

Review

# Applications of *Ulva* Biomass and Strategies to Improve Its Yield and Composition: A Perspective for *Ulva* Aquaculture

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**Simple Summary:** Green sea lettuce (*Ulva* spp.), with its worldwide distribution and remarkable ability to grow rapidly under a range of conditions, represents an important natural resource that is still under-exploited. Its biomass can be used for various applications in the food, feed, pharmaceutical, nutraceutical, biofuel and bioremediation sectors. However, knowledge of *Ulva* genetics, its environmental responses and microbial interactions are far from complete. This knowledge gap is a major constraint for the development of *Ulva* aquaculture and further investigation of these factors is needed to advance strain selection for yield and biochemical composition in a broad range of cultivation environments. In this review, after presenting the characteristics of the biochemical content and the recognised applications of *Ulva* biomass, we present the established knowledge and highlight areas requiring greater investment to develop a sustainable and profitable *Ulva* aquaculture industry.

**Abstract:** Sea lettuce (*Ulva* spp.), with its worldwide distribution and remarkable ability to grow rapidly under various conditions, represents an important natural resource that is still under-exploited. Its biomass can be used for a wide range of applications in the food/feed, pharmaceutical, nutraceutical, biofuel, and bioremediation industries. However, knowledge of the factors affecting *Ulva* biomass yield and composition is far from complete. Indeed, the respective contributions of the microbiome, natural genetic variation in *Ulva* species, environmental conditions and importantly, the interactions between these three factors on the *Ulva* biomass, have been only partially elucidated. Further investigation is important for the implementation of large-scale *Ulva* aquaculture, which requires stable and controlled biomass composition and yields. In this review, we document *Ulva* biomass composition, describe the uses of *Ulva* biomass and we propose different strategies for developing a sustainable and profitable *Ulva* aquaculture industry.

**Keywords:** *Ulva*; metabolites; aquaculture; bioremediation; microbiome; strain-selection; environmental factors



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## 1. Introduction

Species of green macroalgae from the genus *Ulva* (Phylum Chlorophyta, Class Ulvophyceae, Order Ulvales, Family Ulvaceae) are among the most abundant seaweed species, being omnipresent in coastal communities around the world [1]. *Ulva* comprises diverse species which present two main morphologies, either tubular monostromatic (single cell layer) or foliose distromatic (two cell layers) [2,3]. Some species also present both morphotypes, such as *U. compressa* [4,5]. Thus, this morphological diversity is not solely explained by genetic variability, but also by considerable morphological plasticity in response to environmental conditions and variations in the associated microbiome [1,6,7]. For this reason, species identification based on morphological characters is largely unreliable and genetic information is necessary to properly identify *Ulva* species [8–10]. Currently, among the 400 *Ulva* species described, only ca. 40 species have been recognised taxonomically via the use of genetic information [11,12].

From an economic point of view, *Ulva* spp. biomass has long been recognised as sustainable and valuable. It contains valuable metabolites, including bioactive compounds, which can be used in the food, pharmaceutical, nutraceutical, or biorefinery industries [13,14]. Moreover, high growth rates, as well as high rates of carbon, nitrogen and phosphorus assimilation and the ability to adapt rapidly to variable environmental conditions, make *Ulva* spp. “physiologically robust” organisms and suitable candidates to be used as a biological filter (macroalgal “nutrient traps”) to mitigate eutrophication [15,16]. *Ulva* species have already proven their effectiveness for nutrient removal from water, e.g., in finfish and shellfish aquaculture, bio-reactor sludge, or industrial wastewater treatment [17–22]. However, there are still large knowledge gaps around their efficiency for nutrient removal, especially in “extreme environmental conditions”, such as low salinity, high nutrient loads, and varying temperatures. We can expect that some *Ulva* species or even strains are more suitable than others for nutrient removal in given environmental conditions [23] and identifying these might allow increases in *Ulva* bioremediation efficiency. Similarly, in addition to variation in nutrient removal capacity, species and strain-based variation in biomass composition are observed [23] and it is of importance for the valorisation of *Ulva* biomass. Thus, a strain selection programme tailored to both bioremediation efficiency and use of the accumulated biomass could lead to significant gains in yield and economical value of *Ulva* aquaculture, while reducing eutrophication.

Therefore, due to the environmental impact of *Ulva* spp., but also their potential industrial applications, more research effort should be invested to document the natural variation present in the growth rates of the *Ulva* genus in different environments and how this relates to biomass composition. In this review, we summarise the current knowledge of *Ulva* biochemical composition, list the current uses of its biomass and comment on the different strategies we foresee in developing *Ulva* cultivation and the industrial applications of its biomass.

## 2. *Ulva* Biomass Composition and Its Potential Applications

Green seaweeds of the genus *Ulva* have been intensively studied because of their accessibility and abundance in the intertidal zone of many oceans worldwide, as well as for their valuable chemical content, which makes them a target for a number of economically attractive industrial applications [24,25]. *Ulva* spp. biomass contains high levels of nutritional elements, such as proteins, carbohydrates, polysaccharides, minerals and lipids [26–28], which compares favourably with major land crops, especially for minerals (Table 1). Interestingly, the relative abundance of these compounds varies according to genetic differences between species and populations as well as environmental conditions, such as temperature, salinity, irradiance and nutrient composition of the water [25,29–35].

**Table 1.** Biochemical composition of the macroalgae *Ulva* spp. and conventional feedstuffs (% Dry Weight).

	<i>Ulva</i> spp.	Soybean	Corn	Wheat
Proteins	9–29	37–43	10	9–19
Carbohydrates	41–50	20–30	74–85	61–84
Lipids	1–12	20	4	2
Ashes	14–52	6	1.2	1.5–2
Magnesium	2–5.2	0.12	0.13	0.14
Potassium	0.7–1.5	1.5	0.29	0.4
Calcium	0.8–6.2	0.3	0.007	0.04
Sodium	0.4–2.9	0.3	0.04	0.001

Sources: *Ulva* spp. [26,36–38]; Soybean [39–41]; Corn and Wheat [42–45].

*Ulva* protein content is highly variable, from 9 to 29% of the dry weight (DW) [46]. The highest protein content, 29% (DW), was recorded in *U. lactuca* collected from North

Yorkshire in the United Kingdom [47] and the lowest protein content was reported in the same *Ulva* species collected in Tunisia during the summer [46,48], which suggests a role of temperature in regulating protein content, similar to land plants [49,50]. Aspartic and glutamic acids are the most abundant amino acids and taken together can represent up to 26 and 32% of the total amino acids in *U. rigida* and *U. rotundata*, respectively [51,52]. Other essential amino acids required for animal and human nutrition are also abundant in *Ulva* (Table 2), with valine, leucine, lysine and threonine together representing 42% of the total amino acid content in *U. lactuca* [48].

*Ulva* is also considered an important source of minerals, with a relatively high ash content of 14% to 52% DW depending on the species and the growth conditions [26,53–55]. Potassium, magnesium, sodium and calcium are the main minerals in *Ulva* biomass (Table 1) [26,56].

*Ulva* spp. biomass is relatively low in energy due to a low lipid content (1 to 12% DW) and high carbohydrate content (41 to 50% DW) [26,57,58]. The carbohydrates are classified into three major groups, the water-soluble ulvans (8–29% DW) [59,60], the structural water-insoluble cellulose (9% DW) [61], and the non-structural water-insoluble starch (10% DW) [23]. Ulvans are mainly composed of sulfated rhamnose, uronic acids (glucuronic acid and iduronic acid) and xylose and are the major polysaccharides present in the cell wall [62]. The high carbohydrate content and the presence of valuable polysaccharides make *Ulva* spp. of interest for the production of pharmaceutical products and biofuels.

**Table 2.** Essential amino acids composition of the macroalgae *Ulva* spp. and conventional foodstuffs (g/100 g proteins).

	<i>Ulva</i> spp.	Soybean	Corn	Wheat
Phenylalanine	3.9–7.1	2.4	3.5	4.1
Leucine	4.6–6.9	7.3	8.8	5.9
Methionine	1.4–2.6	1.2–1.4	0.9	1.3
Lysine	3.5–4.5	6.4–6.5	1.8	2.9
Isoleucine	2.3–3.7	3.6	2.5	1.8
Valine	4.1–6.2	4.5	3.0	3.1
Threonine	3.1–6.9	4.0	2.0	2.9
Histidine	1.2–4.0	3.8–4.0	2.0	3.8

Sources: *Ulva* spp. (*U. lacinulata* *U. pertusa* and *U. lactuca*) [30,51]; Soybean [63]; Wheat [45]; Corn [64].

Minerals, proteins and fibres (Ulvans and cellulose) make *Ulva* biomass suitable for food and feed industries. In Asian countries, *Ulva* is popularly consumed as a foodstuff or can be used as an extract, for example, in health supplements [65]. In Western countries, seaweeds are mostly used as food additives or extracts and the use of *Ulva* as a foodstuff is still marginal [66,67]. This low popularity as a foodstuff might be partly explained by the legislation in place in Europe. Indeed, since 1997, according to the online European Novel Food Catalogue, only one *Ulva* species, *U. lactuca*, is allowed for human food consumption in all European countries, being classified as “non-novel food”. An exception to this is in France, where all *Ulva* species are accepted as food [13,68]. Molecular improvements to species classification, as well as sequencing type specimens in herbariums, have now determined that the species *U. lactuca* is absent in the East North Atlantic Area [11,69]. With this finding, it is highly likely that much of the *Ulva* spp. biomass consumed in Europe is misattributed and a change in legislation may be necessary. Including other *Ulva* species in the European list of species suitable for human consumption would encourage the consumption of endemic seaweed species and may contribute to the expansion of this market.

However, special attention should be paid to the use of *Ulva* spp. as food for humans regarding food safety regulations [25]. While *Ulva* spp. can be natural accumulators of beneficial compounds, they can also accumulate toxic elements, such as heavy metals

(e.g., mercury, arsenic, lead and cadmium) [70–72]. In Europe, there are strict legal limits concerning the maximum safe exposure levels for heavy metals. These limits are based on the recommendations of the Joint FAO/WHO Expert Committee on Food Additives (JECFA) and the European Food Safety Authority's Expert Group on Contaminants in the Food Chain (CONTAM Group) and are established in legislation by Commission Regulation (EC) No. 1881/2006 [73].

In the 19th and early 20th centuries, seaweeds and in particular, the *Ulva* spp. were commonly used as feed for cattle, horses, and poultry in Europe (Norway, Scotland, France) and America [74]. However, there are limited data on the digestibility and energy values of *Ulva* for animals and especially for ruminants. This would depend on the biochemical content of the seaweed and also on the adaptation of the animal to this particular feed [53,75]. Their use as substitutes for land-based products for protein and other essential nutrients, such as minerals and vitamins has already been tested and led to *Ulva* biomass inclusion as feed for shellfish/finfish aquaculture [76]. Currently, the main use of *Ulva* biomass as feed is for abalone, shrimp, and fish aquaculture [77–81]. Previous works in finfish aquaculture demonstrated the positive impact on fish growth of the inclusion of green seaweeds in their diet. For example, Hashim and Saat (1992) [82] showed that the incorporation of 5% *Ulva* spp. in the feed for Snakehead murrel resulted in an increase in growth rate, feed efficiency and feed consumption. The positive influence of including *Ulva* in fish feed has been demonstrated for other fish species, such as the Atlantic salmon, European sea bass and Nile tilapia [81,83,84].

