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Review Article

Marine Macroalgae as Bioindicators and the Application in Moroccan Coastlines: A Review

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Abstract: Marine organisms represent nearly half of the worldwide biodiversity; thus, marine macroalgae are known to be good biomonitors of pollution and their ability to accumulate a wide range of pollutants to levels higher than those found in the surrounding waters. These macroalgae species have a unique ability to be used to evaluate metals pollution in marine environments as they have long been known to concentrate metals to levels many times greater to those found in the surrounding waters and they have been used as the metal biomonitors agent around the world. It is known the ways the different industrial effluents might affect the aquatic ecosystem, especially some sensitive macroalgae groups combined with big other stressors like climate change and the anthropogenic activities on coastal areas that is creating an increasing anthropogenic stress worldwide that affect coastal habitats, but very little was then known about the mechanisms of uptake and excretion of metals by species used as biomonitors. However, the biomonitoring using these marine organisms is less developed in Morocco; hence, the objective of this review is to give an insight and an update to the information about recent works on macroalgae biomonitoring in Morocco in the purpose of valorization of the Moroccan macroalgae species in the biomonitoring programs in the Atlantic Ocean and Mediterranean Sea.

Keywords: Biomonitoring, Seaweed, Morocco, Valorization, Marine Biodiversity

1. Introduction

On a global scale, it has been widely reported that significant proportions of human populations have accumulated on coastal zones in the last decades, along with related coastal urbanization, and productive and extractive activities. Recent projections, suggest the possibility of a further dramatic increase in coastal populations for the next quarter of 21st century [27]. The main reason for explaining this trend is that coastal systems provide important ecosystem goods and services that produce benefits to humans [54]. Coastal waters usually host heterogeneous and complex shallow habitats and receive considerable inputs of nutrients and organic matter coming from the continent through surface runoff or groundwater flow, or from deeper stands through upwelling [35]. Heterogeneity and productivity are among the main reasons that could explain why coastal marine ecosystems usually host highly diversified marine communities, and are among the most productive systems of the planet [54]. However, biodiversity and ecosystem functions related to coastal ecosystems are severely exposed to a wide array of human impacts, such as direct exploitation and other non-extractive activities, potentially threatening their integrity [40].

Habitat degradation is recognized as a major threat to terrestrial, aquatic and marine ecosystems. However, anthropogenic activities increasingly provoke deleterious impacts in aquatic ecosystems [19, 38, 47]. This may affect ecological processes underlying abundances and distributions of organisms, community structures, the whole functioning of ecosystems, and their resistance and resilience. Ultimately, this may reduce ecosystems' potential to provide sustainably good and services to humans [18, 19, 31, 52]. Anthropogenic stressors that impact coastal habitats, building of corridors facilitating species invasion (e.g. Suez Canal), sedimentation increase and water quality degradation (e.g. due to urbanization, industrialization, intensive agriculture, aquaculture), and land claims [25].

Anthropogenic activities on coastal areas create increasing anthropogenic stress worldwide. 1/3 of the world's population live in coastal areas that represent for approximately 4% of Earth's total land area [78]. The most significant direct causes of change in coastal ecosystems, and as a result the marine biodiversity loss in particular, are believed to be overexploitation of resources, habitat destruction, marine pollution, increases in sedimentation, invasive species and globally climate change [25, 61, 81].

The air and sea surface temperatures change, due to increasing greenhouse gases in the atmosphere, have a significant impact on marine organisms and as a result on the composition and distribution of coastal communities [83]. Algal species that become invasive for many reasons also impact marine ecosystems, and cause of marine species endangerment and extinction [59, 85].

Seaweeds are affected by both global and local stressors [15]. Global stressors result from human activities or natural fluctuations, which occur on a worldwide level. Although they will have local impacts, they cannot be halted by local action. Earth's orbital eccentricity has an impact on global temperature over periods of thousands of years [41]. On a shorter (and contemporary) scale (i.e. since the industrial revolution), global warming is mostly triggered by greenhouse gas emissions (mostly originating from human activities), which are also leading to acidification. Disruption of weather patterns due to global warming will also have an impact on coastal areas with more frequent and stronger storm events. The complex interactions of stressors are gathered under the climate change umbrella, in which we also add the ocean acidification. There is another major global stressor called "biotic homogenization" [56], that results from human mediated introduction and transport of living organisms outside their native biotope, with biological invasions as local impacts. Some local stressors such as seaweed harvesting and trampling on seaweeds may be direct and evident [59].

