity may stabilize production systems, with a higher resilience to disturbance and enhanced biomass production[39]. Specifically adapted SOP for aquaculture are also now urgent because most of the procedures currently used are simply reassigned from agriculture. As established network, we can reach out to national members of parliament throughout Europe to advocate for a policy in support of a sustainable production of valuable algal materials as well as food products and animal feed, thereby supporting several Sustainable Development Goals (SDGs). As a pan-European network, ParAqua may stimulate local, regional and national governments and science foundations to invest in collaborative science-industry programs for furthering sustainable microalgal production, steering Europe to the forefront of a rapidly expanding field in both science and industry. Various members of ParAqua are closely involved in national networks of water management and policy-makers, including national expert groups on harmful cyanobacteria and algae. Therefore, any outcome from the network related to water management can be immediately disseminated during existing science-with-policy meetings, and be tested by water authorities.

4. IMPLEMENTATION

4.1. COHERENCE AND EFFECTIVENESS OF THE WORK PLAN

4.1.1. DESCRIPTION OF WORKING GROUPS, TASKS AND ACTIVITIES

The Management Committee (MC) will elect a Chair and Vice-Chair, Working Group (WG) Leaders and a dedicated STSM committee and Coordinator. Each WG will be led by a representative from academic research and a stakeholder from algal biotech or water management, to ensure that WGs are capitalizing on the combined expertise. The Action Participants will form a large international team, including three International Partner Countries. Four Working Groups (WGs) will be established for this Action (Fig. 2). To complement the MC a Core Group (CG), consisting of Chair, Vice-Chair and duo-WG Leaders. The CG will take the lead in the day to day running of the Action. One of the CG tasks will be to maintain a fully operational Action even in case the current pandemic would not slow down. Actionable items that have already been discussed to “health crisis-proof” ParAqua includes organising online or hybrid-style MC meetings and Training Schools as well as developing guidelines for safe STSM, as ensuring good living and working conditions during initial quarantine periods when visiting another country. Several of us have already experience with organising online meetings that maintains much of the energy and optimism of a real physical meeting. Four Action MC meetings are planned (see Gantt Diagram), which will serve also as milestones at intermediary control points and during which corrective measures can be taken if problems have arisen. We will strive to organise these meetings jointly with other Action activities (e.g. Training Schools and STSM) to consolidate travel expenses.