*Ulva* biomass can be considered a good substitute feed for livestock because it contains more crude protein and minerals than traditional forages [85]. *Ulva* biomass can be incorporated into poultry diets, leading to a nutritional advantage [86]. Indeed, Abudabos et al. (2013) [38] demonstrated that replacing 3.0% of corn in the diet with *U. lactuca* for 21 days, had no negative effects on the measured production parameters of poultry, but improved carcass characteristics in terms of dressing and breast yield.

Ulvans are the most abundant chemical compounds showing biological activity in *Ulva*. An ulvan extract of *U. compressa* has been reported to have antiviral activity, inhibiting virus propagation [87]. In *U. rigida*, antioxidant activity has been associated with its high polyphenolic content [88]. The crude extracts of two others *Ulva* species, *U. intestinalis* and *U. lactuca*, have also demonstrated antiprotozoal and antimycobacterial activity [89]. Sterols from *Ulva* have been reported to reduce blood cholesterol levels and were found to reduce excessive fat deposition in the heart [90]. Beyond *Ulva* biochemical compounds, the antimicrobial potential of *Ulva* epiphytic bacteria has also been reported in the species *U. rigida* [91]. Despite the value of these compounds, procedures for their large-scale extraction are still largely under development. Further advances in these methods are needed to support widespread usage and examination by the pharmaceutical industry [34].

This biomass is up to 50% carbohydrates, with no lignin, making it an excellent candidate for the production of bioethanol [53,92]. With the aim of decreasing reliance on fossil fuels, plant and algal biomass is considered a promising source of raw materials for biofuel production. Among the different biofuel types produced from macroalgae biomass are biodiesel, biogas, biomethane, hydrogen and bioethanol, with the latter being the most widely produced fossil fuel alternative from plant material [93,94]. The use of macroalgae biomass as a raw material for biofuel production offers interesting advantages over many land plant based biomasses. Among the benefits, the use of seaweeds avoids competition with food crops for arable land, many macroalgae do not require freshwater, which is increasingly scarce in many areas in the world, and often macroalgae cultivation does not require the supply of fertilisers, which are environmentally and economically costly [95]. Qarri and Israel (2020) [96] have also demonstrated that *Ulva* spp. dried biomass contained 16 to 22% of its dried biomass as TRS (total Reducing Sugars), and TRS showed a conversion rate of 30% to ethanol upon fermentation. The feasibility of producing *Ulva* feedstock in outdoor land-based cultivation for bioethanol production has been investigated and economic analyses have been conducted [96–99]. A long-term research program has

shown that outdoor ponds of 1000 m<sup>2</sup> can produce 10 tons of *Ulva* biomass (DW) per year which can generate about 730 L of ethanol [96,98]. However, if biofuel production from seaweed biomass has some potential, the use of this biomass for food/feed or extraction of high value compounds is probably economically and environmentally more promising. Hence, we suggest that biofuel production from seaweed biomass shall be beneficial in the frame of a zero-waste strategy, e.g., by producing biofuel after the previous extraction of valuable compounds from the biomass.

Finally, the high growth rate of *Ulva* biomass, up to 30% per day, implies that *Ulva* spp. has a high nutrient assimilation potential. It makes them a suitable candidate for bioremediation processes which could eventually allow for offsetting the biomass production costs [2,100–103]. Moreover, because of their tolerance to different salinities, the use of *Ulva* spp. for the bioremediation of a wide range of wastewaters is possible [22,104]. Several studies have reported the nutrient removal efficiency of *Ulva* spp. with an assimilation rate for ammonium in the range of 50–90  $\mu\text{mol N g}^{-1} \text{DW h}^{-1}$ , the variation is explained by the species and growth conditions used [17,105–108]. Moreover, as mentioned before, *Ulva* species are known to rapidly accumulate high concentrations of heavy metals from its environment, which makes it suitable for heavy metal bioremediation [109,110]. *Ulva* spp. is also already used for bioremediation in shellfish aquaculture and several studies have demonstrated its effectiveness in the treatment of aquaculture effluents and bio-reactor sludge [15,17–19,22].

In recent years, coastal eutrophication associated with shellfish and finfish aquaculture has been a rising issue. In this context, integrated multitrophic aquaculture (IMTA), i.e., co-cultivation of marine livestock with primary producers, such as seaweeds, would mitigate the detrimental effects of aquaculture, enhancing its sustainability. The integration of *Ulva* into livestock monocultures, e.g., shrimp, urchin and abalone has led to several benefits, including a reduction in effluent nutrient loads released into the environment, a reduced need for commercial feed as *Ulva* spp. can be used as feed for those species (see above), and in some cases an increase in the economic value of the final product [19,22,111]. The global distribution of the genus *Ulva* also suggests that this approach may be applied worldwide [18,112]. However, species or even the strains which could be used need to be carefully selected. Indeed, it has been shown that species and strains respond differently in terms of growth performance, biomass composition and nutrient uptake in response to variations in environmental factors, such as nutrient source and concentration, salinity, or water temperature [107,113,114].

### 3. Strategies to Improve *Ulva* Biomass Yield and Composition

*Ulva* is a valuable marine resource, and its biomass can be used for a lot of purposes (see above). However, its biochemical composition varies significantly according to the strains, species, environmental conditions, and likely other factors, such as its associated microbiome [19,32,35,115,116]. Environmental growth conditions are thought to be the main factor influencing the composition of seaweed [117]. However, a recent study has shown that genetic variation can lead up to a five-fold variation in major compounds of *Ulva* biomass [23]. In addition, if the genotype (G) and environment (E), are components explaining the yield of a crop, their interaction (G\*E), is also a major component, as it has been widely described for land crops [118,119]. Unfortunately, G\*E has not yet been properly described in *Ulva* spp. In other words, *Ulva* spp. phenotypic variation is extensive, and the respective contributions of the genotype, environment and their interaction remain to be described. Another significant consideration for *Ulva* spp. phenotypic outcomes is the mutualism with microorganisms. *Ulva* can be considered a holobiont with its associated microbiome which is necessary for the proper development of the organs (rhizoids and thalli) [120]. It is also likely that the microbiome is required for optimal vegetative growth [120]. A lot of research is still required, especially for large-scale cultivation where the biomass is usually outdoors and subject to fluctuating environmental conditions [121].



### 3.1. Environmental Conditions, a Focus on Salinity

Salinity is one of the most important factors influencing the distribution of the coastal green seaweed *Ulva* [122]. It is also probably the most important environmental factor to consider for the use of *Ulva* spp. in the bioremediation of coastal fresh/brackish wastewaters or in any other aquaculture application outside the sea. *Ulva* belongs to the intertidal zone and is a euryhaline genus that tolerates a wide range of salinities, from the hypohaline to hyperhaline zones [123]. Generally, intertidal seaweeds have a higher capacity to withstand changes in salinity than subtidal species. For example, the seaweeds present in the pools formed during the retreat of the sea can experience large variations in salinity during the day, ranging from 0.1 to 3.5 times that of seawater [124]. Importantly, *Ulva* spp. have the remarkable characteristic to include marine, brackish and freshwater species [123]. This makes this genus ideal for the investigation of the mechanisms involved in salinity tolerance and adaptations, as well as a source of diverse species which can be deployed for bioremediation, according to the salinity observed in the wastewater to be treated and the availability of water sources.

Variations in salinity can cause osmotic, ionic and oxidative stresses, which have a strong effect on the cellular functions of photosynthetic organisms [125]. Under salinity stress, variations in osmolarity disturb cell turgor pressure, ion distribution and metabolic reactions, and often lead to an accumulation of reactive oxygen species (ROS). This accumulation of ROS is responsible for damage to protein complexes, membranes and other cellular components, thus affecting metabolism and growth, leading in extreme cases to cell death [122,126–128]. Such damage can result from either hypo or hyper-salinity treatments [129]. A number of publications document the impact of salinity on the growth rate and nitrate and phosphate uptake of *Ulva* species [114,130,131]. Disturbances in carbon and nitrogen metabolism due to changes in hypersaline conditions have also been described in the species *U. pertusa*, with an increase in the compatible solute proline [132]. In response to hyposalinity stresses, growth and physiological impacts of salinity have been largely documented in a number of *Ulva* species, such as *U. intestinalis*, *U. prolifera*, *U. linza*, *U. limnetica*, *U. lactuca* and *U. australis* [129,132–138]. A six-day exposure of *U. prolifera* to hyposaline conditions, from 30 ppt to 10 ppt, has a significant impact on growth rate and photosynthetic performance, decreasing growth rate by 65% [139]. Lu et al. (2006) [129] also found that after only 4 days of exposure of *Ulva fasciata* to hyposalinity (10 ppt), there was a reduction in maximum photosynthetic quantum efficiency (Fv/Fm) of 10%, which was proposed to be due to oxidative damage in chloroplasts [129].

Salinity is also known to affect the morphology of *Ulva* species [140–143]. Some *Ulva* species, such as *U. compressa* and *U. intestinalis* can be found with two distinct morphotypes, tubular and foliose thalli. Indeed, *U. compressa* is found as a monostromatic tubular morphotype in a saline/hypersaline environment and a distromatic foliose form in a low salinity environment, such as estuarine sites [141]. It is not clear whether these differences can be attributed to a direct effect of salinity or are an indirect effect of salinity associated variation in the microbiome [144]. No obligate foliose species have been recorded in freshwater ecosystems and tubular morphotypes are found in a broader range of salinities [3,145,146]. For example, *U. flexuosa* is the only *Ulva* species known to date which is able to grow from ultra-oligohaline to hyperhaline zones where salinity exceeds 50 PSU [4,142,145,147]. *U. torta* also shows a very wide range of salinity tolerance, from 1 to 36 PSU [123]. Valiela et al. (1997) [148] have hypothesised that those tubular cells have a better survival potential under low salinity conditions, e.g., a higher surface-volume ratio allowing for more rapid nutrient uptake compared to the foliose morphotype. In addition, an increase in the number of branches associated with a thallus in an aggregated form under low salinity has been reported for the species *U. prolifera* [6]. It was hypothesised that this may allow for better protection against increased turgor caused by lower salinity, as this new morphology would allow for the establishment of a more stable microenvironment around *Ulva* thalli. Contradictory observations were made in the distribution of *U. compressa*, which more frequently presents the tubular morphotype at high salinity and the foliose morphotype

at low salinity [141,144]. Going further, Rybak et al. (2018) [123] hypothesised that an ancestral tubular morphotype carried tolerance and rapid adaptation mechanisms that are independent of morphotype, with these being lost among more recently diverged foliose and/or tubular species, but experimental evidence is unfortunately lacking.

Recent gene expression studies identified candidate genes for involvement in tolerance to short-term low salinity conditions [125]. In one study, genes involved in photosynthesis and glycolysis were typically shown to be up-regulated in response to hypo-salinity stress [125]. An earlier study demonstrated the downregulation of many genes related to lipid metabolism, membrane and cell adhesion (51–93 genes) when *U. prolifera* and *U. linza* were cultured in fresh/brackish water compared to seawater [149]. The same study also identified some upregulated genes, encoding an ion transporter, a hydrolase and multiple heat shock proteins. Despite the insight that such comparative transcriptomics can offer, a more thorough understanding of the mechanisms of acclimatisation and tolerance to salinity variations is likely to require targeted strategies to identify genes involved in the process, such as via genome-wide association studies or QTL mapping.

