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This Newsletter and other information on ISAP can be retrieved from the ISAP website: http://www.appliedphycologysoc.org/

Message from the President, Dr. Roberto De Philippis

Dear ISAP Members,

I am happy to introduce this new issue of the ISAP Newsletter, where you will find two contributions on topics of interest to our scientific community.

In the time elapsed between the previous and the current Issue of the Newsletter some important novelties occurred in our Society:

1. It was decided the venue and the date of our 6th Congress, which will be held in Nantes, France, from 18th to 23rd June 2017. Put the date in your agenda! You will find more information on ISAP Website in the next months.

2. The payment of ISAP dues using credit card has been activated. Check the link on ISAP Website and please ensure your dues are up to date. This is essential for the life of ISAP, in particular for having the possibility to support Training Courses.

3. The Facebook page and the LinkedIn group of ISAP were created. Please, register yourselves on them through the links you will find on ISAP Website. In this way, you will be in touch with ISAP in an easy way.

4. ISAP Members who are in good standing with their dues have free access to the electronic version of the Journal of Applied Phycology through the ISAP Website. Take advantage of this possibility offered by Springer.

Finally, I would like to thank the Members of the EC Committee that is in charge of editing the Newsletter, Amha Belay (Chair), Celine Rebours, Sasi Nayar; Yannick Lerat and Stephen O'Leary for the work done in preparing this Issue.

I wish you all a happy and fruitful 2016

With my warm regards

Roberto De Philippis
President, International Society for Applied Phycology

Message from the Editor – Amha Belay

I am happy to present to you the latest ISAP Newsletter. We have two interesting articles in this issue. The first article by Greg Mitchell and Niu Du points to the importance of modelling in small and large-scale algal systems to reliably predict sustainability and economic outcomes, which drive investor confidence and further development of cost reduction at large scale. The second by Federico Rossi and Roberto De Philippis, well-known experts in the field, deals with a not-frequently discussed topic of induced biological soil crusts that have significant implication on recovery of deserts and perhaps even planets.

I am sure that both these articles will incite further discussions, which is the main objective of this newsletter. Feel free to comment on these topics through our social media and other avenues. Such free exchange of ideas is the cornerstone of ISAP's main objective of dissemination of knowledge in the field of applied phycology. We invite broader participation from ISAP members and the greater phycological community at large.

We are in the process of revising the editorial process to be far-reaching and guarantee continuity. You will see some changes in future editions of the newsletter. For this, I thank my colleagues in the Editorial Group, Céline Rebours, Sasi Nayar; Yannick Lerat and Stephen O'Leary.

A framework for modeling microalgae production in commercial systems: From laboratory to global scales

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Overview

The proven high rates of microalgal biomass productivity (biomass/area/time) using various production systems suggests the potential for microalgae to make a large contribution to sustainable feed and bioenergy in the future[1,2,3]. These projections are based on developing strains that thrive in saline water using very low cost production systems that do not compete with terrestrial crops for arable land or fresh water. Other significant sustainability drivers are the abilities for microalgae cultivation systems to directly utilize industrial CO_2 (Carbon Capture and Utilization, CCU), and to use nutrients very efficiently. Some believe that biofuel from algae will be economically viable within 5 years[4]. To achieve this short-term scenario would require immediate very large investments which are not evident.

Although the challenges that are common for scaling-up any industry apply to the emerging algae commercialization efforts, other macro-economic and policy issues also pose significant near-term challenges, including a lethargic global economy, low petroleum and natural gas prices, and a lack of climate (carbon) policy. Investment in any industrial technology requires confidence in being able to predict outcomes and to have those outcomes achieve the desired benefits. Certainly, massive scale-up of microalgae as a commodity feed or fuel crop must be economically competitive, but also there must be greater confidence in its huge potential contributions to global sustainability and animal and human nutrition or further investment to achieve cost reduction at large scale is uncertain.

Models at the Smallest and Largest Scales

Two classes of computational models can benefit the goals of developing algae at massive scales. First, we need to employ models that use current production and resource utilization knowledge to evaluate the sustainability potential of algae at global scales. Also, there remains a need to improve models of growth at the cellular-scale to optimize the strains used in different local climates and commercial production systems.

Global-scale models to evaluate the widely claimed algal biomass sustainability proposition should be pursued immediately with data that already exists for use of water, energy, nutrients, and CO_2, together with proven yields of protein, feed and fuel and full life cycle information. Currently, there exist global simulation frameworks that can meld global climate models with agricultural land use, hydrological, greenhouse gas and socio-economic models[5,6]. Rosenzweig et al. (2013)[7] reviewed the "Agricultural Model Inter-comparison and Improvement Project" (AgMIP), a major international effort which linked the climate, crop, and economic modeling communities to simulate climate, water, land use and nutritional impact projections for diverse terrestrial crops out to 2100. It would be relatively trivial to integrate algae crop assumptions into models such as those compared in AgMIP to evaluate future sustainabinlity, nutritional and biofuel outcomes of algae at massive scales in direct comparison to terrestrial crops. If results were positive (as the algae community claims), this would provide motivation for public policy and public investment. *Ad hoc* claims of the sustainability merit alone are not sufficient. Furthermore algae need not be economically viable as a commodity crop to explore the sustainability impact of massive scale-up using data that exists or is currently being created.

This vision for implementing large-scale global modeling of algae production can be achieved within 2-3 years at modest costs - on the order of millions of dollars. We recommend that this type of model, targeted at algae's global sustainability and its security for food and fuel impacts, be supported immediately through public funding. Using currently available data on algae within global models likely will produce highly positive simulations of the potential impact of massive global scale-up of algae, and therefore motivate continued public and private investment. Without more quantitative evidence of a large impact on global sustainability - and security of food and fuel – current macroeconomic externalities are likely to limit investment in microalgae biotechnology for the near term.