Additionally, it has long been recognized that heavy metals in the marine environment since they are highly persistent and can be toxic in traces, have a particular significant in the ecotoxicology [24, 49]. Certain heavy metalsare naturally present in the environment and it is important to distinguish between anthropogenic contamination and natural normal levels to enable evaluating effectively the degree of contamination in a particular area [55].

The effects of contaminants on coastal ecosystems are very difficult to assess. But, in order to better monitor marine coastal pollution, the combination between parameters is more effective [33, 39]; Even if the contaminants are present at low concentrations to cause gross harmful effects, they can cause a number of biochemical reactions in marine organisms. In fact, the use of marine organisms (like algae) as bioindicators for trace metal pollution is currently very common [12, 13]. Molluscs and algae are among the most used organisms for this purpose [68, 75]. Macroalgae are able to accumulate trace metals, reaching concentration values that are thousands of times higher than the corresponding concentrations in sea water [16, 32, 67].

However, very little was then known about the mechanisms of uptake and excretion of metals by species used as bio-monitors. Such data became available slowly through the 1970s, and research continues to the present, serving to hone and improve the techniques employed, both in the sampling and analytical arenas [33].

Marine macroalgae have long been known to concentrate metals to levels many times those found in the surrounding waters [9, 43]. Direct comparisons between metal levels in waters and those in macroalgae generally provided encouraging results [60, 74].

Seeliger and Edwards (1977) found close correlations between dissolved levels of copper and lead in the waters of Raritan Bay near New York and concentrations of these elements in four species of algae. Morris and Bale (1975) produced similar data for cadmium, copper, and zinc in solution and in Fucus vesiculosus from the Bristol Channel. However, the relationship for manganese in the latter studies was poor, and the algae was thought to partially regulate this element [60].

Later studies provided further insight into the extent of the usefulness of macroalgae to monitor metals in aquatic environments. These species essentially respond to metals present in solution in the ambient waters [4, 20, 39, 44, 80].

2. General Aspects of Marine Pollution

Since the 80s, marine pollution was a serious debate for the public and therefore it shared some consciousness worldwide. Over the last two decades, research works on heavy metals has been particularly active as well as the organic wastes [57, 58].

Häder et al. (2020) discussed five sources of anthropogenic pollution that affect marine ecosystems, they are as following:

1) Sewage,
2) Nutrients and terrigenous materials,
3) Crude oil,
4) Heavy metals,
5) And plastics.

However, according to Miller et al. (2010, 2012) there has been very little research on other types of pollution like the thermal one, even though it could be a very interesting tool at local sites for assessing the potential long-term effects of global warming and climate change, without forgetting the emerging anthropogenic problems and ocean acidification.

2.1. Industrial Pollution

According to Laws (2018), the industrial wastewaters or sewage are among the worst sources of water pollution. However, the nature of the pollutants associated with these wastewaters or sewage differs greatly from one industry to another. Moreover, in almost all cases the problems are caused by one or a combination of the following conditions in the wastewater:

1) High concentration Biochemical Oxygen Demand (BOD).
2) High concentration of Total Suspended Solids (TSS).
3) High presence of toxic substances.

In most cases the main source of pollution is industrial. However, plastic pollution comes also from industrial activities (oil, mining, agriculture) or urban waste. Furthermore, the dispersal of the industrial pollutants or others is mostly water or wind driven [38].

2.2. Plastic Pollution

According to the United Nations, not less than 800 species worldwide are affected by almost 80% of marine plastic debris. It is estimated, from the same source, that each year, up to 13 million metric tons of plastic ends up in the ocean, the equivalent of a truck loads worth every minute [66].

2.3. Thermal Pollution

Many industries discharge heated wastewater into aquatic systems worldwide and the Moroccan thermal plant at Safi city is an example of that. It is clear the ways in which this heated effluent might adversely affect aquatic biota.

The ambient water temperature is considered as a chronic stress to some organisms in the ecosystem. Furthermore, any increase in temperature would only increase this chronic stress and probably create lethal conditions for some marine organisms, including seaweed [50].