### 3.2. Microbiome

*Ulva* spp. depend on mutualistic bacteria for proper development and growth [1,150–152]. This dependence is not related to the presence of a single, defined bacterium, rather, it can be achieved by redundant partnerships and the details of these requirements are poorly described [153]. A useful study system for this dependency has been developed and termed “tripartite symbiosis”, where *Roseovarius* sp. MS2 and *Maribacter* sp. MS6 are sufficient to restore normal development in the *Ulva* host [154]. *Ulva* does not survive or grows at a very low rate with an undeveloped cell wall when deprived of its microbiome [120]. *Ulva*-associated bacteria also provide nutrient cycling and disease resistance for their host [155,156].

The change in environmental conditions during establishment in aquaculture settings often causes stress in the seaweed and changes in the associated microbiome [155,157]. *Ulva* adaptation to new environmental conditions can be considered to occur via changes in the metabolism of the seaweed depending on its genetic characteristics and changes in the bacterial community associated with *Ulva* that provides support through the production of algal growth and morphogenesis-promoting factors (AGMPFs) [158]. The composition of the microbiome associated with *Ulva* spp. is influenced by the geographical location as well as abiotic factors, such as temperature, salinity and nutrient concentrations [159,160]. Even if a core microbiome with the essential bacteria exists in macroalgae, Burke et al., 2010 [159] and Tujula et al. (2010) [161] have demonstrated that the composition of the microbiome changes both seasonally and geographically. Understanding this microbiome-*Ulva* complex is, therefore, essential given its importance for the adaptation of *Ulva* spp. to its environment, which will vary between aquaculture systems.

Many studies have examined the impact of growing conditions on the epiphytic microbiomes of seaweed [162,163]. In *Fucus vesiculosus*, an increase in salinity can cause a significant loss in bacterial community diversity [164]. Saha et al. (2020) [162] have shown that the epibacterial communities of an invasive red seaweed (*Agarophyton vermiculophyllum*) changed significantly in terms of species richness and diversity according to the salinity. Concerning *Ulva* species, Tujula et al. (2010) [161] have shown that the microbiome associated with the species *Ulva australis* can vary considerably among the individuals collected from the same area and between different seasons. Califano et al. (2020) [157] have investigated the impact of wild *Ulva* transfer in a controlled environment (IMTA) on the composition of its microbiome and showed that the implementation of IMTA results in detectable changes in the epiphytic bacterial community. Another more recent study, focusing on the impact of one environmental factor, salinity, on the *Ulva* bacterial community has shown that the *Ulva*-associated microbiome is strongly structured by salinity [144]. Interestingly, the differences in bacterial communities at low and high salinity were quantitative rather than qualitative. These studies highlight that changes in bacterial

communities are strongly environment dependent, which is an important consideration for the establishment of a new *Ulva* aquaculture farm [91,165,166].

To date, studies on associations between microbiota and conditions remain correlative, and only hypotheses can be made regarding the ability of bacteria to facilitate host adaptation to environmental factors. While studies have identified the bacteria required for *Ulva* development [1,150,151], studies identifying specific bacteria influencing the growth of mature thallus and the biochemical composition of the biomass are still lacking. To date, a limited number of studies have attempted to demonstrate that certain bacteria can promote *Ulva* growth [167,168] and can affect the biochemical composition of *Ulva* [116]. Further, examination of the molecular mechanisms driving *Ulva*: microbial interactions is still limited. For example, are there certain bacteria adapted to a specific environment that may be better than others for promoting *Ulva* growth? If they exist, such bacteria could be of critical importance to the optimisation of *Ulva* yields and biomass composition in aquaculture conditions. Thus, the use of different “cocktails” of bacteria could directly impact the biochemical content and the growth of *Ulva* [158,169]. Future studies should investigate the effect on *Ulva* phenotype of the microbiome: host genotype interactions, and the impact of environmental conditions on these interactions. For example, the exchange of resources and chemical signals from both host seaweed and epiphytic bacteria, and the impact of environmental conditions on these exchanges, should be documented.

### 3.3. Natural Variation within the Genus *Ulva* spp.

Natural variation refers to changes in phenotype between individuals from the same species, which are explained by genetic differences. As a result, to assess the extent of natural variation within a species, individuals must be grown in the same environmental conditions in order to exclude changes in phenotypes due to the environment. Natural variation within *Ulva* species has been studied both for foliose and tubular species [23,170–172]. Lawton et al. (2013) [171] reported high levels of variation in the specific growth rate of the foliose thallus of *U. ohnoi*, with strains cultivated in the same location showing > two-fold variation in growth rates. Fort et al. (2019) [23] also reported extensive variation within *U. lacinulata* species, >four-fold, from 0.092 to 0.371 mg·mg<sup>-1</sup>·d<sup>-1</sup>. This variation was in fact as high as that observed between six different *Ulva* foliose species. Moreover, the authors reported a similar extent of natural variation for a large range of biochemical traits, e.g., starch content and protein content. Interestingly, Fort et al. (2020) [103] subsequently reported that for a given species, the *Ulva* strains originating from green tide areas have higher protein, pigments, lower starch content and higher growth rates than other samples, making green tide areas suitable places for the collection of strains for aquaculture if the biomass produced is destined to feed/food applications. Huo et al. (2013) [173] also identified several strains from a same species in greentides.

Although natural variation has been identified as being very high within *Ulva* species, the associated genes are still unknown. A recent study has demonstrated the importance of intraspecific variation in mitochondrial genomes within the species *Ulva compressa* [174]. However, many previous studies of *Ulva* organellar genomes have shown very few differences within *Ulva* species, and high variation between species, suggesting that a large part of the natural variation within *Ulva* species is explained by nuclear encoded genes [43,172]. A recent study written by Fort et al. 2022 [11], details the genomic resources available in *Ulva*. Hence, nuclear DNA marker association studies, such as genome wide association studies or quantitative trait loci analyses, should be considered with growth and metabolite profiles to engineer, select or breed for improved yield and biomass characteristics in aquaculture.

However, before undertaking such targeted improvement strategies, significant productivity gains can already be achieved by simply screening this existing natural genetic variation to identify and isolate fast-growing strains with desirable characteristics. An important aspect of strain selection is to select strains in the environment they will be cultivated in afterward. The phenotype is dependent on the genotype (G), as well as the

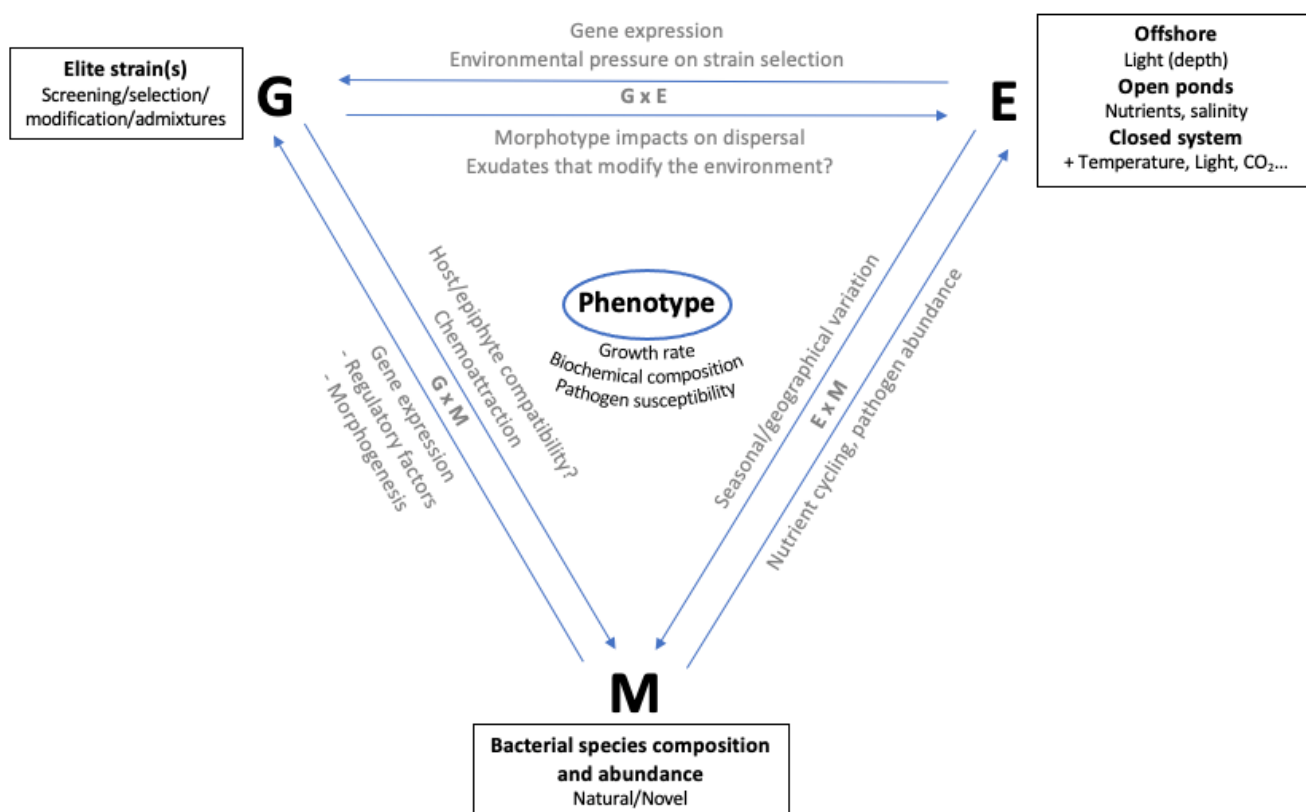


environment (E), and their interaction (G\*E); hence, strain selection must be performed under environmental conditions as close as possible to those the strains will be cultivated in. To avoid the introduction of invasive strains, representing a threat to ecosystem balance and biodiversity and to ensure the preservation of the local genetic diversity, we suggest that such selection should be performed using local strains.

#### 4. Conclusions

The global distribution, with wide environmental tolerance, high growth rate and nutrient uptake as well as a unique biochemical composition has made the green algal genus *Ulva* an attractive model for aquaculture and bioremediation. *Ulva* spp. biomass is becoming increasingly important economically, with many different industrial applications investigated, but the economic viability of large-scale cultivation needs further consideration.

A “perfect programme” to obtain the best *Ulva* product is obviously very complex to define because of the many parameters which can influence the yield and quality of the biomass produced (Figure 1, “Phenotype”). Each aquaculture system has different growing conditions (“E”) that will have a direct impact on the final product obtained, but the impact of natural variation (“G”), microbiome composition (“M”), and the interaction between all these factors cannot be neglected. Three-way interactions between G, E and M may also be important [175], particularly in key developmental phases, such as substrate adhesion during colonization [176]. Furthermore, it is important to emphasise that the optimal growing conditions for biomass yield do not necessarily correspond exactly to the ideal growing conditions for obtaining a valuable final product for the desired application.



**Figure 1.** Description of the main factors controlling the phenotype. G: Genotype [123,151,152,177]. Elite or strains of interest can be selected by screening wild type strains and/or the creation of artificial populations. E: Environment [103,125,159,161]. M: Microbiome [155,156,169]. Variations in the impact of the microbiome on *Ulva* phenotype are expected via qualitative and quantitative changes in bacterial composition. Importantly, the interactions between those three factors are also expected to influence *Ulva* phenotype.