The second class of models is a more detailed integration of strain-specific physiological attributes and production system characteristics in support of predicting commercial algal biomass yields and resource utilization. Increasingly, the terrestrial commodity agricultural markets are more efficient as they utilize knowledge of regional climate and weather patterns to optimize crop plantings and harvests. Specifically, diverse cultivars of the major commodity crops are planted to optimize yields based on knowledge of the performance of those cultivars within the local agronomic system (soil, temperature, water, season, climate, etc). Tens of millions of dollars of public and private investment are made each year to further understand the detailed performance of these commodity-scale commercial terrestrial cultivars. The same will be essential for microalgae, if algae are to become a large part of the sustainability, nutrition and fuel solution of the future. Not only will a diversified set of optimized algal strains (including genetically modified strains) produce a diversity of important bio-products (high value feed, commodity feeds, nutritional oils and, protein, specialty chemicals, fuels, etc.), but the optimization of where and how to grow these strains will be an important aspect of the maturation of the microalgal biomass industry. Therefore, the framework for developing predictive models for biomass yield within specific production systems and for locally specific abiotic regulation of growth will be an essential part of a mature microalgal biotechnology industry.

Modeling Framework at the Cellular Scale

Over the past 30 years, our group has focused on developing models of microalgal cellular growth and acclimation in the abiotic matrix of light, temperature and nutrients[8,9,10], including applications to ocean ecosystems[11]. The rate of cellular carbon biomass production is the difference between its gross growth rate, μg and its dark respiration rate, Rd, times the cellular carbon quota C:P = $(\mu g - Rd)*C$. Since O_2 is evolved in the process as CO_2 is fixed, O_2 evolution or organic carbon (C) fixation are both convenient proxies for biomass production. Below, we generalize in terms of C:

$$\mu_n = \mu_g - R_d \qquad\qquad 1$$

$$\mu_n = \mu_g - (r_m + r_{bio}) \qquad\qquad 2$$

$$r_{bio} = b \times \mu_g, \; b = \text{a constant} \qquad\qquad 3$$

$$\mu_g = \frac{[Chl]}{[C]} \int_{400\,nm}^{700\,nm} a_{Chl}^*(\lambda)\phi(\lambda)E(\lambda)d\lambda \qquad\qquad 4$$

$$\mu_n = (1-b) \times \frac{[Chl]}{[C]} \int_{400\,nm}^{700\,nm} a_{Chl}^*(\lambda)\phi(\lambda)E(\lambda)d\lambda - r_m \qquad\qquad 5$$

$$F_{Chl} = \int_{400\,nm}^{700\,nm} a_{Chl}^*(\lambda)E(\lambda)\,d\lambda \qquad\qquad 6$$

The instantaneous net growth rate is defined in Equation 1. μ_n and μ_g are the specific net and gross photosynthesis rates and R_d is the specific dark respiration rate, respectively; these carbon specific growth rates have units of 1/time, typically reported as hr^{-1} or day^{-1}. Shuter (1979)[12] proposed that R_d can be further divided into maintenance cost (r_m) and biosynthesis cost (r_{bio}) (Equation 2), and r_{bio} is proportional to μ_g (Equation 3). In many studies, r_m was found to be small relative to r_{bio} under moderate

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or optimal growth conditions, thus $\dfrac{R_d}{m_g}$ often has been treated as a constant. As we show below, these simplifications for respiration are not reasonable for very low light experienced by the majority of the crop in commercial systems. The gross photosynthesis can be defined by Equation 4 (rearranged from Kiefer and Mitchell 1983), where $\dfrac{[Chl]}{[C]}$ is the chlorophyll to carbon ratio (mg Chl-a / mg C), a_{chl}^* is the chlorophyll specific absorption (m^2 / mg Chl a), Φ is quantum yield (mol C fixed / mol photon absorbed), and E is incident irradiance (μmol quanta m^{-2}s^{-1}). The overall net growth is described in Equation 5. In Equation 5, the integral of the product of chlorophyll-specific absorption and spectral irradiance are defined as FChl in Equation 6, which is a term that estimates the flux of photons to the photosystem per unit chlorophyll.

The explicit integration of absorbed photons over the spectral intensity of irradiance is essential, since both light intensity and spectral quality change dramatically over the frist few centimeters of commercial systems that have very high biomass density. Therefore, parameterization only in terms of intensity (*e.g.* PAR) is inadequate and full spectral integration is essential[9]. Fchl allows estimates of photon flux into the algal photosystem for any arbitrary light spectrum and intensity (*e.g.* at different depths) to be contained in a simple variable that will prove efficient for using computational fluid dynamic models. It should be noted that Equations 4 and 5 are definitions of gross and net photosynthesis and all terms, except for Φ can be measured, although good estimates of respiration over the full range of light and temperature have been rare.

Both μ_g and R_d are a function of acclimation state, light absorption and temperature (nutrients are assumed to be saturating). For a typical commercial system the crop can be considered homogenously acclimated since the mixing time-scales are faster than the acclimation time-scales. While acclimation may be homogenous, the instantaneous light the cells experience is far from steady-state. Since the cells are experiencing highly variable light forcing at short time scales, a combination of improved knowledge of gross photosynthesis and respiration in the rapidly changing light regime is needed for prediction. Also large temperature fluctuations can be experienced on a diel and seasonal cycles for commercial systems. Unfortunately, the vast majority of laboratory studies and modeling efforts have been carried out at "steady-state" conditions of constant light and temperature, so there is uncertainty if the models can apply in a straightforward way to commercial systems. Furthermore there are very few studies over a wide range of temperature or light conditions that mimic the highly fluctuating light expected from both capillary wave focusing and mixing. Still, there is good progress using the framework specified by equations 1-6 for steady-state light and temperature regulated growth.