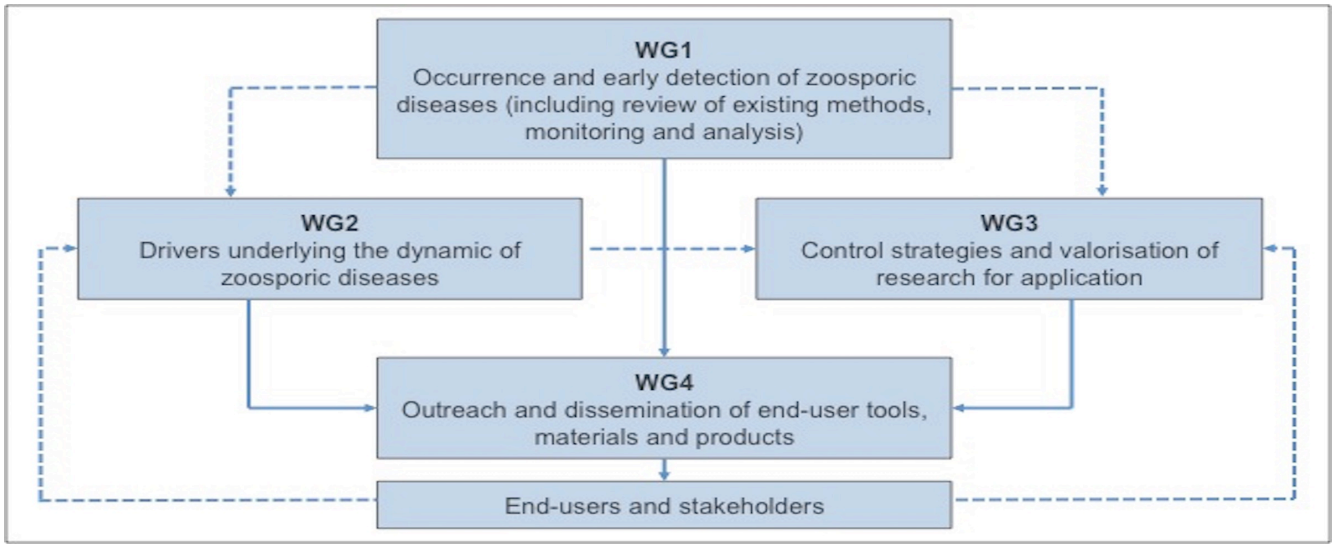


Figure 2. Working groups organization showing their interconnection to facilitate the flow of information and results, particularly among academia and end-users. Dotted lines show the flow of information, solid lines show the flow of information, results and products. The four WGs are closely interconnected, while WG1-WG3 are more technical, WG4 is fully dedicated to the integration and dissemination of information, products and tools.

WG1: Occurrence and early detection of zoosporic diseases in natural and artificial aquatic systems

Aims: The lack of harmonized methods for the detection of zoosporic parasites is the main obstacle in our ability to compare parasites occurring in diverse environments. Standard tools are urgently needed to achieve a complete overview of occurrence of infections and their relation with the hosts, and to support professionals in the development of control mechanisms for diseases and to implement new tools for prevention in large-scale production systems. In addition, understanding the ecology and occurrence of parasites will broaden our view i.e. their functional role in ecosystem functioning. The aim of WG1 is therefore to collect, compare and integrate all available techniques, experiences and data pertaining to the occurrence of zoosporic infections in natural and industrial systems throughout Europe. Tools will be developed for intercalibration of the different methods used. The collation of all available knowledge on occurrence and identification of zoosporic parasites will be essential to identify the best performing and most cost-effective techniques for early detection.

Tasks: The WG will first implement an online Observatory as interactive platform using questionnaires and open web applications with the aforementioned two main aims, i.e. to 1) survey and summarize all the currently available information on zoosporic parasites occurrence, diversity, biogeography, including information on which strains are already isolated, and 2) stimulate constant monitoring with standardised protocols for emerging infections in natural and industrial systems and study of their occurrence, genetic characterisation, host range and associated risks. A Training School will be organized at the beginning of the Action by expert water managers in the Action for guidance, harmonisation and validation of analytical methods, particularly targeted to young researchers and users from industry. The program will include traditional state of the art methods for detection (staining, fluorescence microscopy, flow cytometry, enrichment assays), advanced molecular methods (eDNA based amplicon sequencing and qPCR, microarrays) and innovative approaches (automated high frequency monitoring, GC-MS, antibodies, metabolites).

STSM: will be organized between academia, industry and water management on the monitoring of zoosporic parasites occurrence, including opportunities for inter-laboratory exchange of samples, cross-evaluation of methods and training classes with case studies from algal biotech and natural systems. The obtained expertise will be finalized during a workshop dedicated to identify needs and solutions for best-performing, feasible, and cost-effective techniques for the early detection of zoosporic parasites, even at low abundance.

WG2: Drivers underlying the dynamics of zoosporic diseases in algal biotech and natural systems

Aims: Complementary to WG1, WG2 aims to elucidate the drivers and evaluate impacts of zoosporic parasitism in algal biotech and natural systems. The aim of the WG2 is to assemble and integrate all available information on the ecology and functional traits of zoosporic parasites into an occurrence database. The database will then allow the evaluation of which environmental conditions promote or suppress infections by zoosporic parasites. Using the information on environmental drivers of infection will help formulating a risk assessment tool for algal biotech and water managers, as well as improve our understanding of how climate and land-use change will impact the spread, occurrence and severity of zoosporic parasite infections in natural and industrial ecosystems.

Tasks: Complete the online catalogue (WG1) with ecological and functional traits of zoosporic parasites by tallying available data on biotic and abiotic environmental drivers of infection, virulence and host sensitivity in natural and industrial systems throughout Europe. This will allow us to build a curated DNA sequence and reference databases to feed the existing datasets, contribute isolated strains to existing culture collections, characterize parasites associated with their host and discover the specificity of parasites threatening industrial production. This overview will be made publicly available through the webpage via factsheets and will greatly improve the exchange of material for effective use of isolation and cultivation efforts, which is also expected to help understanding the complex relationships of co-occurrence and co-evolution among hosts and parasites. A Training School will be organized on isolation of parasite strains and their characterisation. We will host a special stakeholders meeting to share methods, assess the opportunity of introducing zoosporic parasites in regular monitoring and promote knowledge of biodiversity and on potential positive effects of parasites in natural systems (e.g. foodweb stability[18]).