The species within the genus *Ulva* possess a large diversity in environmental tolerances, necessitating the careful selection of a species for cultivation to achieve a desirable balance of biomass yield and biochemical composition. Therefore, further research should be conducted on improving the selection of strains according to the application, and to facilitate this work, the identification of the genes involved should be considered as they could be used, for example, as markers to assist the selection process. Moreover, those genes could provide the basis for genetic engineering to introduce novel traits and/or optimise metabolic throughput towards a desired biochemical composition. The creation of transgenic macroalgae has already proven to be successful in the genus *Ulva* and the progress of knowledge in this field seems to be promising [177,178]. However, the acceptance of these modified organisms remains questionable. Will the cultivation/commercialisation of an improved/engineered strain be accepted, even if it is generated from a local genotype? What will be the potential impacts of the spread of these modified genes on local biodiversity, as *Ulva* is already considered a highly invasive species worldwide? Moreover, for such targeted improvement strategies to succeed in *Ulva*, more genomic resources are required to empower genomic selection and molecular breeding. Fortunately, the extensive phenotypic diversity present among wild isolates means that large-scale selection programs, supported by marker-assisted selection, but not involving transgenic approaches, are likely to achieve significant improvements to yield, resilience and biomass quality [179].

While large-scale cultivation of *Ulva* spp. is still in its infancy, *Ulva* species represent a promising source of biomass with many exciting valorisation opportunities. Exploiting the valuable ecosystem services that *Ulva* can provide, such as in wastewater bioremediation, provides new avenues to increase the industrial competitiveness of *Ulva* cultivation.

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## References

1. Wichard, T.; Charrier, B.; Mineur, F.; Bothwell, J.H.; De Clerck, O.; Coates, J.C. The Green Seaweed *Ulva*: A Model System to Study Morphogenesis. *Front. Plant Sci.* **2015**, *6*, 72. [[CrossRef](#)] [[PubMed](#)]
2. Cocquyt, E.; Verbruggen, H.; Leliaert, F.; De Clerck, O. Evolution and Cytological Diversification of the Green Seaweeds (Ulvophyceae). *Mol. Biol. Evol.* **2010**, *27*, 2052–2061. [[CrossRef](#)] [[PubMed](#)]
3. Rybak, A.S.; Gabka, M. The Influence of Abiotic Factors on the Bloom-Forming Alga *Ulva flexuosa* (Ulvaceae, Chlorophyta): Possibilities for the Control of the Green Tides in Freshwater Ecosystems. *J. Appl. Phycol.* **2018**, *30*, 1405–1416. [[CrossRef](#)] [[PubMed](#)]
4. Tan, I.H.; Blomster, J.; Hansen, G.; Leskinen, E.; Maggs, C.A.; Mann, D.G.; Sluiman, H.J.; Stanhope, M.J. Molecular Phylogenetic Evidence for a Reversible Morphogenetic Switch Controlling the Gross Morphology of Two Common Genera of Green Seaweeds, *Ulva* and *Enteromorpha*. *Mol. Biol. Evol.* **1999**, *16*, 1011–1018. [[CrossRef](#)] [[PubMed](#)]
5. Steinhagen, S.; Weinberger, F.; Karez, R. Molecular Analysis of *Ulva compressa* (Chlorophyta, Ulvales) Reveals Its Morphological Plasticity, Distribution and Potential Invasiveness on German North Sea and Baltic Sea Coasts. *Eur. J. Phycol.* **2019**, *54*, 102–114. [[CrossRef](#)]
6. Gao, G.; Zhong, Z.; Zhou, X.; Xu, J. Changes in Morphological Plasticity of *Ulva prolifera* under Different Environmental Conditions: A Laboratory Experiment. *Harmful Algae* **2016**, *59*, 51–58. [[CrossRef](#)]

7. Alsufyani, T.; Alsufyani, T.; Califano, G.; Deicke, M.; Grueneberg, J.; Weiss, A.; Engelen, A.H.; Kwantes, M.; et al. Macroalgal-Bacterial Interactions: Identification and Role of Thallusin in Morphogenesis of the Seaweed *Ulva* (Chlorophyta). *J. Exp. Bot.* **2020**, *71*, 3340–3349. [[CrossRef](#)]
8. Fort, A.; Linderhof, C.; Coca-Tagarro, I.; Inaba, M.; McHale, M.; Cascella, K.; Potin, P.; Guiry, M.D.; Sulpice, R. A Sequencing-Free Assay for Foliose *Ulva* Species Identification, Hybrid Detection and Bulk Biomass Characterisation. *Algal Res.* **2021**, *55*, 102280. [[CrossRef](#)]
9. Malta, E.J.; Kamermans, P.; Draisma, S. Free-Floating *Ulva* in the Southwest Netherlands: Species or Morphotypes? A Morphological, Molecular and Ecological Comparison. *Eur. J. Phycol.* **1999**, *34*, 443–454. [[CrossRef](#)]
10. Heesch, S.; Broom, J.E.S.; Neill, K.F.; Farr, T.J.; Dalen, J.L.; Nelson, W.A. *Ulva*, *Umbraulva* and *Gemina*: Genetic Survey of New Zealand Taxa Reveals Diversity and Introduced Species. *Eur. J. Phycol.* **2009**, *44*, 143–154. [[CrossRef](#)]
11. Fort, A.; McHale, M.; Cascella, K.; Potin, P.; Perrineau, M.-M.; Kerrison, P.D.; Costa, E.; Calado, R.; Domingues, M.d.R.; Costa Azevedo, I.; et al. Exhaustive Reanalysis of Barcode Sequences from Public Repositories Highlights Ongoing Misidentifications and Impacts Taxa Diversity and Distribution. *Mol. Ecol. Resour.* **2022**, *22*, 86–101. [[CrossRef](#)] [[PubMed](#)]
12. Guiry, M.; Guiry, G. World-Wide Electronic Publication, National University of Ireland, Galway. Available online: <http://www.algaebase.org> (accessed on 15 August 2022).
13. Barbier, M.; Charrier, B.; Araujo, R.; Holdt, S.; Jacquemin, B.; Rebours, C. *PEGASUS-PHYCOMORPH European Guidelines for a Sustainable Aquaculture of Seaweeds*; COST Action FA1406: Roscoff, France, February 2019.
14. Mabeau, S.; Fleurence, J. Seaweed in Food Products: Biochemical and Nutritional Aspects. *Trends Food Sci. Technol.* **1993**, *4*, 103–107. [[CrossRef](#)]
15. Kang, Y.H.; Park, S.R.; Chung, I.K. Biofiltration Efficiency and Biochemical Composition of Three Seaweed Species Cultivated in a Fish-Seaweed Integrated Culture. *Algae* **2011**, *26*, 97–108. [[CrossRef](#)]
16. Hurd, C.L.; Harrison, P.J.; Bischof, K.; Lobban, C.S. *Seaweed Ecology and Physiology*; Cambridge University Press: Cambridge, UK, 2014; ISBN 9781139192637.
17. Anibal, J.; Madeira, H.T.; Carvalho, L.F.; Esteves, E.; Veiga-Pires, C.; Rocha, C. Macroalgae Mitigation Potential for Fish Aquaculture Effluents: An Approach Coupling Nitrogen Uptake and Metabolic Pathways Using *Ulva rigida* and *Enteromorpha clathrata*. *Environ. Sci. Pollut. Res.* **2014**, *21*, 13324–13334. [[CrossRef](#)] [[PubMed](#)]
18. del Río, M.J.; Ramazanov, Z.; García-Reina, G. *Ulva rigida* (Ulvales, Chlorophyta) Tank Culture as Biofilters for Dissolved Inorganic Nitrogen from Fishpond Effluents. *Hydrobiologia* **1996**, *326*, 61–66. [[CrossRef](#)]
19. Cruz-Suárez, L.E.; León, A.; Peña-Rodríguez, A.; Rodríguez-Peña, G.; Moll, B.; Rique-Marie, D. Shrimp/*Ulva* Co-Culture: A Sustainable Alternative to Diminish the Need for Artificial Feed and Improve Shrimp Quality. *Aquaculture* **2010**, *301*, 64–68. [[CrossRef](#)]
20. El-Sikaily, A.; El Nemr, A.; Khaled, A.; Abdelwehab, O. Removal of Toxic Chromium from Wastewater Using Green Alga *Ulva lactuca* and Its Activated Carbon. *J. Hazard. Mater.* **2007**, *148*, 216–228. [[CrossRef](#)]
21. de Oliveira, V.P.; Martins, N.T.; Guedes, P.d.S.; Pollery, R.C.G.; Enrich-Prast, A. Bioremediation of Nitrogenous Compounds from Oilfield Wastewater by *Ulva lactuca* (Chlorophyta). *Bioremediat. J.* **2016**, *20*, 1–9. [[CrossRef](#)]
22. Bolton, J.J.; Robertson-Andersson, D.V.; Shuuluka, D.; Kandjengo, L. Growing *Ulva* (Chlorophyta) in Integrated Systems as a Commercial Crop for Abalone Feed in South Africa: A Swot Analysis. *J. Appl. Phycol.* **2009**, *21*, 575–583. [[CrossRef](#)]
23. Fort, A.; Lebrault, M.; Allaire, M.; Esteves-Ferreira, A.A.; McHale, M.; Lopez, F.; Fariñas-Franco, J.M.; Alseekh, S.; Fernie, A.R.; Sulpice, R. Extensive Variations in Diurnal Growth Patterns and Metabolism Among *Ulva* Spp. Strains. *Plant Physiol.* **2019**, *180*, 109–123. [[CrossRef](#)]
24. Trivedi, N.; Baghel, R.S.; Bothwell, J.; Gupta, V.; Reddy, C.R.K.; Lali, A.M.; Jha, B. An Integrated Process for the Extraction of Fuel and Chemicals from Marine Macroalgal Biomass. *Sci. Rep.* **2016**, *6*, 30728. [[CrossRef](#)] [[PubMed](#)]
25. Bleakley, S.; Hayes, M. Algal Proteins: Extraction, Application, and Challenges Concerning Production. *Foods* **2017**, *6*, 33. [[CrossRef](#)] [[PubMed](#)]
26. Fleurence, J. *Seaweeds as Food*; Elsevier Inc.: Amsterdam, The Netherlands, 2016; ISBN 9780128027936.
27. Holdt, S.L.; Kraan, S. Bioactive Compounds in Seaweed: Functional Food Applications and Legislation. *J. Appl. Phycol.* **2011**, *23*, 543–597. [[CrossRef](#)]
28. Rasyid, A. Evaluation of Nutritional Composition of The Dried Seaweed. *Trop. Life Sci. Res.* **2017**, *28*, 119–125. [[CrossRef](#)]
29. Abdel-Fattah, A.F.; Edrees, M. Seasonal Changes in the Constituents of *Ulva lactuca*. *Phytochemistry* **1973**, *12*, 481–485. [[CrossRef](#)]
30. Fleurence, J.; Chenard, E.; Luçon, M. Determination of the Nutritional Value of Proteins Obtained from *Ulva armoricana*. *J. Appl. Phycol.* **1999**, *11*, 231–239. [[CrossRef](#)]
31. Shpigel, M.; Ragg, N.L.; Lupatsch, I.; Neori, A. Protein Content Determines the Nutritional Value of the Seaweed *Ulva lactuca* L for the Abalone *Haliotis Tuberculata* L. and *H. Discus Hannai* Ino. *J. Shellfish Res.* **1999**, *18*, 227–233.
32. Marinho-Soriano, E.; Panucci, R.A.; Carneiro, M.A.A.; Pereira, D.C. Evaluation of *Gracilaria Caudata* J. Agardh for Bioremediation of Nutrients from Shrimp Farming Wastewater. *Bioresour. Technol.* **2009**, *100*, 6192–6198. [[CrossRef](#)]
33. Singh, R.P.; Reddy, C.R.K. Unraveling the Functions of the Macroalgal Microbiome. *Front. Microbiol.* **2016**, *6*, 1488. [[CrossRef](#)]
34. Harnedy, P.A.; Fitzgerald, R.J. Bioactive Proteins, Peptides, and Amino Acids from Macroalgae. *J. Phycol.* **2011**, *47*, 218–232. [[CrossRef](#)]