We take the approach of direct parameterization of the biophysical variables Fchl and Φ as functions of abiotic forcing (light, temperature and nutrients). This is an important improvement over other widely cited models[13] as we account explicitly for absorbed photons, whereas the other models used data that does not resolve total photon flux by integrating the spectral absorption and irradiance as we do (*e.g.* Equation 6). While the other approaches do have robust predictive ability for the simple experimental illumination systems for which they were parameterized (constant spectral quality, for example), this is a flawed approach for realistic aquatic systems, including commercial algae systems, where the spectral quality varies dramatically with depth. Since light and temperature are primary environmental factors that cannot be controlled in commercial systems, these variables have been an area of focus for our group with good results as shown in Figure 1. Microalgae saturate their nutrient uptake at very low concentrations (1-10 μM), which is far lower than typical concentrations in commercial systems. Also pH and associated availability of CO_2 can be important considerations; we have an ability to control pH within narrow ranges, and we expect this level of pH control will also be the norm for future commercialization. Therefore we can simplify our approach to limit the experimental matrix to light and temperature regulation of growth.

Modeling of Light and Temperature Limited Growth at Steady-State

Microalgae in natural or commercial systems experience variable light intensity and spectral quality as a result of vertical mixing, attenuation with depth due to particulate and dissolved material and water itself, and rapid fluctuations related to capillary wave focusing and defocusing of the solar beam. The most common commercial systems are shallow ponds of 10-30 cm depth that use low energy systems to circulate the algal crop. In such systems the cells move from potentially hyper-saturating light pulses caused by capillary wave focusing near the surface, to darkness at deeper depth. In fact, because commercial systems require very high biomass density to minimize costs of harvest and boost areal productivity, most of the microalgal crop resides in the dark or sub-optimal light at any given time. In such dense culture systems, a typical "euphotic zone" depth, or depth of 1% surface irradiance, is 3-5 cm. For pond depths of 30 cm typical of many commercial systems, as much as 90% of the crop is deeper than the euphotic zone at each instant in time.

While most people assume temperatures must be in the 20-30 °C range for reasonable algal productivities, this simply is not true. There are microalgae that grow extremely fast down to 10°C. Even at the freezing point of water, under a meter of sea ice, we have documented productivities of 3 gC/m^2/day[14]. This yield per unit area-time is too low for commercial viability, but it remains a remarkable fact that at such low temperature and very low light a natural crop can sustain such high productivities. It is our view that the reasonable range for commercialization is 10-40°C, with optimized strains that are site-selected, as in terrestrial agriculture, for the specific agronomic conditions locally.

Since light and temperature are abiotic regulators of growth that are not easily or economically controlled using systems engineering with added energy input, we need to understand the performance of the algae crops for the light and temperature scenarios that exist at local scales. Although light will change rapidly on short time scales and temperature on the diel scale, acclimation time scales are relatively long compared to these variations so the crop will have a mean acclimation state to light and temperature that can be modeled. Figure 1 shows observed and modelled net growth (μ_n) rate of a commercial strain, *Dunaliella tertiolecta* in a light and temperature matrix where the model was based on parameterizations for F_{chl} and Φ applied to the equations above. Details of the methods for parameterizations are not presented here.

The direct comparison of observed versus predicted growth in Figure 1B is excellent but this is for net growth at steady-state conditions for light and temperature without consideration of respiration. Also the temperature limited data were collected for only one light level due to limited funding. Considering the non-steady state reality of commercial systems where much of the crop will be in a very low light or dark at any moment, we expect that state-of-the-art models such as those in Figure 1, while very good for steady-state, will not be satisfactory for commercial systems that are operating far from steady-state in terms of instantaneous light. Still, we expect the modeling framework is relevant and can be parameterized if sufficient data is collected for conditions that mimic commercial systems.

Algal Respiration

Respiration accounts for a significant loss of photosynthetically fixed cellular carbon, yet the specific interactions between respiration and photosynthesis in dynamic light environments as described above, together with changes in temperature at daily and seasonal scales, are not well studied or modelled. Previous studies completed for a few strains, and for a very limited range of steady-state light and temperature conditions have resulted in simplistic model parameterizations that predict respiration as a function of gross photosynthesis[12,13,15,16]. Consequently, the assumptions used may have oversimplified the complex relationship between these two processes.

Our recent DOE-funded experiments with the marine diatom *Phaeodactylum tricornutum* demonstrate the dynamic relationship between dark respiration and gross photosynthesis as a function of light. Figure 2 illustrates that the ratio of respiration to gross photosynthesis is relatively small at high light (higher growth rates) but increases dramatically at low light. This has important implications for commercial