2.4. Heavy Metals

Heavy metals have a direct toxic effect to aquatic organisms and significantly accumulated by many marine organisms. Therefore, monitoring programs are required to establish spatial and temporal trends in metal abundance and bioavailability in coastal waters [33]. According to Häder et al. (2020), mine tailings are the most important sources of heavy metal pollution, especially lead and zinc. Concentrations of pH, temperature degree, amongst others, and the presence of additional ions, have a variety of effects on the metal uptake process [10]. Generally, heavy metals become toxic when they are not metabolized by the organism and accumulate in the soft tissues [55].

In the environment, soils and cocks are the principal natural sources of heavy metals [14]. Industries, wastewater, mining, agriculture, metallurgical processes, and runoffs lead to the release of different pollutants to different environmental compartments. Anthropogenic processes of heavy metals have been noticed to go beyond the natural norm for some toxic metals [55].

Cd can be found in many consumer goods and also used as a fungicide in some products. The free Cu2+ ion of copper is considered to be the most toxic form of Cu to aquatic life rather than the complexed forms. Moreover, Mn along with Fe is also constituents of a variety of plant enzymes responsible for respiration, protein synthesis and functions in chlorophyll formation. Metal Fe makes up 5% of Earth’s crust and it is 2d in abundance to aluminum among the metals and 4th in abundance behind oxygen, silicon, and aluminum among the trace elements. Additionally, Zn is involved in various metallo-enzymes, in the stability of root cell plasma membrane and cytoplasmic ribosomes; it also catalyzes oxidation and protein synthesis. If Zn concentrations are greater than 100 ppm are encountered, symptoms of phytotoxicity similar to chlorosis may occur [14]. However, Mn and Zn concentrations are higher than Bosphorus but lower than at Marmara [77].

2.5. Marine Pollution in Morocco

Over the last 2 decades, there has been the worst sources of water pollution, and Morocco is no exception of that.

Since the 50s, some industries in Morocco discharge polluted water into aquatic systems without pre-treatment (a highly industrial activity at Eljadida and Safi city, organic pollution that is increasing and a huge decrease of algae biodiversity).

It is not hard to imagine the ways these effluents might affect the aquatic ecosystem, combined with big other stressors like climate change.

In Morocco, over the past years, to monitor the pollution in coastal areas, some authors refer to organisms like mussels [29, 46], other animal species [22, 30, 37] and seaweed [5, 12, 53, 72].

A study done by Strezov and Novora (2005) concluded that the use of bioindicators reduces the need for complex studies on the chemical speciation of aquatic contaminants. However, some authors, like Topcuoğlu et al. (2003) have concluded that abiotic parameters and sediment have some inconvenience in bio-monitoring. It cost a lot of money, it took a lot of time and effort and it is not very effective in the marine ecosystems.

In contrast, the biotic parameters have many advantages in seawater bio-monitoring [48, 65]. Among these marine biotas, Seaweeds are good bio-monitors of pollutants, especially heavy metals and have been included in European coastal monitoring programs. Indeed, seaweed have a widespread distribution with considerable biomass, they are easy to identify and they have adequate thallus for analysis. However, data for seaweed bio-monitoring in Morocco is missing.

Some authors like Sabri et al. (2020); Bahammou et al. (2021) and Boundir et al (2021, 2022) conducted some researches on seaweed biodiversity at the Atlantic coast of Morocco have noticed working in Eljadida, Safi and Essaouira, the decline and degradation of species from the reference stations to the polluted ones. The most impacted group of seaweed is the brown species (Figure 1).