35. Toth, G.B.; Harrysson, H.; Wahlström, N.; Olsson, J.; Oerbekke, A.; Steinhagen, S.; Kinnby, A.; White, J.; Albers, E.; Edlund, U.; et al. Effects of Irradiance, Temperature, Nutrients, and PCO<sub>2</sub> on the Growth and Biochemical Composition of Cultivated *Ulva fenestrata*. *J. Appl. Phycol.* **2020**, *32*, 3243–3254. [[CrossRef](#)]
36. Probst, Y. A Review of the Nutrient Composition of Selected Rubus Berries. *Nutr. Food Sci.* **2011**, *45*, 242–254. [[CrossRef](#)]
37. Nisizawa, K.; Noda, H.; Kikuchi, R.; Watanabe, T. The Main Seaweed Foods in Japan. *Hydrobiologia* **1987**, *151–152*, 5–29. [[CrossRef](#)]
38. Abudabos, A.M.; Okab, A.B.; Aljumaah, R.S.; Samara, E.M.; Abdoun, K.A.; Al-Haidary, A.A. Nutritional Value of Green Seaweed (*Ulva lactuca*) for Broiler Chickens. *Ital. J. Anim. Sci.* **2013**, *12*, 177–181. [[CrossRef](#)]
39. Soybean, Nutrition and Health. In *Soybean-Bio-Active Compounds*; InTech: London, UK, 2013.
40. Spolaore, P.; Joannis-Cassan, C.; Duran, E.; Isambert, A. Commercial Applications of Microalgae. *J. Biosci. Bioeng.* **2006**, *101*, 87–96. [[CrossRef](#)]
41. Sharma, D.; Gupta, I.J.R. Nutrient Analysis of Raw and Processed Soybean and Development of Value Added Soybean Noodle. *Inven. J.* **2015**, *1*, 1–5.
42. Rajauria, G.; Cornish, L.; Ometto, F.; Msuya, F.E.; Villa, R. *Identification and Selection of Algae for Food, Feed, and Fuel Applications*; Elsevier Inc.: Amsterdam, The Netherlands, 2015; ISBN 9780124186972.
43. Gwartz, J.A.; Garcia-Casal, M.N. Processing Maize Flour and Corn Meal Food Products. *Ann. N. Y. Acad. Sci.* **2014**, *1312*, 66–75. [[CrossRef](#)]
44. Gutiérrez-Alamo, A.; Pérez De Ayala, P.; Verstegen, M.W.A.; Den Hartog, L.A.; Villamide, M.J. Variability in Wheat: Factors Affecting Its Nutritional Value. *Worlds Poult. Sci. J.* **2008**, *64*, 20–39. [[CrossRef](#)]
45. Ranhotra, G.S.; Gelroth, J.A.; Glaser, B.K.; Lorenz, K.J. Baking and Nutritional Qualities of a Spelt Wheat Sample. *LWT-Food Sci. Technol.* **1995**, *28*, 118–122. [[CrossRef](#)]
46. Fleurence, J.; Morançais, M.; Dumay, J. Seaweed Proteins. In *Proteins Food Process*, 2nd ed.; Woodhead Publishing: Sawston, UK, 2018; Volume 10, pp. 245–262. [[CrossRef](#)]
47. Marsham, S.; Scott, G.W.; Tobin, M.L. Comparison of Nutritive Chemistry of a Range of Temperate Seaweeds. *Food Chem.* **2007**, *100*, 1331–1336. [[CrossRef](#)]
48. Yaich, H.; Garna, H.; Besbes, S.; Paquot, M.; Blecker, C.; Attia, H. Chemical Composition and Functional Properties of *Ulva lactuca* Seaweed Collected in Tunisia. *Food Chem.* **2011**, *128*, 895–901. [[CrossRef](#)]
49. Stitt, M.; Hurry, V. A Plant for All Seasons: Alterations in Photosynthetic Carbon Metabolism during Cold Acclimation in Arabidopsis. *Curr. Opin. Plant Biol.* **2002**, *5*, 199–206. [[CrossRef](#)]
50. Pyl, E.T.; Piques, M.; Ivakov, A.; Schulze, W.; Ishihara, H.; Stitt, M.; Sulpice, R. Metabolism and Growth in Arabidopsis Depend on the Daytime Temperature but Are Temperature-Compensated against Cool Nights. *Plant Cell* **2012**, *24*, 2443–2469. [[CrossRef](#)] [[PubMed](#)]
51. Shuuluka, D.; Bolton, J.J.; Anderson, R.J. Protein Content, Amino Acid Composition and Nitrogen-to-Protein Conversion Factors of *Ulva rigida* and *Ulva capensis* from Natural Populations and *Ulva lactuca* from an Aquaculture System, in South Africa. *J. Appl. Phycol.* **2013**, *25*, 677–685. [[CrossRef](#)]
52. Fleurence, J.; Le Coeur, C.; Mabeau, S.; Maurice, M.; Landrein, A. Comparison of Different Extractive Procedures for Proteins from the Edible Seaweeds *Ulva rigida* and *Ulva rotundata*. *J. Appl. Phycol.* **1995**, *7*, 577–582. [[CrossRef](#)]
53. Van Den Burg, S.; Stuiver, M.; Veenstra, F.; Bikker, P.; Contreras, A.L.; Palstra, A.; Broeze, J.; Jansen, H.; Jak, R.; Gerritsen, A.; et al. *A Triple P Review of the Feasibility of Sustainable Offshore Seaweed Production in the North Sea*; Wageningen University & Research: Wageningen, The Netherlands, 2013; Volume 13-077, ISBN 9789086156528.
54. Peña-Rodríguez, A.; Mawhinney, T.P.; Ricque-Marie, D.; Cruz-Suárez, L.E. Chemical Composition of Cultivated Seaweed *Ulva clathrata* (Roth) C. Agardh. *Food Chem.* **2011**, *129*, 491–498. [[CrossRef](#)] [[PubMed](#)]
55. Foster, G.G.; Hodgson, A.N. Consumption and Apparent Dry Matter Digestibility of Six Intertidal Macroalgae by Turbo Sarmaticus (Mollusca: Vetigastropoda: Turbinidae). *Aquaculture* **1998**, *167*, 211–227. [[CrossRef](#)]
56. MacArtain, P.; Gill, C.I.R.; Brooks, M.; Campbell, R.; Rowland, I.R. Nutritional Value of Edible Seaweeds. *Nutr. Rev.* **2007**, *65*, 535–543. [[CrossRef](#)]
57. Shanmugam, A.; Palpandi, C. Biochemical Composition and Fatty Acid Profile of the Green Alga *Ulva reticulata*. *Asian J. Biochem.* **2008**, *3*, 26–31. [[CrossRef](#)]
58. Echave, J.; Lourenço-Lopes, C.; Carreira-Casais, A.; Chamorro, F.; Fraga-Corral, M.; Otero, P.; Garcia-Perez, P.; Baamonde, S.; Fernández-Saa, F.; Cao, H.; et al. Nutritional Composition of the Atlantic Seaweeds *Ulva rigida*, *Codium tomentosum*, *Palmaria palmata* and *Porphyra purpurea*. *Chem. Proc.* **2022**, *5*, 67. [[CrossRef](#)]
59. Robic, A.; Sassi, J.F.; Dion, P.; Lerat, Y.; Lahaye, M. Seasonal Variability of Physicochemical and Rheological Properties of Ulvan in Two *Ulva* Species (Chlorophyta) from the Brittany Coast1. *J. Phycol.* **2009**, *45*, 962–973. [[CrossRef](#)] [[PubMed](#)]
60. Morelli, A.; Puppi, D.; Chiellini, F. Perspectives on Biomedical Applications of Ulvan. In *Seaweed Polysaccharides*; Elsevier: Amsterdam, The Netherlands, 2017; pp. 305–330. [[CrossRef](#)]
61. Prabhu, M.S.; Israel, A.; Palatnik, R.R.; Zilberman, D.; Golberg, A. Integrated Biorefinery Process for Sustainable Fractionation of *Ulva ohnoi* (Chlorophyta): Process Optimization and Revenue Analysis. *J. Appl. Phycol.* **2020**, *32*, 2271–2282. [[CrossRef](#)]
62. Lahaye, M.; Robic, A. Structure and Function Properties of Ulvan, a Polysaccharide from Green Seaweeds. *Biomacromolecules* **2007**, *8*, 1765–1774. [[CrossRef](#)] [[PubMed](#)]
63. Fowden, L. A Comparison of the Compositions of Some Algal Proteins. *Ann. Bot.* **1954**, *18*, 257–266. [[CrossRef](#)]