systems where the crop spends most of the time at very low light, or in the dark. Proper consideration of the dynamic relation between photosynthesis and respiration is essential for robust predictive capability of microalgae in commercial systems. New data is required on net and gross photosynthesis, and respiration, within realistic illumination and temperature scenarios expected with commercial production systems. This type of data does not exist in the literature, but likely some of the commercial companies have explored these relationships in detailed unpublished experiments. Fortunately, there are advances in higher throughput algal physiology and laboratory culturing systems that allow collection of data at the correct time-scales to facilitate advanced model parameterizations beyond the steady-state conditions of current models (*e.g.* Figure 1). Also, modern computational fluid dynamics (CFD) can now simulate the trajectory of a microalgal cell within a realistic production system so that the rapid time-scales of light change and the diel changes in temperature can be estimated instantaneously and then integrated for the full crop[17].
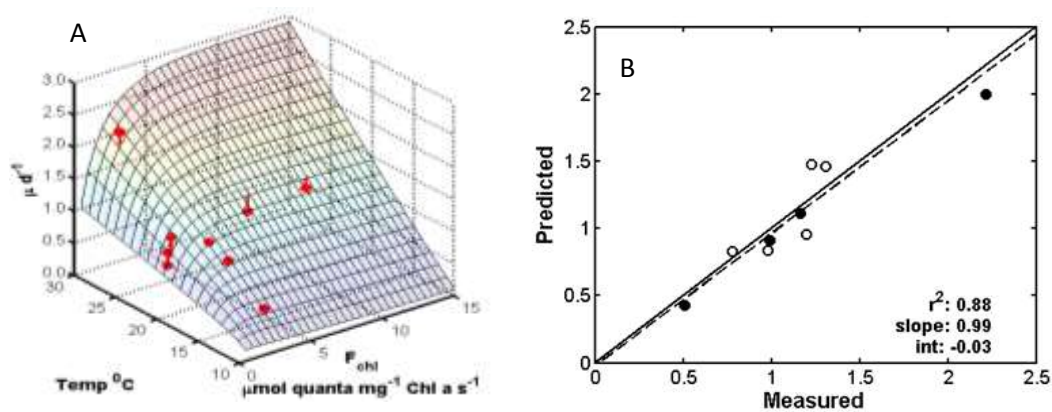
Figure 1. Model prediction for *Dunaliella tertiolecta* net growth (μn) in a light and temperature matrix, grown with saturating nutrients, and constant pH 8 conditions. A. Predicted growth rate as a function of temperature and Fchl, the quantum flux absorbed by the cell. Observations are closed red symbols and the 3-D surface is the overall model domain. B. Comparison of modelled vs. measured growth rate, for the same data in 1A. Closed circles are temperature limited growth data at 127 μmol quanta m^{-2} s^{-1}, and the open circles are at 20°C for light intensity ranging from 30-800 μmol quanta m^{-2} s^{-1}. The model has high predictive fidelity (r^2 = 0.88) and virtually no bias (slope = 0.99 and intercept = -0.03).
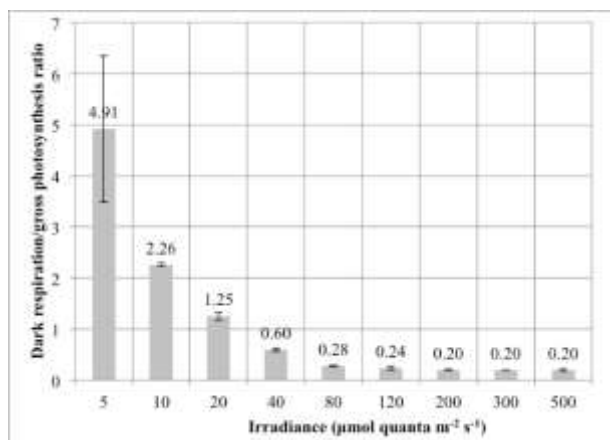
Figure 2. The ratio of R$_d$ / μ$_g$ as a function of short-term light intensity for the diatom *Phaeodactylum tricornutum* acclimated to 127 μmol quanta m^{-2} s^{-1}.

Looking Forward

Our approach to modelling explicitly and accurately estimates photon flux to microalgae as a product of spectral absorption and spectral irradiance (Equations 4-6; Sosik and Mitchell, 1991; Moisan and Mitchell, 1999), and allows an accurate framework for determining the quantum yield of photosynthesis, Φ, which is the fundamental biophysical term that represents conversion of solar energy into biomass energy. With knowledge of how Φ and F_{chl} vary with light and temperature, robust steady-state models with excellent predictive ability can now be created (Figure 1). The framework outlined in Equations 1-6 is superior for application when the spectral quality of light exhibits extreme variability, as it will for high biomass density commercial systems. This approach explicitly computes photon flux based on direct measurement of spectral absorption and irradiance, whereas other models (Geider et al. 1998) do not explicitly account for spectral variations that can result is large errors in estimates of photon flux to the photosystem.

Advances in our ability to properly model commercial microalgal production systems is now feasible using a combination of modern tools, including: (1) computational fluid dynamics (CFD) models that can track a cell through its travels within a simulated commercial system in time (James et al. 2010); (2) proper determination of spectral light and absorption as outlined in the model equations above and applied in Figure 1; (3) physiological experimental systems that allow for short time-scale observations (as represented in Figure 2 for oxygen), and stable isotope discrimination of carbon flux studies using membrane inlet mass spectrometry (MIMS; Hopkinson et al. (2011); and (4) high-intensity, programmable LED illumination systems that can mimic the short time-scale fluctuations that occur in a commercial production systems.

Furthermore, detailed experiments with proper time-scales and with non-steady state light and temperature regimes that mimic commercial systems will allow us to address questions such as: (1) how do algal cells regulate their photosynthesis and respiration rates in the dynamically shifting light and temperature environment in the production system? (2) What are the key metabolic pathways and corresponding enzymes that are associated with such dynamic changes and how different isoenzymes are expressed with different acclimation states? (3) How is this regulation implemented on the molecular level and how can we use modern tools to modify metabolic expression to optimize strains? (4) How can we integrate a more accurate model of photosynthesis, as outlined in the equations above with modern knowledge of computational fluid dynamics to simulate accurately commercial microalgae production systems?

Algae biotechnology publications and presentations at meetings routinely claim that given progress in the reduction of costs with scale (*e.g.* economies of scale at ca. 5,000-10,000 acres) current knowledge and technology will achieve economically competitive production of higher value nutraceutical crops (*e.g.* Omega 3 and ω-6 fatty acids; phytochemical anti-oxidants), and possibly even high value animal feed that is comparable in quality to fish meal. To achieve such goals would require producing biomass at a cost less than \$2,000/ton, whereas current costs of production at scales of a few hundred acres are approximately \$10,000/ton. Can we expect that a commitment to scale can meet these more ambitious targets? Or at even larger scales, yet bring prices below \$1,0000/ton to access massive-scale markets such as low value animal feed and fuel?