STSM: will be organized to participate in ongoing studies in European experimental facilities (e.g. AQUACOSM) and algal biotech systems to test the effect of different stressors on hosts and consumers, assess future environmental and/or operation conditions and explore preventive measures for the protection of algal production, including environmental refuges, (e.g. low or high temperatures where infections do not proceed[40]), mismatch in phenology and timing of infection. Special case studies on the industrial partners installations will be included for training on applicable solutions in real conditions.

WG3: Control strategies and valorisation of research for application

Aims: WG3 aims to bring together all current practical and theoretical knowledge on control strategies for parasitism risk in algal biotech, but also to explore the benefits of using zoosporic infections as metrics in natural systems monitoring or as source material for bio-refined products. WG3 will make the acquired knowledge from WG1 and 2 available and put this into practise for the prevention, management and control of zoosporic parasites for industrial production, and on the potential use of zoosporic parasites in natural ecosystem management.

Tasks: A Workshop will be organized to compile all available information on management and control of zoosporic parasites, to assess and prioritize the most promising methods for research, industry and society based on ecological (e.g. genetic diversity in host populations, crop rotation, environmental variance) and evolutionary principles (e.g. host strain selection, beneficial microbiome evolution). A Training School will be held to explore adapted tools and specific early warning signals based on automated monitoring parameters (e.g. fluorescence, nutrients uptake…) for control strategies for parasitism risk in algal biotech and to carefully explore the potential utilisation of zoosporic parasites for natural environments monitoring. Parasites specific metrics (occurrence, diversity, rate of infection) will be used to calculate models and indices using free-software (e.g.[41,42]) for assessing ecosystem properties which indicate food web resilience and stability (such as productivity, recycling, and trophic transfer efficiency).

STSM: will be organized as exchange visits among the Action's partners to test predictive models for production shifts based on the parameters identified during the workshop and training school (see above). Missions will be also organised on particularly problematic sites (e.g. partners from industry that have experienced recurrent infections). Outcome from this STSM will also enable public and private laboratories in European countries without established protocols for prevention and monitoring of environmental risks in natural ecosystems (i.e. as in one of the ITC participants to the network) to benefit from others with in depth this expertise. As innovative and more pioneering topics, STSM will also explore the potential for re-using wastewater or eutrophic water for industrial production, or the valorisation of parasites as sources of useful or even beneficial compounds such as commercially valuable fatty acids and sterols produced by parasitic chytrids[43].

WG4: Integration and Dissemination

Aims: WG4 will be responsible for dissemination of the Action's outcomes and results with the aim to maximize the knowledge transfer between scientists, industry, lake managers and the general public. A WG leader will be appointed from within the Action MC and this leader will hold the overall responsibility and closely collaborate with the Science Communication Manager. Other members of WG4 will be WG1-WG3 leaders. WG4 will be responsible for dissemination of publications specially targeted to lake and industry managers through multimedia content and media interviews. The exchange is greatly supported by the direct collaboration between (i) academic researchers with a proven track-record in research on zoosporic fungi, (ii) owners/developers from the algal production industry, and (iii) members of national expert groups involving scientists and water managers. Using this multidisciplinary group, WG4 will immediately start with the development of dissemination and communication plans, in close collaboration with institutional public relations departments, experienced with translating science and technology to the general public and with a wide access to various national media outlets (newspapers, popular journals, etc.). At the first meeting of ParAqua, the Science Communication Manager will be chosen among ECI from ITC. She/he will be responsible for dissemination and promotion of the network and the Action activities, including the development and maintenance of the website, editing a bimonthly newsletter, updating social media, and coordinating the materials for distribution (leaflets, flyers, infographics, posters etc.). The WG leader and COST Science Communication Manager will also collaborate with Local Organizers of the Action`s meetings to invite local

stakeholders so that each meeting will act as a focal point for dissemination of knowledge in the hosting country. Care will be taken that at least 50% of the meetings over the lifetime of the Action are organised physically or virtually by ITC hosts. A list of stakeholders' contact details will be constantly updated to be used for targeted dissemination. WG4 will also monitor the Action's impact on science and society, e.g. by monitoring visitors to the website, followers in social media, the number of citations as well as downloads of (scientific) publications.