64. Sumbo, H.A.; Victor, I.A. Comparison of Chemical Composition, Functional Properties and Amino Acids Composition of Quality Protein Maize and Common Maize (*Zea mays* L.). *Afr. J. Food Sci. Technol.* **2014**, *5*, 81–89. [CrossRef]
65. Kasimala, M.B.; Mebrahtu, L.; Magoha, P.; Asgedom, G. A Review on Biochemical Composition and Nutritional Aspects of Seaweed. *Caribb. J. Sci. Technol.* **2015**, *3*, 789–797.
66. Yu-Qing, T.; Mahmood, K.; Shehzadi, R.; Ashraf, M.F. *Ulva lactuca* and Its Polysaccharides: Food and Biomedical Aspects. *J. Biol.* **2016**, *6*, 140–151.
67. CEVA. Macroalgues et Microalgues Alimentaires-Statut Règlementaire En France et En Europe. Available online: <https://www.ceva-algues.com/document/synthese-reglementaire-algues-alimentaires/> (accessed on 19 June 2022).
68. Roleda, M.Y.; Heesch, S. Chemical Profiling of *Ulva* Species for Food Applications: What Is in a Name? *Food Chem.* **2021**, *361*, 130084. [CrossRef]
69. Hughey, J.R.; Maggs, C.A.; Mineur, F.; Jarvis, C.; Miller, K.A.; Shabaka, S.H.; Gabrielson, P.W. Genetic Analysis of the Linnaean *Ulva lactuca* (Ulvales, Chlorophyta) Holotype and Related Type Specimens Reveals Name Misapplications, Unexpected Origins, and New Synonymies. *J. Phycol.* **2019**, *55*, 503–508. [CrossRef]
70. Haritonidis, S.; Malea, P. Bioaccumulation of Metals by the Green Alga *Ulva rigida* from Thermaikos Gulf, Greece. *Environ. Pollut.* **1999**, *104*, 365–372. [CrossRef]
71. Villares, R.; Puente, X.; Carballeira, A. Seasonal Variation and Background Levels of Heavy Metals in Two Green Seaweeds. *Environ. Pollut.* **2002**, *119*, 79–90. [CrossRef]
72. Almela, C.; Algora, S.; Benito, V.; Clemente, M.J.; Devesa, V.; Súnier, M.A.; Vélez, D.; Montoro, R. Heavy Metal, Total Arsenic, and Inorganic Arsenic Contents of Algae Food Products. *J. Agric. Food Chem.* **2002**, *50*, 918–923. [CrossRef] [PubMed]
73. Health and Food Safety | European Commission. (EC) No 118/2006-MAXIMUM Levels for Contaminants in FOOD Incl Mycotoxins. Available online: <https://eur-lex.europa.eu/eli/reg/2021/1323/oj> (accessed on 12 July 2022).
74. Chapman, V.J.; Chapman, D.J. Seaweeds and Their Uses. In *Chapman & Hall*; Springer: Dordrecht, The Netherlands, 1980; pp. 1–29, ISBN 978-94-009-5808-1.
75. Makkar, H.P.S.; Tran, G.; Heuzé, V.; Giger-Reverdin, S.; Lessire, M.; Lebas, F.; Ankers, P. Seaweeds for Livestock Diets: A Review. *Anim. Feed Sci. Technol.* **2015**, *212*, 1–17. [CrossRef]
76. Shields, R.; Lupatsch, I. Algae for Aquaculture and Animal Feeds. In *Microalgal Biotechnology: Integration and Economy*; DE GRUYTER: Berlin, Germany, 2012; pp. 23–27.
77. Guerreiro, I.; Magalhães, R.; Coutinho, F.; Couto, A.; Sousa, S.; Delerue-Matos, C.; Domingues, V.F.; Oliva-Teles, A.; Peres, H. Evaluation of the Seaweeds *Chondrus Crispus* and *Ulva lactuca* as Functional Ingredients in Gilthead Seabream (*Sparus Aurata*). *J. Appl. Phycol.* **2019**, *31*, 2115–2124. [CrossRef]
78. Qiu, X.; Neori, A.; Kim, J.K.; Yarish, C.; Shpigel, M.; Guttman, L.; Ben Ezra, D.; Odintsov, V.; Davis, D.A. Green Seaweed *Ulva* Sp. as an Alternative Ingredient in Plant-Based Practical Diets for Pacific White Shrimp, *Litopenaeus Vannamei*. *J. Appl. Phycol.* **2018**, *30*, 1317–1333. [CrossRef]
79. Santizo-Taan, R.; Bautista-Teruel, M.; Maquirang, J.R.H. Enriched *Ulva pertusa* as Partial Replacement of the Combined Fish and Soybean Meals in Juvenile Abalone *Haliotis Asinina* (Linnaeus) Diet. *J. Appl. Phycol.* **2020**, *32*, 741–749. [CrossRef]
80. Wassef, E.A.; El-Sayed, A.F.M.; Sakr, E.M. *Pterocladia* (Rhodophyta) and *Ulva* (Chlorophyta) as Feed Supplements for European Seabass, *Dicentrarchus Labrax* L., Fry. *J. Appl. Phycol.* **2013**, *25*, 1369–1376. [CrossRef]
81. Valente, L.M.P.; Gouveia, A.; Rema, P.; Matos, J.; Gomes, E.F.; Pinto, I.S. Evaluation of Three Seaweeds *Gracilaria Bursa-Pastoris*, *Ulva rigida* and *Gracilaria Cornea* as Dietary Ingredients in European Sea Bass (*Dicentrarchus Labrax*) Juveniles. *Aquaculture* **2006**, *252*, 85–91. [CrossRef]
82. Hashim, R.; Saat, M.A.M. The Utilization of Seaweed Meals as Binding Agents in Pelleted Feeds for Snakehead (*Channa Striatus*) Fry and Their Effects on Growth. *Aquaculture* **1992**, *108*, 299–308. [CrossRef]
83. Moroney, N.C.; Wan, A.H.L.; Soler-Vila, A.; O’Grady, M.N.; FitzGerald, R.D.; Johnson, M.P.; Kerry, J.P. Influence of Green Seaweed (*Ulva rigida*) Supplementation on the Quality and Shelf Life of Atlantic Salmon Fillets. *J. Aquat. Food Prod. Technol.* **2017**, *26*, 1175–1188. [CrossRef]
84. Ergün, S.; Soyutürk, M.; Güroy, B.; Güroy, D.; Merrifield, D. Influence of *Ulva* Meal on Growth, Feed Utilization, and Body Composition of Juvenile Nile Tilapia (*Oreochromis niloticus*) at Two Levels of Dietary Lipid. *Aquac. Int.* **2009**, *17*, 355–361. [CrossRef]
85. Arieli, A.; Sklan, D.; Kissil, G. A Note on the Nutritive Value of *Ulva lactuca* for Ruminants. *Anim. Prod.* **1993**, *57*, 329–331. [CrossRef]
86. Wong, W.H.; Leung, K.L. Sewage Sludge and Seaweed (*Ulva* Sp.) as Supplementary Feed for Chicks. *Environ. Pollut.* **1979**, *20*, 93–101. [CrossRef]
87. Lopes, N.; Ray, S.; Espada, S.F.; Bomfim, W.A.; Ray, B.; Faccin-Galhardi, L.C.; Linhares, R.E.C.; Nozawa, C. Green Seaweed *Enteromorpha compressa* (Chlorophyta, Ulvaceae) Derived Sulphated Polysaccharides Inhibit Herpes Simplex Virus. *Int. J. Biol. Macromol.* **2017**, *102*, 605–612. [CrossRef] [PubMed]
88. Yildiz, G.; Celikler, S.; Vatan, O.; Dere, S. Determination of the Anti-Oxidative Capacity and Bioactive Compounds in Green Seaweed *Ulva rigida* C. Agardh. *Int. J. Food Prop.* **2012**, *15*, 1182–1189. [CrossRef]
89. Spavieri, J.; Kaiser, M.; Casey, R.; Hingley-Wilson, S.; Lalvani, A.; Blunden, G.; Tasdemir, D. Antiprotozoal, Antimycobacterial and Cytotoxic Potential of Some British Green Algae. *Phyther. Res.* **2010**, *24*, 1095–1098. [CrossRef]



90. Bhakuni, D.S.; Rawat, D.S. *Bioactive Marine Natural Products*; Springer: Dordrecht, The Netherlands, 2005; ISBN 978-1-4020-3472-5.
91. Ismail, A.; Ktari, L.; Ahmed, M.; Bolhuis, H.; Bouhaouala-Zahar, B.; Stal, L.J.; Boudabbous, A.; El Bour, M. Heterotrophic Bacteria Associated with the Green Alga *Ulva rigida*: Identification and Antimicrobial Potential. *J. Appl. Phycol.* **2018**, *30*, 2883–2899. [[CrossRef](#)]
92. van der Wal, H.; Sperber, B.L.H.M.; Houweling-Tan, B.; Bakker, R.R.C.; Brandenburg, W.; López-Contreras, A.M. Production of Acetone, Butanol, and Ethanol from Biomass of the Green Seaweed *Ulva lactuca*. *Bioresour. Technol.* **2013**, *128*, 431–437. [[CrossRef](#)]
93. Manochio, C.; Andrade, B.R.; Rodriguez, R.P.; Moraes, B.S. Ethanol from Biomass: A Comparative Overview. *Renew. Sustain. Energy Rev.* **2017**, *80*, 743–755. [[CrossRef](#)]
94. Coelho, M.S.; Barbosa, F.G.; Souza, M. The Scientometric Research on Macroalgal Biomass as a Source of Biofuel Feedstock. *Algal Res.* **2014**, *6*, 132–138. [[CrossRef](#)]
95. Adenle, A.A.; Haslam, G.E.; Lee, L. Global Assessment of Research and Development for Algae Biofuel Production and Its Potential Role for Sustainable Development in Developing Countries. *Energy Policy* **2013**, *61*, 182–195. [[CrossRef](#)]
96. Qarri, A.; Israel, A. Seasonal Biomass Production, Fermentable Saccharification and Potential Ethanol Yields in the Marine Macroalga *Ulva* Sp. (Chlorophyta). *Renew. Energy* **2020**, *145*, 2101–2107. [[CrossRef](#)]
97. Ramachandra, T.V.; Hebbale, D. Bioethanol from Macroalgae: Prospects and Challenges. *Renew. Sustain. Energy Rev.* **2020**, *117*, 109479. [[CrossRef](#)]
98. Reznik, A.; Israel, A. *Fuel from Seaweeds: Rationale and Feasibility*; Springer: Dordrecht, The Netherlands, 2012; Volume 25, pp. 341–354, ISBN 978-94-007-5109-5.
99. Korzen, L.; Peled, Y.; Shamir, S.Z.; Shechter, M.; Gedanken, A.; Abelson, A.; Israel, A. An Economic Analysis of Bioethanol Production from the Marine Macroalga *Ulva* (Chlorophyta). *Technology* **2015**, *3*, 114–118. [[CrossRef](#)]
100. Naldi, M.; Wheeler, P.A. <sup>15</sup>N Measurements of Ammonium and Nitrate Uptake by *Ulva fenestrata* (Chlorophyta) and *Gracilaria pacifica* (Rhodophyta): Comparison of Net Nutrient Disappearance, Release of Ammonium and Nitrate, and <sup>15</sup>N Accumulation in Algal Tissue. *J. Phycol.* **2002**, *38*, 135–144. [[CrossRef](#)]
101. Yokoyama, H.; Ishihi, Y. Bioindicator and Biofilter Function of *Ulva* Spp. (Chlorophyta) for Dissolved Inorganic Nitrogen Discharged from a Coastal Fish Farm-Potential Role in Integrated Multi-Trophic Aquaculture. *Aquaculture* **2010**, *310*, 74–83. [[CrossRef](#)]
102. Nielsen, M.M.; Bruhn, A.; Rasmussen, M.B.; Olesen, B.; Larsen, M.M.; Møller, H.B. Cultivation of *Ulva lactuca* with Manure for Simultaneous Bioremediation and Biomass Production. *J. Appl. Phycol.* **2012**, *24*, 449–458. [[CrossRef](#)]
103. Fort, A.; Mannion, C.; Fariñas-Franco, J.M.; Sulpice, R. Green Tides Select for Fast Expanding *Ulva* Strains. *Sci. Total Environ.* **2020**, *698*, 134337. [[CrossRef](#)]
104. Ryther, J.H.; Debusk, T.A.; Blakeslee, M. *Cultivation and Conversion of Marine Macroalgae. [Gracilaria and Ulva]*; Harbor Branch Foundation: Fort Pierce, FL, USA, 1984.
105. Hernandez, I.; Peralta, G.; Perez-Llorens, J.L.; Vergara, J.J.; Niell, F.X. Biomass and Dynamics of Growth of *Ulva* Species in Palmones River Estuary. *J. Phycol.* **1997**, *33*, 764–772. [[CrossRef](#)]
106. Cahill, P.L.; Hurd, C.L.; Lokman, M. Keeping the Water Clean—Seaweed Biofiltration Outperforms Traditional Bacterial Biofilms in Recirculating Aquaculture. *Aquaculture* **2010**, *306*, 153–159. [[CrossRef](#)]
107. Shahar, B.; Shpigel, M.; Barkan, R.; Masasa, M.; Neori, A.; Chernov, H.; Salomon, E.; Kiflawi, M.; Guttman, L. Changes in Metabolism, Growth and Nutrient Uptake of *Ulva fasciata* (Chlorophyta) in Response to Nitrogen Source. *Algal Res.* **2020**, *46*, 101781. [[CrossRef](#)]
108. Copertino, M.D.S.; Tormena, T.; Seeliger, U. Biofiltering Efficiency, Uptake and Assimilation Rates of *Ulva clathrata* (Roth) J. Agardh (Chlorophyceae) Cultivated in Shrimp Aquaculture Waste Water. *J. Appl. Phycol.* **2009**, *21*, 31–45. [[CrossRef](#)]
109. Henriques, B.; Teixeira, A.; Figueira, P.; Reis, A.T.; Almeida, J.; Vale, C.; Pereira, E. Simultaneous Removal of Trace Elements from Contaminated Waters by Living *Ulva lactuca*. *Sci. Total Environ.* **2019**, *652*, 880–888. [[CrossRef](#)] [[PubMed](#)]
110. Ibrahim, W.M.; Hassan, A.F.; Azab, Y.A. Biosorption of Toxic Heavy Metals from Aqueous Solution by *Ulva lactuca* Activated Carbon. *Egypt. J. Basic Appl. Sci.* **2016**, *3*, 241–249. [[CrossRef](#)]
111. Shpigel, M.; Shauli, L.; Odintsov, V.; Ashkenazi, N.; Ben-Ezra, D. *Ulva lactuca* Biofilter from a Land-Based Integrated Multi Trophic Aquaculture (IMTA) System as a Sole Food Source for the Tropical Sea Urchin *Tripneustes Gratilla* *Elatensis*. *Aquaculture* **2018**, *496*, 221–231. [[CrossRef](#)]
112. Msuya, F.E.; Neori, A. *Ulva reticulata* and *Gracilaria crassa*: Macroalgae That Can Biofilter Effluent from Tidal Fishponds in Tanzania. *West. Indian Ocean J. Mar. Sci.* **2002**, *1*, 117–126.
113. Fan, X.; Xu, D.; Wang, D.; Wang, Y.; Zhang, X.; Ye, N. Nutrient Uptake and Transporter Gene Expression of Ammonium, Nitrate, and Phosphorus in *Ulva linza*: Adaption to Variable Concentrations and Temperatures. *J. Appl. Phycol.* **2020**, *32*, 1311–1322. [[CrossRef](#)]
114. Choi, T.-S.; Kang, E.-J.; Kim, J.-H.; Kim, K.-Y. Effect of Salinity on Growth and Nutrient Uptake of *Ulva pertusa* (Chlorophyta) from an Eelgrass Bed. *Algae* **2010**, *25*, 17–26. [[CrossRef](#)]
115. Cherry, P.; O'hara, C.; Magee, P.J.; Mcsorley, E.M.; Allsopp, P.J. Risks and Benefits of Consuming Edible Seaweeds. *Nutr. Rev.* **2019**, *77*, 307–329. [[CrossRef](#)]