The physiological model framework for cellular growth outlined above, combined with advanced CFD modelling, will be an essential part of the process of predicting performance of elite strains in realistic large-scale production systems. Major advances in lowering the costs of installation and operation of the production systems, harvesting and downstream processing are also essential to achieve commodity scale for fuel or feed. However, considering current estimates of production systems ranging from \$10,000-\$100,000 per acre, the break-even size that many cite (ca.10, 000 acres) will cost between 0.1 – 1 billion dollars just for construction. Clearly, this magnitude of financial commitment is presently unrealistic, given current actual production costs of algal biomass at small scale and low prices for fuel and feed. However, Brazilian ethanol from sugar cane is an excellent example of massive scale-up of biomass for fuel. Goldemberg et al. (2004)[15] show a learning curve (progress ratio, economy of scale) slope of about 0.7, that over 20 years and 10's of billions of dollars of investment resulted in sugarcane ethanol in Brazil being produced at a cost per energy unit comparable to petroleum-derived fuel. Brazil's

approach was rational and required large public investment that then leveraged private investment (e.g. re-designed automotive engines by all global manufacturers for the Brazilian market). Even though it was already well known how to grow, harvest and crush sugar cane and ferment the syrup to ethanol, the end result still took 10's of billions of dollars and 20 years to accomplish. A sports analogy is that this was a marathon, not a sprint, and Brazil reached the finish line in due time. Continuing the analogy, producing algae biomass for low cost commodities such as animal feed and fuel would be more like an Iron Man triathlon, since we do not yet even know which are the optimal cultivars, much less how to design systems for low cost production, harvesting and downstream processing into fuel and feed. We believe that low cost algae commodity biomass will take at least as much investment and time as it took for Brazilian ethanol to become cost competitive with petroleum fuels. Further, we believe that the multi-trillion dollar economic transformation, and the sustainability proposition that algae might deliver are worth the risk of near-term investments many times what have been spent on algal biotechnology thus far.

A part of the near term investment should be in the advancement of computational models at the smallest scales (*e.g.* cells absorbing light in dynamic realistic production systems informed with properly acquired laboratory data), and at the largest scale (*e.g.* currently known yields of protein, oils and carbohydrate; resource utilization of water, land and nutrients; and life-cycles of energy and greenhouse gases; introduced into global climate, population and agricultural production models[7]. The former will provide ever greater confidence that the yields can be predicted accurately across a range of strains and agronomic conditions. Considering recently published literature regarding yields, life cycle assessments, and sustainability resource utilization metrics, we expect that the latter will demonstrate to the public and policy makers that the investment is worth the risk to get to scale sooner than later. Both of these modelling scenarios can be pursued aggressively now at relatively low costs. The question remains: what are we waiting for?

References:

1.   Wijffels R.H. & M. J. Barbosa An outlook on microalgal biofuels. Science, 329, 796. DOI: 10.1126/science.1189003 (2010).

2.   Georgianna, D. R. & S. P. Mayfield. Exploiting diversity and synthetic biology for the production of algal biofuels. Nature, 488(7411), 329-335 (2012).

3.   Draaisma R.B., Wijffels R.H., Slegers P.M., Brentner L.B., Roy A. & M.J. Barbosa. Food commodities from microalgae. Current Opinion in Biotechnology, 24, 169–177 (2013).

4.   http://www.appliedphycologysoc.org/newsletter/ISAP_Newsletter_March_2014.pdf

5.   Wise M., Calvin K., Thomson A., Clarke L., Sands R., Smith S.J., Janetos A., & J. Edmonds.. The Implications of Limiting CO_2 Concentrations for Agriculture, Land-use Change Emissions, and Bioenergy. Technical Report. [PNNL-17943] (2009).

6.   Joshua E. *et al.* Constraints and potentials of future irrigation water availability on agricultural production under climate change Proceedings of the National Academy of Sciences USA, 111(9), 3239–3244 (2014).

7.   Rosenzweig, C. *et al.* The Agricultural Model Intercomparison and Improvement Project (AgMIP): Protocols and pilot studies. Agricultural and Forest Meteorology., 170, 166-182, doi:10.1016/j.agrformet.2012 09.011. (2013).

8.   Kiefer D. A. & B. G. Mitchell. A simple, steady state description of phytoplankton growth based on absorption cross section and quantum efficiency. Limnology and Oceanography, 28(4), 770-776 (1983).

9.   Sosik H. M. & B. G. Mitchell. Absorption, fluorescence, and quantum yield for growth in nitrogen-limited *Dunaliella tertiolecta*. Limnology and Oceanography, 36(5), 910-921 (1991).

10. Moisan T. A. & B. G. Mitchell. Photophysiological acclimation of *Phaeocystis antarctica* Karsten under light limitation. Limnology and Oceanography, 44(2), 247-258 (1999).

11. Hiscock M.V. *et al.* Photosynthetic maximum quantum yield increases are an essential component of the Southern Ocean phytoplankton response to iron. Proceedings of the National Academy of Sciences USA, 105(12), 4775-4780 (2008).

12. Shuter B. A model of physiological adaptation in unicellular algae. Journal of Theoretical Biology, 78(4), 519-552 (1979).

13. Geider R. J., MacIntyre H. L. & T. M. Kana. A dynamic regulatory model of phytoplankton acclimation to light, nutrients, and temperature. Limnology and Oceanography, 43(4), 679-694 (1998).

14. Arrigo K. R. *et al.* Massive phytoplankton blooms under Arctic sea ice. Science, 336, 1408 (2012).

15. Laws E. A. & T. T. Bannister. Nutrient-and light-limited growth of *Thalassiosira fluviatilis* in continuous culture, with implications for phytoplankton growth in the ocean. Limnology and Oceanography, 25(3), 457-473 (1980).

16. Falkowski P.G., Dubinsky Z. & G. Santostefano. Light-enhanced dark respiration in phytoplankton. Verhandlungen des Internationalen Verein Limnologie 22, 2830-2833 (1985).