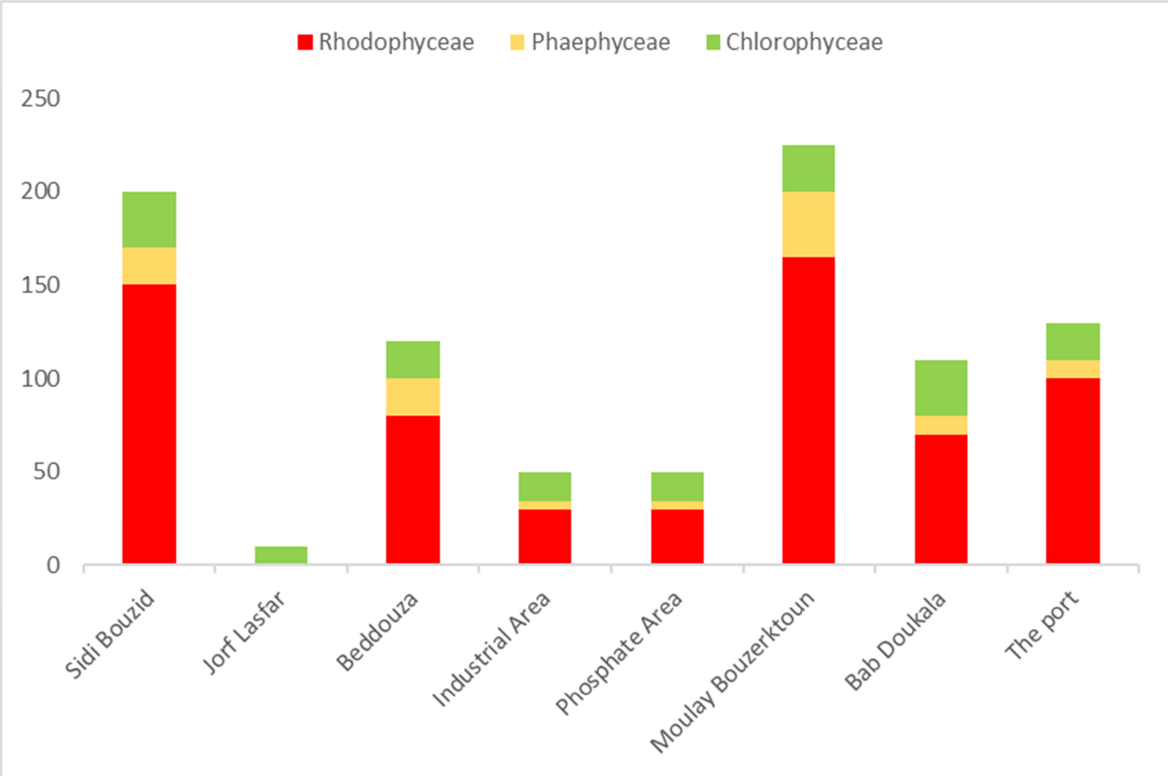

Figure 1. *Seaweed inventory at the 8 stations of Eljadida, Safi and Essaouira cities in the Atlantic coast of Morocco.*

3. Marine Pollution Impact

According to WWF, 80% of marine pollution is generated by land-based activities, it is having an enormous effect on oceans as well as the degradation of ecosystems.

When chemicals like fertilizers, detergents, or sewage containing a variety of chemicals are dumped into oceans in large doses, it can engender eutrophication. The excess of nutrients in seawater cause plants and algae to bloom, reducing water quality as well as the dissolved oxygen concentrations in seawater [86].

In general, the adverse effects of pollutants on aquatic organisms are identified in terms of their lethal and sub-lethal impacts [42].

Luypaert et al. (2020) discussed the changes affecting the ecosystem from a pollution anthropogenic impact (Figure 2). In some areas that were previously dominated by macroalgae, have been replaced by sea urchin and crusting algae because of reduced predation. Marine pollution can have a very important consequences for marine ecosystem, Seaweed among them.

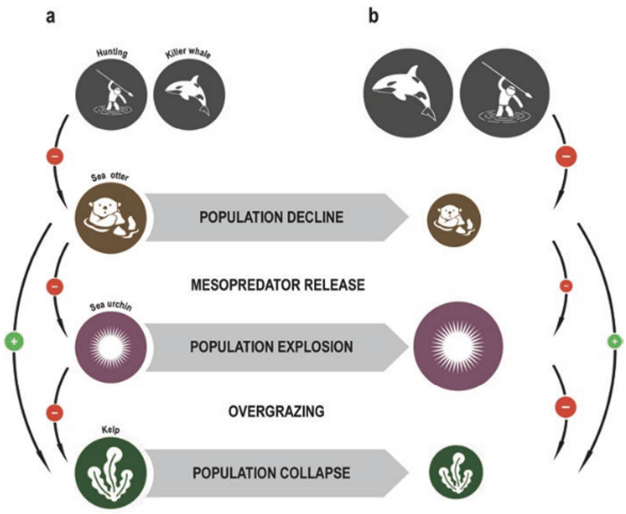

Figure 2. *Changes representation of abundance between trophic groups in a normal ecosystem. From [10].*

(a) Equal interactions.