116. Polikovskiy, M.; Califano, G.; Dunger, N.; Wichard, T.; Golberg, A. Engineering Bacteria-Seaweed Symbioses for Modulating the Photosynthate Content of *Ulva* (Chlorophyta): Significant for the Feedstock of Bioethanol Production. *Algal Res.* **2020**, *49*, 101945. [[CrossRef](#)]
117. McCauley, J.I.; Winberg, P.C.; Meyer, B.J.; Skropeta, D. Effects of Nutrients and Processing on the Nutritionally Important Metabolites of *Ulva* Sp. (Chlorophyta). *Algal Res.* **2018**, *35*, 586–594. [[CrossRef](#)]
118. Kang, M.S. Using Genotype-by-Environment Interaction for Crop Cultivar Development. *Adv. Agron.* **1997**, *62*, 199–252. [[CrossRef](#)]
119. Hill, J. Genotype-Environment Interactions—A Challenge for Plant Breeding. *J. Agric. Sci.* **1975**, *85*, 477–493. [[CrossRef](#)]
120. Fries, L. Some Observations on the Morphology of *Enteromorpha linza* and *Enteromorpha compressa* in Axenic Culture. *Bot. Mar.* **1975**, *18*, 251–253.
121. Zertuche-González, J.A.; Sandoval-Gil, J.M.; Rangel-Mendoza, L.K.; Gálvez-Palazuelos, A.I.; Guzmán-Calderón, J.M.; Yarish, C. Seasonal and Interannual Production of Sea Lettuce (*Ulva* Sp.) in Outdoor Cultures Based on Commercial Size Ponds. *J. World Aquac. Soc.* **2021**, *52*, 1047–1058. [[CrossRef](#)]
122. Kirst, G.O. Salinity Tolerance of Eukaryotic Marine Algae. *Annu. Rev. Plant Physiol. Plant Mol. Biol.* **1990**, *41*, 21–53. [[CrossRef](#)]
123. Rybak, A.S. Species of *Ulva* (Ulvophyceae, Chlorophyta) as Indicators of Salinity. *Ecol. Indic.* **2018**, *85*, 253–261. [[CrossRef](#)]
124. Zaneveld, J.S. Factors Controlling the Delimitation of Littoral Benthic Marine Algal Zonation. *Integr. Comp. Biol.* **1969**, *9*, 367–391. [[CrossRef](#)]
125. Xing, Q.; Bi, G.; Cao, M.; Belcour, A.; Aite, M.; Mo, Z.; Mao, Y. Comparative Transcriptome Analysis Provides Insights into Response of *Ulva compressa* to Fluctuating Salinity Conditions. *J. Phycol.* **2021**, *57*, 1295–1308. [[CrossRef](#)] [[PubMed](#)]
126. Liu, F.; Pang, S.J. Stress Tolerance and Antioxidant Enzymatic Activities in the Metabolisms of the Reactive Oxygen Species in Two Intertidal Red Algae *Grateloupia Turuturu* and *Palmaria Palmata*. *J. Exp. Mar. Biol. Ecol.* **2010**, *382*, 82–87. [[CrossRef](#)]
127. Karsten, U.; Wiencke, C.; Kirst, G. The Effect of Salinity Changes upon the Physiology of Eulittoral Green Macroalgae from Antarctica and Southern Chile. *J. Exp. Bot.* **1991**, *42*, 1533–1539. [[CrossRef](#)]
128. Wu, T.M.; Lee, T.M. Regulation of Activity and Gene Expression of Antioxidant Enzymes in *Ulva fasciata* Delile (Ulvales, Chlorophyta) in Response to Excess Copper. *Phycologia* **2008**, *47*, 346–360. [[CrossRef](#)]
129. Lu, I.F.; Sung, M.S.; Lee, T.M. Salinity Stress and Hydrogen Peroxide Regulation of Antioxidant Defense System in *Ulva fasciata*. *Mar. Biol.* **2006**, *150*, 1–15. [[CrossRef](#)]
130. Martins, I.; Oliveira, J.M.; Flindt, M.R.; Marques, J.C. The Effect of Salinity on the Growth Rate of the Macroalgae *Enteromorpha intestinalis* (Chlorophyta) in the Mondego Estuary (West Portugal). *Acta Oecol.* **1999**, *20*, 259–265. [[CrossRef](#)]
131. Lartigue, J.; Neill, A.; Hayden, B.L.; Pulfer, J.; Cebrian, J. The Impact of Salinity Fluctuations on Net Oxygen Production and Inorganic Nitrogen Uptake by *Ulva lactuca* (Chlorophyceae). *Aquat. Bot.* **2003**, *75*, 339–350. [[CrossRef](#)]
132. Kakinuma, M.; Coury, D.A.; Kuno, Y.; Itoh, S.; Kozawa, Y.; Inagaki, E.; Yoshiura, Y.; Amano, H. Physiological and Biochemical Responses to Thermal and Salinity Stresses in a Sterile Mutant of *Ulva pertusa* (Ulvales, Chlorophyta). *Mar. Biol.* **2006**, *149*, 97–106. [[CrossRef](#)]
133. Zheng, M.; Lin, J.; Zhou, S.; Zhong, J.; Li, Y.; Xu, N. Salinity Mediates the Effects of Nitrogen Enrichment on the Growth, Photosynthesis, and Biochemical Composition of *Ulva prolifera*. *Environ. Sci. Pollut. Res.* **2019**, *26*, 19982–19990. [[CrossRef](#)] [[PubMed](#)]
134. Gao, G.; Qu, L.; Xu, T.; Burgess, J.G.; Li, X.; Xu, J.; Norkko, J. Future CO<sub>2</sub>-Induced Ocean Acidification Enhances Resilience of a Green Tide Alga to Low-Salinity Stress. *ICES J. Mar. Sci.* **2019**, *76*, 2437–2445. [[CrossRef](#)]
135. Ichihara, K.; Miyaji, K.; Shimada, S. Comparing the Low-Salinity Tolerance of *Ulva* Species Distributed in Different Environments. *Phycol. Res.* **2013**, *61*, 52–57. [[CrossRef](#)]
136. Kamer, K.; Fong, P. A Fluctuating Salinity Regime Mitigates the Negative Effects of Reduced Salinity on the Estuarine Macroalga, *Enteromorpha intestinalis* (L.) Link. *J. Exp. Mar. Biol. Ecol.* **2000**, *254*, 53–69. [[CrossRef](#)]
137. Xiao, J.; Zhang, X.; Gao, C.; Jiang, M.; Li, R.; Wang, Z.; Li, Y.; Fan, S.; Zhang, X. Effect of Temperature, Salinity and Irradiance on Growth and Photosynthesis of *Ulva prolifera*. *Acta Oceanol. Sin.* **2016**, *35*, 114–121. [[CrossRef](#)]
138. McAvoy, K.M.; Klug, J.L. Positive and Negative Effects of Riverine Input on the Estuarine Green Alga *Ulva intestinalis* (Syn. *Enteromorpha intestinalis*) (Linnaeus). *Hydrobiologia* **2005**, *545*, 1–9. [[CrossRef](#)]
139. Luo, M.B.; Liu, F. Salinity-Induced Oxidative Stress and Regulation of Antioxidant Defense System in the Marine Macroalga *Ulva prolifera*. *J. Exp. Mar. Biol. Ecol.* **2011**, *409*, 223–228. [[CrossRef](#)]
140. Messyasz, B.; Rybak, A. Abiotic Factors Affecting the Development of *Ulva* Sp. (Ulvophyceae; Chlorophyta) in Freshwater Ecosystems. *Aquat. Ecol.* **2011**, *45*, 75–87. [[CrossRef](#)]
141. Hofmann, L.C.; Nettleton, J.C.; Neefus, C.D.; Mathieson, A.C. Cryptic Diversity of *Ulva* (Ulvales, Chlorophyta) in the Great Bay Estuarine System (Atlantic USA): Introduced and Indigenous Distromatic Species. *Eur. J. Phycol.* **2010**, *45*, 230–239. [[CrossRef](#)]
142. Blomster, J.; Maggs, C.A.; Stanhope, M.J. Molecular and Morphological Analysis of *Enteromorpha intestinalis* and *E. compressa* (Chlorophyta) in the British Isles. *J. Phycol.* **1998**, *34*, 319–340. [[CrossRef](#)]
143. Burrows, E.M.; De Silva, M.W.R.N. An Experimental Assessment of the Status of the Species *Enteromorpha intestinalis* (L.) Link and *Enteromorpha compressa* (L.) Grev. *J. Mar. Biol. Assoc. U. K.* **1973**, *53*, 895–904. [[CrossRef](#)]