17. James S.C., Seetho E., Jones C. & J. Roberts. Simulating environmental changes due to marine hydrokinetic energy installations, in: B. Spindel, T. Brockett (Eds.) OCEANS 2010, Seattle, WA, pp. 1-10 (2010).

18. Hopkinson B.M., *et al.* Efficiency of the CO_2-concentrating mechanism of diatoms. Proceedings of the National Academy of Sciences USA, 108(10), 3830-3837 (2011).

19. Goldemberg J. *et al*. Ethanol learning curve—the Brazilian experience. Biomass and Bioenergy 26, 301 – 304 (2004).

See also: http://www.globalchange.umd.edu/models/gcam/

Induced biological soil crusts: an example of applied phycology still little known.

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The progression of desertification is well recognised as an increasing environmental, social and economic emergency existing on all the continents. Desertification has been defined as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climate variation and human activity". In order to remediate degraded soils and return to sustainable land use, an increase in soil organic matter (SOM) content and a more efficient and sustainable use of water resources are key factors to be considered. Soil quality depends on several physical, chemical and biological properties, but generally soil microbial communities are key players in several important soil processes and both composition and activities of these communities can affect such processes.

Many different approaches have been proposed for counteracting desertification and for the restoration of desert soils. Among them, an environmentally sustainable biotechnology based on the induction of the formation of biological soil crusts (BSCs) was recently proposed and applied in the field.

Role of BSCs in nature

Natural BSCs are complex associations of cyanobacteria, microalgae, chemoheterotrophic bacteria, fungi, mosses, liverworts that aggregate soil particles due to the release of extracellular polymeric substances and to the presence of filamentous cyanobacteria and fungal hyphae[1]. It has been calculated that BSCs cover up to 70% of soil area in arid and semiarid environments, but can be found also in a large number of other hot and cold environments of the world (Figures 1 and 2).

Natural BSCs are a combination of micro- and macro-organisms, some of which are common in desert soils throughout the world. In 2005, Büdel[2] reported that globally 46 genera of cyanobacteria, 70 of eukaryotic microalgae, 14 of cyanolichens, 70 of chlorolichens, 65 of mosses and liverworts had been identified in BSCs overall. These complex communities play a multifunctional role, creating the movement of material and energy in and out of the soil and controlling biogeochemical cycles[3]. They are involved in carbon and nitrogen fixation, soil stabilization, mineralization, dust trapping, as well as affecting local hydrological cycles [3,4].

Figure 1. Natural BSCs in the Sonoran Desert Picture (Arizona, USA).
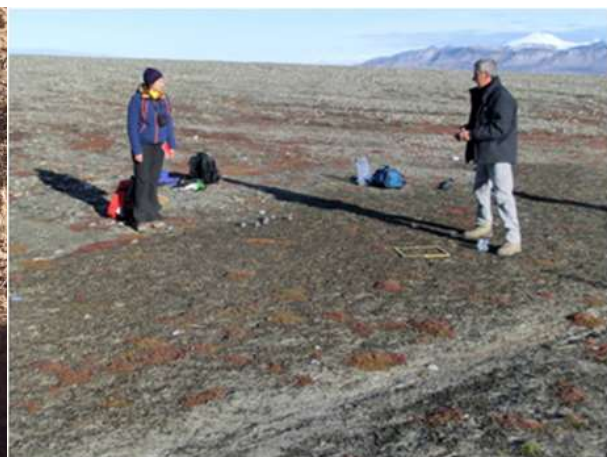
Figure 2. Natural BSCs in Svalbard Islands (Norway).

The induction of BSCs: an example of applied phycology utilized for counteracting environmental threats

Background

Although BSCs have been only rarely considered or discussed in restoration literature[5], the possibility of improving soil health and productivity by restoring disturbed indigenous BSCs or by artificially introducing BSCs on hyper-arid soils to counteract desertification has recently attracted an increasing interest. Effectively, due to their key ecological roles, support to BSC recovery can help in rehabilitating the ecosystem in its entirety[5], especially where unassisted recovery is not easy to achieve. The use of inoculation-based techniques (IBTs), based on the introduction of non-native BSC material and/or mass-cultured organisms previously isolated from natural BSCs[6-8], has been massively tested in field experiments in Chinese deserts. This eco-friendly and natural approach recreates natural conditions that facilitates later plant colonization[9-10].

The induction of BSCs: the technology

For obtaining good results in large-scale inoculation treatments using cyanobacteria three main issues have to be addressed: i) an effective screening for selecting suitable strains among those isolated from indigenous BSCs; ii) mass cultivation of the selected cyanobacteria in proper devices employing stable and cheap biomass production processes; iii) the choice and the optimization of a proper culture-dispersal strategy[11]. The selection process of cyanobacterial strains needs to address the problem of the capability of the selected strains to grow well in the field. The capability of secreting large amounts of EPSs is also considered important, as it increases the sediment gluing capability and enhances the strain capability to withstand different stresses, particularly water stress[12]. Mass cultivation and biomass concentration are important issues to be considered for moving from small to large culture volumes, up to industrial raceway ponds[6] (Figure 3). Efforts must be directed towards the proper photo-bioreactor's design and the control of light intensity, temperature and refresh rate of the medium[7]. Regarding the culture dispersal strategies, two types of large-scale inoculation approaches have been proposed and tested, a ground dispersal[8] or an aircraft-based technology[11].

Figure 3. Mass cultivation facilities at the Shapotou Scientific Station of the Chinese Academy of Sciences, Inner Mongolia, China.

Conditions for good BSC development

The development of BSCs is affected by internal and external factors[13]. Internal factors are those depending on the physiological characteristics of the species and their interactions, while external factors include soil moisture, temperature, light intensity and nutrient availability. Soil pH and K content are important for microalgal and cyanobacterial colonization in early successional stages, while N content, total P, salinity are known to affect the abundance of organisms[14].