(b) Trophic cascade following disturbance. In this case, the otter is the dominant predator and the macroalgae are kelp.

The bubbles size represents the population abundance change. + signs indicate positive effects on abundance while those with - signs indicate negative effects on abundance.

3.1. Impact on Marine Water

Heavy metals concentrations of metals in seawater are low and variation depends on many environmental factors [65].

The increase of human population became a major issue; it was observed by many authors that the human generated waste is accumulating in marine environment. It was reported by Gola et al. (2021) that he concentration of micro-plastic in the marine environment is increasing in an alarming rate, which not only affecting the marine environment, but affecting the whole marine life and seaweeds are not exception of that. (Figure 3).

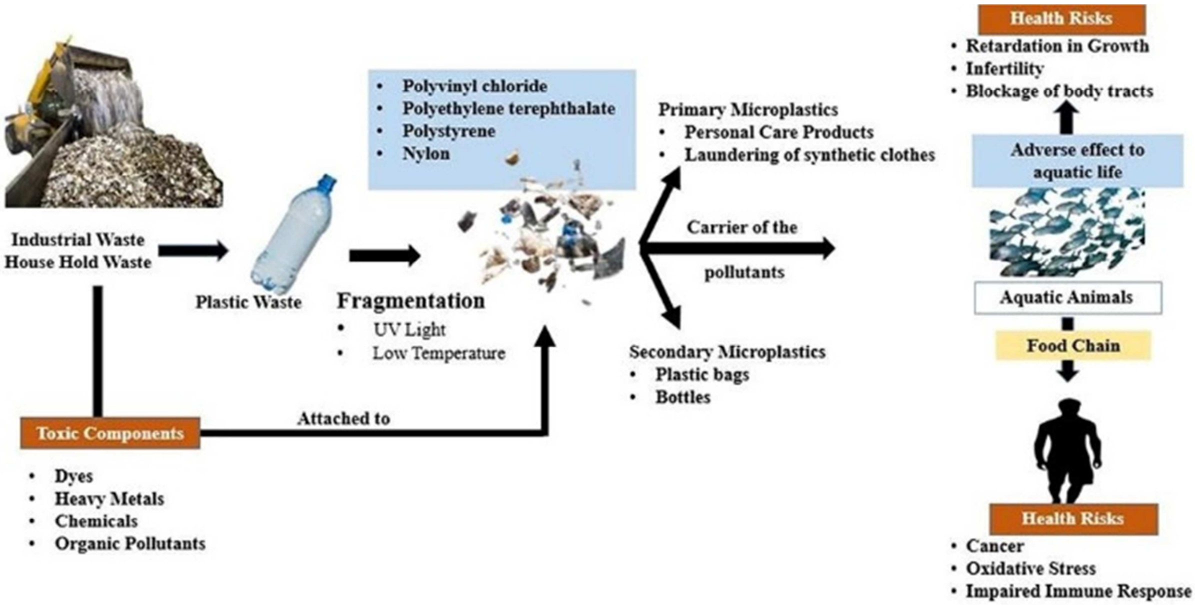

Figure 3. *Schematic presentation of the plastic impact on marine environment. From [36].*

3.2. Impact on Living Organisms and Algae

Certain seaweed flourished in polluted water with organic wastes and as algae play an important significant part of food chain of aquatic marine life, whatever can affect algae strongly affects all organisms in the food chain [17]. However, industrial wastes affect negatively algal communities qualitatively and quantitatively. In reality, under the anthropogenic impact, most algae are vulnerable to disappearance [8].

The heavy metals can have a direct harmful effect on photosynthesis, cell division, growth, and cause the destruction of primary metabolites in some marine algae and reduce the chloroplast content, making a direct death of cells and marine organisms [69].

Hurd et al (2014) classified the possible sublethal responses of an organism to the following elements according to the effects on the organisms:

1) Morphology,
2) Behavior,
3) Biochemistry,
4) Physiology,
5) Genetics and
6) Reproduction.

4. Marine Pollution Monitoring of Coastal Areas

Recently, many efforts have been focused on the use of biomonitoring tools to assess the environment pollution by heavy metals toxicity [39]. However, there is debate about how to measure responses to sub-lethal concentrations of a pollutant and whether laboratory bioassays give meaningful results [7]. Moreover, there is also debate about the responses observed in the laboratory, if they can be extrapolated to the more varied and natural conditions in the oceans [84].