144. van der Loos, L.M.; D'hondt, S.; Engelen, A.H.; Pavia, H.; Toth, G.B.; Willems, A.; Weinberger, F.; De Clerck, O.; Steinhagen, S. Salinity and Host Drive *Ulva*-associated Bacterial Communities across the Atlantic–Baltic Sea Gradient. *Mol. Ecol.* **2022**, *1*–18. [[CrossRef](#)] [[PubMed](#)]
145. Messyasz, B.; Rybak, A. The Distribution of Green Algae Species from the *Ulva* genera (Syn. Enteromorpha; Chlorophyta) in Polish Inland Waters. *Oceanol. Hydrobiol. Stud.* **2009**, *38*, 121–138. [[CrossRef](#)]
146. Blomster, J.; Bäck, S.; Fewer, D.P.; Kiirikki, M.; Lehvo, A.; Maggs, C.A.; Stanhope, M.J. Novel Morphology in Enteromorpha (Ulvophyceae) Forming Green Tides. *Am. J. Bot.* **2002**, *89*, 1756–1763. [[CrossRef](#)] [[PubMed](#)]
147. Rybak, A.S. Revision of Herbarium Specimens of Freshwater Enteromorpha-like *Ulva* (Ulvaceae, Chlorophyta) Collected from Central Europe during the Years 1849–1959. *Phytotaxa* **2015**, *218*, 001–029. [[CrossRef](#)]
148. Valiela, I.; McClelland, J.; Hauxwell, J.; Behr, P.J.; Hersh, D.; Foreman, K. Macroalgal Blooms in Shallow Estuaries: Controls and Ecophysiological and Ecosystem Consequences. *Limnol. Oceanogr.* **1997**, *42*, 1105–1118. [[CrossRef](#)]
149. Masakiyo, Y.; Ogura, A.; Ichihara, K.; Yura, K.; Shimada, S. Candidate Key Genes for Low-Salinity Adaptation Identified by RNA-Seq Comparison between Closely Related *Ulva* Species in Marine and Brackish Waters. *Algal Resour.* **2016**, *9*, 61–76.
150. Matsuo, Y.; Imagawa, H.; Nishizawa, M.; Shizuri, Y. Isolation of an Algal Morphogenesis Inducer from a Marine Bacterium. *Science* **2005**, *307*, 1598. [[CrossRef](#)] [[PubMed](#)]
151. Spoerner, M.; Wichard, T.; Bachhuber, T.; Stratmann, J.; Oertel, W. Growth and Thallus Morphogenesis of *Ulva mutabilis* (Chlorophyta) Depends on A Combination of Two Bacterial Species Excreting Regulatory Factors. *J. Phycol.* **2012**, *48*, 1433–1447. [[CrossRef](#)] [[PubMed](#)]
152. Provasoli, L.; Pintner, I.J. Bacteria Induced Polymorphism in an Axenic Strain of *Ulva lactuca* (Chlorophyceae). *J. Phycol.* **1980**, *16*, 196–201. [[CrossRef](#)]
153. Marshall, K.; Joint, I.; Callow, M.E.; Callow, J.A. Effect of Marine Bacterial Isolates on the Growth and Morphology of Axenic Plantlets of the Green Alga *Ulva linza*. *Microb. Ecol.* **2006**, *52*, 302–310. [[CrossRef](#)]
154. Ghaderiadekani, F.; Coates, J.C.; Wichard, T. Bacteria-Induced Morphogenesis of *Ulva intestinalis* and *Ulva mutabilis* (Chlorophyta): A Contribution to the Lottery Theory. *FEMS Microbiol. Ecol.* **2017**, *93*, 1–12. [[CrossRef](#)] [[PubMed](#)]
155. Lin, G.; Sun, F.; Wang, C.; Zhang, L.; Zhang, X. Assessment of the Effect of Enteromorpha Prolifera on Bacterial Community Structures in Aquaculture Environment. *PLoS ONE* **2017**, *12*, e0179792. [[CrossRef](#)] [[PubMed](#)]
156. Singh, R.P.; Mantri, V.A.; Reddy, C.R.K.; Jha, B. Isolation of Seaweed-Associated Bacteria and Their Morphogenesis-Inducing Capability in Axenic Cultures of the Green Alga *Ulva fasciata*. *Aquat. Biol.* **2011**, *12*, 13–21. [[CrossRef](#)]
157. Califano, G.; Kwantes, M.; Abreu, M.H.; Costa, R.; Wichard, T. Cultivating the Macroalgal Holobiont: Effects of Integrated Multi-Trophic Aquaculture on the Microbiome of *Ulva rigida* (Chlorophyta). *Front. Mar. Sci.* **2020**, *7*, 52. [[CrossRef](#)]
158. Ghaderiadekani, F.; Quartino, M.L.; Wichard, T. Microbiome-Dependent Adaptation of Seaweeds Under Environmental Stresses: A Perspective. *Front. Mar. Sci.* **2020**, *7*, 575228. [[CrossRef](#)]
159. Burke, C.; Thomas, T.; Lewis, M.; Steinberg, P.; Kjelleberg, S. Composition, Uniqueness and Variability of the Epiphytic Bacterial Community of the Green Alga *Ulva australis*. *ISME J.* **2011**, *5*, 590–600. [[CrossRef](#)] [[PubMed](#)]
160. Campbell, A.H.; Marzinelli, E.M.; Gelber, J.; Steinberg, P.D. Spatial Variability of Microbial Assemblages Associated with a Dominant Habitat-Forming Seaweed. *Front. Microbiol.* **2015**, *6*, 230. [[CrossRef](#)] [[PubMed](#)]
161. Tujula, N.A.; Crocetti, G.R.; Burke, C.; Thomas, T.; Holmström, C.; Kjelleberg, S. Variability and Abundance of the Epiphytic Bacterial Community Associated with a Green Marine Ulvacean Alga. *ISME J.* **2010**, *4*, 301–311. [[CrossRef](#)]
162. Saha, M.; Ferguson, R.M.W.; Dove, S.; Künzel, S.; Meichssner, R.; Neulinger, S.C.; Petersen, F.O.; Weinberger, F. Salinity and Time Can Alter Epibacterial Communities of an Invasive Seaweed. *Front. Microbiol.* **2020**, *10*, 2876. [[CrossRef](#)]
163. Lozupone, C.A.; Knight, R. Global Patterns in Bacterial Diversity. *Proc. Natl. Acad. Sci. USA* **2007**, *104*, 11436–11440. [[CrossRef](#)] [[PubMed](#)]
164. Stratil, S.B.; Neulinger, S.C.; Knecht, H.; Friedrichs, A.K.; Wahl, M. Salinity Affects Compositional Traits of Epibacterial Communities on the Brown Macroalga *Fucus Vesiculosus*. *FEMS Microbiol. Ecol.* **2014**, *88*, 272–279. [[CrossRef](#)] [[PubMed](#)]
165. Singh, R.P.; Reddy, C.R.K. Seaweed-Microbial Interactions: Key Functions of Seaweed-Associated Bacteria. *FEMS Microbiol. Ecol.* **2014**, *88*, 213–230. [[CrossRef](#)]
166. Ghaderiadekani, F.; Califano, G.; Mohr, J.; Abreu, M.; Coates, J.; Wichard, T. Analysis of Algal Growth- and Morphogenesis-Promoting Factors in an Integrated Multi-Trophic Aquaculture System for Farming *Ulva* spp. *Aquac. Environ. Interact.* **2019**, *11*, 375–391. [[CrossRef](#)]
167. Gemin, M.; Peña-Rodríguez, A.; Quiroz-Guzmán, E.; Magallón-Servín, P.; Barajas-Sandoval, D.; Elizondo-González, R. Growth-Promoting Bacteria for the Green Seaweed *Ulva clathrata*. *Aquac. Res.* **2019**, *50*, 3741–3748. [[CrossRef](#)]
168. Wang, H.; Elyamine, A.M.; Liu, Y.; Liu, W.; Chen, Q.; Xu, Y.; Peng, T.; Hu, Z. *Hyunsoonleella* Sp. HU1-3 Increased the Biomass of *Ulva fasciata*. *Front. Microbiol.* **2022**, *12*, 788709. [[CrossRef](#)] [[PubMed](#)]
169. Wichard, T. From Model Organism to Application: Bacteria-Induced Growth and Development of the Green Seaweed *Ulva* and the Potential of Microbe Leveraging in Algal Aquaculture. In *Seminars in Cell & Developmental Biology*; Academic Press: Cambridge, MA, USA, 2022. [[CrossRef](#)]
170. Ogawa, T.; Ohki, K.; Kamiya, M. High Heterozygosity and Phenotypic Variation of Zoids in Apomictic *Ulva prolifera* (Ulvophyceae) from Brackish Environments. *Aquat. Bot.* **2015**, *120*, 185–192. [[CrossRef](#)]

171. Lawton, R.J.; Mata, L.; de Nys, R.; Paul, N.A. Algal Bioremediation of Waste Waters from Land-Based Aquaculture Using Ulva: Selecting Target Species and Strains. *PLoS ONE* **2013**, *8*, e77344. [[CrossRef](#)]
172. Fort, A.; McHale, M.; Cascella, K.; Potin, P.; Usadel, B.; Guiry, M.D.; Sulpice, R. Foliose *Ulva* Species Show Considerable Inter-Specific Genetic Diversity, Low Intra-Specific Genetic Variation, and the Rare Occurrence of Inter-Specific Hybrids in the Wild. *J. Phycol.* **2020**, *233*, 219–233. [[CrossRef](#)]
173. Huo, Y.; Zhang, J.; Chen, L.; Hu, M.; Yu, K.; Chen, Q.; He, Q.; He, P. Green Algae Blooms Caused by *Ulva prolifera* in the Southern Yellow Sea: Identification of the Original Bloom Location and Evaluation of Biological Processes Occurring during the Early Northward Floating Period. *Limnol. Oceanogr.* **2013**, *58*, 2206–2218. [[CrossRef](#)]
174. Liu, F.; Melton, J.T. Chloroplast Genomes of the Green-Tide Forming Alga *Ulva compressa*: Comparative Chloroplast Genomics in the Genus *Ulva* (Ulvophyceae, Chlorophyta). *Front. Mar. Sci.* **2021**, *8*, 668542. [[CrossRef](#)]
175. Oyserman, B.O.; Cordovez, V.; Flores, S.S.; Leite, M.F.A.; Nijveen, H.; Medema, M.H.; Raaijmakers, J.M. Extracting the GEMs: Genotype, Environment, and Microbiome Interactions Shaping Host Phenotypes. *Front. Microbiol.* **2021**, *11*, 574053. [[CrossRef](#)]
176. Joint, I.; Callow, M.E.; Callow, J.A.; Clarke, K.R. The Attachment of Enteromorpha Zoospores to a Bacterial Biofilm Assemblage. *Biofouling* **2000**, *16*, 151–158. [[CrossRef](#)]
177. Oertel, W.; Wichard, T.; Weissgerber, A. Transformation of *Ulva mutabilis* (Chlorophyta) by Vector Plasmids Integrating into the Genome. *J. Phycol.* **2015**, *51*, 963–979. [[CrossRef](#)] [[PubMed](#)]
178. Walker, T.L.; Collet, C.; Purton, S. Algal Transgenics in the Genomic Era. *J. Phycol.* **2005**, *41*, 1077–1093. [[CrossRef](#)]
179. Robinson, N.; Winberg, P.; Kirkendale, L. Genetic Improvement of Macroalgae: Status to Date and Needs for the Future. *J. Appl. Phycol.* **2013**, *25*, 703–716. [[CrossRef](#)]