The effects of BSC induction in hyper-arid environments

Only a few reports are available on large-scale inoculation of desert soils. It was reported that *Microcoleus vaginatus*, mass-cultivated in a 240 m^2 raceway pond and inoculated in seven hyper-arid sites in Chinese deserts, induced the formation of BSCs capable of withstanding up to 19 mm rain and a grade 4.3 wind after 20 days[15]. The inoculation procedure was improved by using a mixture of two cyanobacteria, *M. vaginatus* and *Scytonema javanicum*, and by preventively stabilizing the sites using straw checkerboards[8] (Figure 4). The BSCs induced by inoculating with the two cyanobacteria were already visible 7 to 20 days after the inoculation[15,16], although it was demonstrated that the BSC forming velocity depends on the characteristics and the degree of fixation of the dunes. During the first stages, biolayers appeared flat, fragile, and with limited stability, before increasing in thickness and darkening in colour. After 8 years from the inoculation, induced BSC (IBSC) thickness may reach 9 mm, developing a compressive strength up to 106 N.cm^{-2}, starting from null values[8].

Figure 4. Eight years old induced BSCs in Hobq Desert, Inner Mongolia, China. The crust was broken to show the thickness and the underlying sandy soil.

The development of BSCs fosters the natural onset of herbaceous and subshrub species (Figure 5) along with the recovery time[8], increasing the diversity of the plant community[7].

Figure 5. Induced BSCs in Hobq Desert (Inner Mongolia, China) surrounded by plants eight years after the inoculation.

Role of EPSs in induced BSCs

In dryland soils, where C content is low, a huge share of the introduced C comes from microbial-secreted exopolysaccharides (EPSs)[17], which represent the primary substrate respired after rainfall events by BSC microflora[18]. EPS accumulation in the soil is evident when comparing soils where BSCs were induced with bare sandy counterparts[19]. EPSs and their chemical and physical features strongly affect soil hydrological processes. Although the role of BSCs in water relations have still to be thoroughly clarified, in North American soils covered by natural crusts, it was demonstrated that BSCs affect water sorptivity[9], while high molecular weight EPSs of IBSCs on sandy soils were demonstrated to affect hydraulic conductivity and water capture from non-rainfall sources[19]. Indeed, the abundance of EPSs was proved to be positively correlated to the water capture capability of IBSCs, and when EPSs were artificially removed, the capability to capture water was not statistically different from that of bare sand[19].

Conclusions

The data available on the capability of induced BSCs to stabilize and rehabilitate arid and degraded soils in lab and field experiments point out that a promising new biotechnology for the restoration of desert soils is now available, even if a number of issues have still to be addressed in order to optimize this eco-friendly biotechnological process.

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References

1.   Belnap J., Laxalt M. & P. Peterson. Biological soil crusts: ecology and management. (US Department of the Interior, Bureau of Land Management, National Science and Technology Center, Information and Communications Group (2001).

2.   Büdel B. *in* Microorganisms in Soils: Roles in Genesis and Functions *eds. Varma, P. D. A. & Buscot, P. F.,* 307–323 Springer Berlin Heidelberg, (2005). http://link.springer.com/chapter/10.1007/3-540-26609-7_15

3.   Pointing S. B. & J. Belnap. Microbial colonization and controls in dryland systems. Nat. Rev. Microbiol. 10, 551–562 (2012).

4.   Rossi F., Potrafka R. M., Garcia Pichel F. & R. De Philippis. The role of the exopolysaccharides in enhancing hydraulic conductivity of biological soil crusts. Soil Biology and Biochemistry, 46, 33-40 (2012).

5.   Bowker M. A. Biological soil crust rehabilitation in theory and practice: an underexploited opportunity. Restororation Ecology, 15, 13–23 (2007).

6.   Liu, Y. & al. The control of desertification by algae, herbaceous plants and shrubs: in the framework of the regional sustainable development in north China. Science Press, (2013).

7.   Liu & et al. Environmental biology of desert cyanobacteria: its application in the desertification control by induced biological soil crusts. Science Press, (2013).

8.   Wang W., Liu, Y., Li D., Hu C. & B. Rao. Feasibility of cyanobacterial inoculation for biological soil crusts formation in desert area. Soil Biology and Biochemistry, 41, 926–929 (2009).

9.   Rossi F., Olguín E. J., Diels L. & R. De Philippis. Microbial fixation of CO_2 in water bodies and in drylands to combat climate change, soil loss and desertification. New Biotechnology, 32, 109–120 (2015).

10.   Chapin F. S., Walker L. R., Fastie C. L. & L. C. Sharman. Mechanisms of primary succession following deglaciation at Glacier Bay, Alaska. Ecological Monographs, 64, 149–175 (1994).

11.   Sears, J. T. & B. Prithiviraj. Seeding of large areas with Biological Soil Crust starter culture formulations: Using an aircraft disbursable granulate to increase stability, fertility and CO_2 sequestration on a landscape scale. In 2012 IEEE Green Technologies Conference 1–3 (2012). doi:10.1109/GREEN.2012.6200934

12.   De Philippis R. & M. Vincenzini. Exocellular polysaccharides from cyanobacteria and their possible applications. FEMS Microbiology Reviews 22, 151–175 (1998).

13.   Bu C., Wu S., Yang Y. & M. Zheng. Identification of factors influencing the restoration of Cyanobacteria-dominated Biological Soil Crusts. PLoS ONE 9, e90049 (2014).

14.   Nan Wu H. W. Temporal-spatial dynamics of distribution patterns of microorganism relating to biological soil crusts in the Gurbantunggut Desert. Chinese Science Bulletin, 51, 124–131 (2006).

15.   Chen L. Xie Z., Hu C., Li D., Wang G. & Y. Liu. Man-made desert algal crusts as affected by environmental factors in Inner Mongolia, China. Journal of Arid Environments, 67, 521–527 (2006).

