Executive summary of the Ecology, Ecotoxicology and Economy of Sargassum (Eco3Sar) Project

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Massive strandings of pelagic sargassum seaweeds recorded since 2011 pose significant problems throughout the Caribbean basin and for some African coastlines. Indeed, when Sargassum rots on the beach and in intertidal waters, it causes foul odours, mechanical and public health problems with major economic consequences for various business sectors, including tourism and for those making their living from the sea or the coast. Furthermore, these strandings alter public perception but also trigger requests from local communities to intervene, which involves reorganising arrangements to deal with these events. Currently, Sargassum is mostly collected once it has beached. Even though it is the most common method used in the French West Indies to deal with harmful effects of massive Sargassum strandings, new issues related to the collection, storage and reuse of these algae have emerged.

The Eco3Sar Project used an interdisciplinary approach to better understand the composition of Sargassum windrows, particularly by researching chemical, organic and biological contaminants. It is in fact conceivable that the organic, chemical or bacteriological substances having built up in the Sargassum could become a source of contamination during storage and repurposing processes, or even for products made from these algae. As the production of fertiliser is currently one of the viable sectors in the French West Indies, the project also sought to study in more detail

contamination and decontamination processes when converting the Sargassum into fertiliser, but also during the natural drying process. At the same time, studies on the social acceptability of this new industry to reuse Sargassum were introduced as a key issue for the economy and society as well as for related forms of governance.

During the project, it was deemed vital to conduct relatively comprehensive sampling campaigns to analyse spatial and temporal differences in the main components of Sargassum (carbon, nitrogen, sulphur, phosphorus, heavy metals, metalloids) and to detect the presence of chlordecone, a persistent organic pollutant. Two sampling campaigns were undertaken, the first in July and August 2018 and the second in March and April 2019. In total, 230 samples were analysed, taking the form, in most cases, of triplicate analysis at each site. The studied sites covered the Atlantic coastlines of Martinique and Guadeloupe, including the islands of Marie-Galante, La Désirade and Les Saintes. It should be noted that several storage sites in Martinique were sampled for the study together with offshore samples taken 20 to 30 km from the southeast tip of Martinique.

Average concentrations recorded in the Sargassum samples were: 0.45 mg/kg for Cadmium (Cd), 11.4 mg/kg for Chromium (Cr), 1.1 mg/kg for Cobalt (Co), 4.3 mg/kg for Copper (Cu), 3.8 mg/kg for Nickel (Ni), 0.55 mg/kg for Lead (Pb), 7.4 mg/kg for Zinc (Zn) and below detectable limits for Mercury (Hg) and Methyl Mercury ($HgX\text{-}CH_3$). Given the low concentrations that are below current standards, Sargassum does not seem to be contaminated by these elements, which is in accordance with the international literature on this subject. These metals do not appear to pose an environmental issue and so are no obstacle to using Sargassum, particularly as an organic fertiliser.

The study has shown that the mineral form of arsenic (As) which is largely present in the Sargassum is the least hazardous form arsenic (V). On average, mineral forms accounted for three-quarters of total arsenic (albeit with wide variations). Regardless of form, the average total concentration of phyto-accumulated arsenic in beached Sargassum was 80 mg per kg of dry matter (min = 9.5, max = 156) considering both sampling campaigns. An interannual variability was identified. It was also shown that during the drying process on the beaches, the total quantity of arsenic could drop markedly in the Sargassum. Sargassum from storage sites also featured significantly lower concentrations of arsenic than samples taken from stranding sites. The presence of arsenic in Sargassum requires specific treatment for beached seaweed as leaving Sargassum in the water could cause potentially large amounts of arsenic to leach into the surrounding environment. This then supports the logic that collecting still fresh Sargassum could help cut arsenic transfers to the environment. Although the environmental impact of the leaching of arsenic from the Sargassum is not covered in this study, it would be useful to question what happens to it in food webs and the possibility of bioaccumulations by some edible or non-edible organisms. What actually

happens to arsenic from harvested Sargassum at storage and reusing sites is indeed a key matter. The leachates from the Sargassum decomposition can contain very high levels of arsenic that can exceed 1,000 µg/L. As such, while we have confirmed that Sargassum-based products made by Holdex Environnement comply with current French standards (see Annex), our analyses advocate the importance of using classified facilities for this type of reusing operation.