Tasks: WG4 will facilitate the organization and outreach of the different Training Schools and the Short-Term Scientific Missions within WG1-WG3. Moreover, WG4 will be responsible for timely communication of new findings, which can occur through international journals or websites (e.g. na-turetoday.com), as well as through the various social media accounts. Also, it will promote outreach by all members through the development of standardized press materials and will lead international media campaigns about the Action. Besides, WG4 will organize an own Training School at the start of the Action about best practices in the communication of results within an interdisciplinary team (i.e. science, management an industry), as well as outreach to the general public (e.g. media training, press release writing, etc.). ParAqua will remain open for new members, and WG4 will be responsible for actively recruiting these new members. WG 4 will also be responsible to work with the Action Core Group in designing and implementing future-proof meetings, e.g. by organising online workshops, webinars and meetings.

4.1.2. DESCRIPTION OF DELIVERABLES AND TIMEFRAME

See the Gantt Diagram for the timeframe of the deliverables.

WG1: (i) Synthesis paper (D1.1) on occurrence and previous work done on zoosporic parasites in natural and industrial systems, including field surveys, experimental studies, and algal production ponds, (ii) Interactive web page and on-line catalogue (D2.1) with the data collected from the Observatory and with an interactive blog that will be kept updated regularly with the opportunity to integrate info and interactive sharing of information by the users, (iii) Handbook chapters (D3.1) with guidelines on analytical techniques for the identification and quantification of zoosporic infections in natural and industrial systems which will serve also as "Standard Operating Procedures" (SOPs) for early detection, identification and monitoring methods of zoosporic parasitic infection for end-users, including aquatic scientists, water managers and microalgae biotechnology engineers, (iv) Transfer of knowledge and information through exchange visits and outreach initiatives (press communication, special stands at organized open days), (v) Substantial feed of information and results to all other WGs.

WG2: (i) Review article(s) (D1.2) in open access journal(s) on the available knowledge on the environmental drivers of zoosporic parasite infection, and the potential of rapid evolution leading to shifts in host-parasite interactions, (ii) Fact-sheets (D2.2) freely available online for end-users and professionals highlighting key environmental drivers (abiotic and biotic) involved in zoosporic parasite infections, (iii) Conference (D3.2) on zoosporic parasites, their role in food webs, and responses to environmental drivers as well as changes therein, targeted to aquatic scientists, engineers from microalgae industry, and water managers, (iv) Sessions at international conferences to promote general awareness on the role of aquatic zoosporic parasites within the scientific community, (v) Scientific articles (D4.2) in open access journals to publish the results of the STSM on biotic and abiotic drivers of parasitic infections with implications from climate change and link to application, (vi) Public events and press communications to inform the public on positive and negative effects of parasites.

WG3: (i) Searchable database (D1.3) to catalogue and identify available expertise based on a questionnaire survey, (ii) Handbook chapters (D2.3), reviews in scientific and vocational journals on best practises in the prevention, management and control of zoosporic infections in production systems; current strategies based on the learning from nature principles for prevention; management and control of zoosporic infections in microalgal biotech including an evaluation of cost-effectiveness and scaling up potentials; the potential use of zoosporic parasites as biocontrol agents to control harmful algal or cyanobacterial blooms in natural systems; the potential of innovative biorefinery approaches to extract more than one valuable compound from (infected) host cultures.

WG4: (i) Action website (D1.4) as an interactive platform to host the various digital products of the Action (e.g. online catalogue of host-parasite cultures; Decision Support Tool, blogs, fact-sheets, links to other networks and resources, etc.), (ii) Open access ebook (D2.4) of the COST Action on the ecological and industrial implications of zoosporic parasites, synthesizing all state-of-the-art methods for detection, monitoring and control through synthesis of WG1-WG3, (iii) Evaluation of the cost-effectiveness, feasibility, and scaling up prospects of the various detection methods, monitoring techniques and control measures, (iv) Predictive model for early warning signals of production shift from expected values (D3.4) Decision Support Tool (D4.4) as an online open flow scheme guiding end-users towards factsheets containing the most cost-effective and feasible method for detection, monitoring and/or control of parasites with respect to their needs, (v) Provide the basis for future product development and production lines on the monitoring and control of zoosporic parasites in industry through network building and method development.