16.   Lan S., Zhang Q., Wu L., Liu Y., Zhang D. & C. Hu. Artificially accelerating the reversal of desertification: Cyanobacterial inoculation facilitates the succession of vegetation communities. Environmental Science and Technology, 48, 307–315 (2014).

17.   Mager D. M. Carbohydrates in cyanobacterial soil crusts as a source of carbon in the southwest Kalahari, Botswana. Soil Biology and Biochemistry, 42, 313–318 (2010).

18.   Thomas A. D., Hoon S. R. & P. E. Linton. Carbon dioxide fluxes from cyanobacteria crusted soils in the Kalahari. Applied Soil Ecology, 39, 254–263 (2008).

19.   Colica G., Li H., Rossi F., Li D., Liu Y. & R. De Philippis. Microbial secreted exopolysaccharides affect the hydrological behavior of induced biological soil crusts in desert sandy soils. Soil Biology and Biochemistry, 68, 62–70 (2014).

News and Views

Reserve the dates!

Fifth ISAP Congress, Nantes, France 2017

ISAP breaks waves on social media

To appeal to our social media savvy members and non-members and to encourage better interaction between our members our Executive Committee decided to go 'live' on social media. This came into fruition after the brainstorming exercise initiated by the President of our society Professor Roberto De Philippis in July 2014. There was an overwhelming support from the members of the Executive Committee to create an informal forum where members of the society would be kept informed of the latest developments in applied phycology and notifications about the society and its activities. We also foresee this as a good media to advertise the society and her activities and expect to attract new members.

The Facebook page went online on the 7th of July 2015. At the time of penning this news clip, the society's Facebook and LinkedIn page received over 90 posts. The Facebook page is gradually gaining the interest of the wider community interested in various aspects of applied phycology. The current statistics include 65 likes, 350 post reaches per week and 19 post engagements. We encourage you to join by visiting **https://www.facebook.com/AppliedPhycology1/**

The LinkedIn group was also created at the same time as the Facebook page. Currently it is an extension of the Facebook page but we anticipate to use it as a discussion forum down the track. We have about 33 members who are subscribed to the group. You can visit the page at **https://www.linkedin.com/groups/6981672**

Plankton Net is a secure e-list created in 1999 to provide a forum to post or view job advertisements in aquatic sciences, besides graduate studentships, conference announcements, workshops and training announcements. This active list also serves as a general forum for discussion pertaining to ecology, taxonomy, physiology, productivity and monitoring of phytoplankton and zooplankton, in fresh, brackish and seawater throughout the world. The list has a membership of about 1500 subscribers from over 150 countries. To join the list visit:
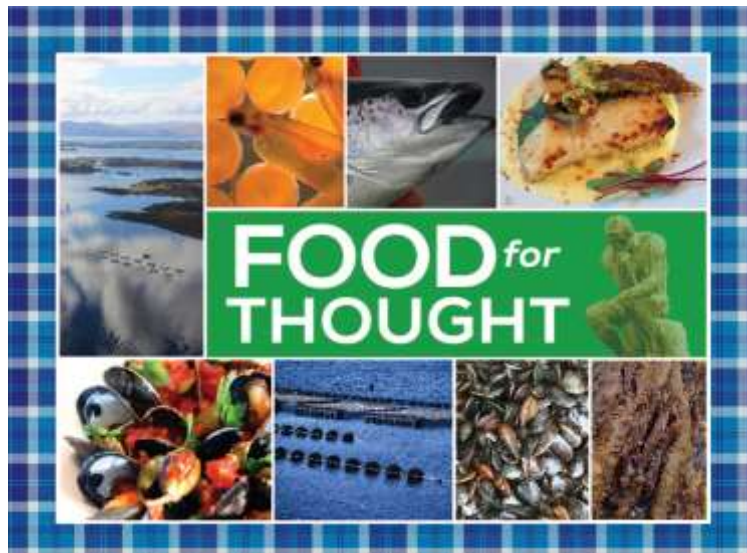**https://groups.yahoo.com/neo/groups/planktonnet/info**

Other meetings in 2016

https://www.iss-2016.org/ehome/index.php?eventid=130925&

http://easonline.org/39-uncategorised/346-aquaculture-europe-2016

http://www.algaebiomasssummit.org/

http://www.algalbbb.com/

This Newsletter and other information on ISAP can be retrieved from the ISAP website: http://www.appliedphycologysoc.org/

Committee announcements

Articles for the newsletter

The editorial committee of ISAP newsletter solicits articles of general interest relevant to the field of applied phycology for forthcoming issues of our newsletter. The articles may be formatted in a semi-technical or in a popular science article format. We welcome articles from members as well as non-members of the society. **For details on how to contribute to the newsletter please contact the Editor of ISAP newsletter Dr. Amha Belay at abelay@earthrise.com**.

Email list for Members Only on Yahoogroups

The current committee of our society realised a gap in regular communication with members other than through our periodic newsletter and meetings every 3 years. As a growing society, the committee identified the need for regular communication and therefore investigated various options available to create an e-list that required low maintenance, was cost effective, user friendly and most important offered a secure platform to communicate. This closed list will have the following features:

i.   Restricted membership approved by moderators only
ii.   Fully moderated list with each and every message approved by the moderators
iii. No access to the membership database as per yahoogroups security policies
iv.   Ability to create polls, upload photos, create links, events, database, files, etc.

In the next month, the administration team will send out invitation emails to the members of the society. It is entirely up to the members choose whether to accept the invitation or not. Alternatively, the member may choose to subscribe to the list by visiting the homepage by following the link below. This subscription request will however be subject to the list moderator accepting the request after confirming that the request has originated from a current member.

https://au.groups.yahoo.com/neo/groups/Applied_Phycology/info

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This Newsletter and other information on ISAP can be retrieved from the ISAP website: http://www.appliedphycologysoc.org/