Regarding the molecule of chlordecone present in some beached Sargassum on the coasts of Guadeloupe and Martinique, the findings from the Eco3sar Project supplement and expand our knowledge on contamination by this persistent pollutant. As such, analyses at fifteen sites in Martinique and almost twenty in the Guadeloupe Archipelago recorded no chlordecone in sargassum samples taken from areas without fishing restrictions. For areas with fishing limitations or restrictions, we found a certain spatial and temporal consistency in the concentrations measured. This ranged from a few µg per kg of dry matter (DM) of Sargassum, right up to 1.9 mg/kg of DM at the Plage des Roseaux in Capesterre-Belle-Eau in Guadeloupe, or 0.58 mg/kg of DM at Quartier Bac, in Martinique. The average concentrations measured at the same sites during the sampling campaign in early spring 2019 were consistently higher than those of summer 2018 (by a factor or 1.5 to 2). Without any real explanation, it was noted that Sargassum from the 2019 sampling campaign more systemically corresponded to recent strandings, inferring a potential influence of on-site degradation, leaching and drying, or even interannual differences in marine chlordecone concentrations. A pilot experiment to monitor Sargassum composting windrow with deliberately chlordecone-contaminated Sargassum showed that the concentration of chlordecone after two months of industrial processing was less than at the start of the process (see Annex).

The Eco3Sar Project also studied the molecular diversity of eukaryotic (protists and fungi, etc.) and prokaryotic (bacteria and archea) organisms related to beached Sargassum. It was shown that several tens of thousands of organisms (approx. 22,000 prokaryotic and around 18,000 eukaryotic molecules) were living in association or interdependently and/or close to the Sargassum. Statistical differences in the composition of communities but also specific organisms were demonstrated between surrounding seawater and beached Sargassum, as well as between offshore Sargassum and that from storage sites. These findings also highlight the range of species potentially involved in generating hydrogen sulphide, fermentation, the nitrogen metabolism or the breakdown of complex organic compounds from Sargassum. Monitoring microbiological quality as well as using the microbial diversity in possible future biotechnology applications could be one of the outcomes of this study.

In parallel to the researches mentioned above, we also began analysing public perception on the use of repurposed Sargassum products. Indeed, a greater

understanding of the way local communities might view the reuse of this potential resource that can contain harmful substances could provide different ways of managing urbanised and natural coastlines, as well as helping mitigate health problems and potential environmental and economic effects. The purpose of the survey was to update levels of acceptability for using Sargassum to produce fertiliser, involving a full range of social stakeholders. As we might have sensed, people consider Sargassum and especially when it decomposes on the shore, troublesome given the historical background sensitive to environmental problems. Using data gathered from 31 different types of social stakeholders from various ethnographic settings in different localities in Martinique and Guadeloupe, three public perception diagrams were developed:

(i) Indifference to a situation from being unaffected by potential health hazards mainly due to sporadic visits to the locations affected. This public wholeheartedly considers using Sargassum into fertiliser.

(ii) Constant vigilance from the desire to understand and see action to address a situation seen as complex, serious and impacting all areas of society. This heightened alertness, especially to public health and ecological hazards, prompts the need for detailed and consistent information, reassurance about reusing options to personally try out composting Sargassum.

(iii) These social stakeholders refuse to live with this nuisance on a daily basis, which results in the inability to perceive Sargassum as a resource.

As such, the intended recommendations must feature the unadulterated diffusion of the findings but also applicable guidelines and standards for manufacturers. It would also be useful to assess the introduction of labels for products and information on the traceability and provenance of the Sargassum seaweed used. Aside from education, which is vital, composting workshops with the general public and visits of production facilities could help develop and transfer knowledge about the industry and meanwhile encourage people to individually adopt support techniques for local gardening.

By training several French West Indies-based students, contributions by researchers and lecturers from mainland France and the University of the French West Indies (UA) together with expert input from the Departmental Analytical Laboratory for the Drôme, the Eco3Sar Project highlights the need to focus on the origin of Sargassum, improve storage site management, analyse the quality of products from repurposing and finally communicate. The project also advocates for consideration to be given to shared standards and labels for Sargassum-based products. Finally, developing an interface to publish the results of this study would demonstrate the governmental desire for transparency on the subject, which combines issues as public health, the environment and repurposing.

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