4.1.3. RISK ANALYSIS AND CONTINGENCY PLANS

For this paragraph we developed the following SWOT analysis:

Strengths

A. ParAqua has its foundations in an existing network, in which the 3 partners of the Action, academic research, industry and water management, already worked together successfully (published joint reviews, organising workshops, etc.).

B. The aforementioned key partners are involved from the beginning, input from all sectors has already been available at the writing stage.

C. The deliverables of the Action have clear socio-economic, technical and scientific impacts.

D. Already at the time of submission we have strong representation of ITC countries and an established balance in gender- and career stage.

E. Some of the key partners that put together ParAqua are experienced in running successful COST Actions as (Vice)-Chair, Working Group Leaders, etc.

F. Teaming up academia with other sectors of society, industry or water management

G. Several key Experience in designing and organising interactive virtual conferences and meetings, ensuring productivity and knowledge exchange in circumstances that discourage travel (e.g. carbon neutral meetings, pandemics).

Weaknesses

H. The role of zoosporic parasites in aquatic environments is understudied and this research topic only recently gained momentum. The research community does not have a long, established history, of successful EU FP projects of COST Actions, like in the topics of some other COST Actions.

I. Algal biotechnology is mainly based upon a dozen different species/strains. In this there is a discrepancy between a substantial part of the phytoplankton research, with an emphasis on biodiversity effects, and industry, based upon optimizing conditions for a limited number of organisms.

Opportunities

1. In expanding the Action, we will strive for an even better balance between professionals from water management, industry, policy and science. Likewise, we see a potential to increase participation of even more ITC and near-neighbouring countries (link with D).

2. The timing of the Action is excellent as the research field is expanding rapidly, so is the economic and societal value of algal biotech. ParAqua will capitalize on the momentum in both science and industry and create synergy by bringing them together, synchronizing vocabulary and improving collaborations between partners (link with B and G).

3. Raise awareness in the biotech industry about the risks and consequences of zoosporic parasitic infections. Advocate that with early detection and innovative, ecologically based ideas we can manage infections without great economic losses (link with C).

4. Valorize a “learning from nature” approach, i.e. benefitting from biodiversity in algal biotech industry, which should promote production and minimize losses through infections (link with H).

Threats

5. When different disciplines come together, as is the case in ParAqua, there is room for synergy, but also a risk of miscommunication, since groups do not share the same vocabulary, culture of working together etc. The solution begins with acknowledgment of the issue. Therefore a special task-force for communication and culture during the Action will work from the start to minimize this risk (link with A, B and 2).

6. There may be a risk that partners from industry are reluctant to share knowledge and experience with colleagues - but potential competitors too, holding back on sharing data and ideas. The industry partners that are already part of ParAqua acknowledged the principle of open co-operation and agreed in sharing and disseminating knowledge. We will work with them during the Action to set up as much as possible an atmosphere of trust. (link with B).

7. If the current COVID pandemic continues during (part of) the Action, it may interfere with the networking that is so essential for a successful Action. It will be the responsibility of the CG to develop timely contingency plans to ensure the success of the Action, and initial ideas were outlined in 4.1.1. (link with G).

4.1.4. GANTT DIAGRAM

Quarter months	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
General and MC meetings																
Milestones																
Workgroup meetings		WG4	WG1			WG2						WG3				
Training schools		WG4			WG1						WG2			WG3		
STSM			WG1				WG2					WG3				
Deliverables		D1.4		D1.1	D1.3	D2.1	D1.2	D3.1	D2.2	D3.2		D2.3	D2.4	D4.2	D3.4	D4.4
Outreach activities																

Acknowledgments:

This publication is based upon work from COST Action 20125 - Applications for zoosporic parasites in aquatic systems (ParAqua), supported by COST (European Cooperation in Science and Technology).

COST (European Cooperation in Science and Technology) is a funding agency for research and innovation networks. Our Actions help connect research initiatives across Europe and enable scientists to grow their ideas by sharing them with their peers. This boosts their research, career and innovation.

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