Because of the simplicity experimental laboratory conditions in comparison with the complexity of the marine environment fieldwork, there is a need to also make direct observations during the fieldwork and take into account the seasonal and variability. The long-term monitoring of community structural changes in the field is required for a minimum of several years to take into account the variability and to monitor effectively the effects at low pollutant concentrations. As the pollutants will end up in the sediments, the mechanisms and dynamics of pollutants uptake and release from sediments and their transfer to organisms needs further investigation [3].

Presently, we cannot effectively estimate how the biological consequences of the physico-chemical aspects of contaminants will affect the toxicity, because only living systems can integrate the effects of those variables that are biologically important. The total concentration of a pollutant may give just a little indication of its toxicity in the environment [28, 34]. As Seaweed represent an important element in the marine ecosystem, they are today, a significant number of them originating from different parts of the world used for testing pollutants, substances, effluent waters, and other complex mixtures. Giving the example of the growth rate and germination, they are used instead of mortality that is used for animals, since death is difficult to determine in seaweed. In toxicity experiments, the response is expressed as the concentration where a 50% reduction in growth rate occurs compared to the control test, and it is called the 50% effective concentration (EC50) [42].

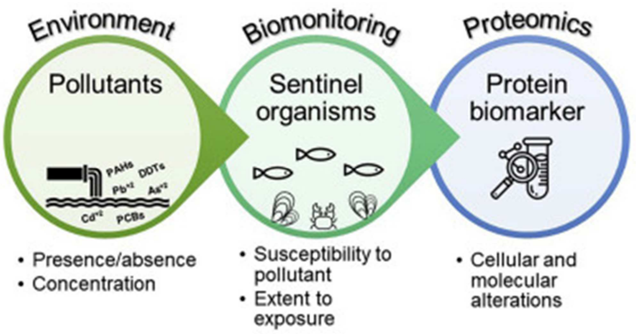

Figure 4. *Biomonitoring of aquatic pollution by [51].*

4.1. Monitoring Using Abiotic Parameters

The environment physico-chemical composition to which an algae specie is exposed is often strongly linked to vertical zonation along the phytal zone, with intertidal species populating the most demanding, least stable habitat [26]. Valdivia et al. (2011) showed that vertical variation in community structure was significantly higher than site-scale horizontal variation but lower than shore-scale horizontal variation. Research efforts from the local to the global scale are now directed towards the additional anthropogenic sources of variation in the abiotic environment. Additionally, the biomonitoring using abiotic and physico-chemical parameters still important to determine the key paremeters influencing the seaweed environment.

However, some authors, like Topcuoğlu et al (2003) have concluded that abiotic parameters and sediment have some inconvenience in bio-monitoring. It cost a lot of money, it took a lot of time and effort and it is not very effective in the marine ecosystems. A study done by Strezov and Novora (2005) concluded that the use of bioindicators reduces significantly the need for complex studies on the chemical speciation of aquatic contaminants.

4.2. Monitoring Using Biotic Parameters

Assemblages dominated by Fucales serve as nursery habitats for some littoral fishes [1, 21]. Normally, biomonitors needs to fulfill a number of required characteristics including easy to identify, widespread distribution with considerable biomass, sedentary nature, etc..., in addition to being an excellent pollutant accumulators [68].

However, seaweeds are therefore considered to be good agents for bio-monitoring of heavy metals in seawater [4, 20, 62]. Currently, in Europe, as documented in the European Water Framework Directive [6, 45] algae have been included as important key organisms to monitor and classify the ecological status of coastal ecosystems with decades of studies [70, 80].

Ballesteros et al. (2007) provided the likely effects of pollutants and desalinated water plumes, on a coastal zone without significant tidal currents. However, industrial and domestic discharges through deep submarine water are widespread on all coastlines, with likely significant impact on subtidal communities. Besides, ecological status is concerned with other kinds of anthropogenic pressures, as important as discharges, that should also be taken into account and that may affect the subtidal communities to a greater extent [11].

Regarding the relationships between stressors and effects at the communities, species or community level on marine ecosystems is a difficult task that requires the use of multiple lines of evidence [2]. Thus, there is an urgent necessity for tools that contribute to the management of anthropogenic activities in the marine environment, by providing an effective indicator that measure the direct impact of an activity on part of the ecosystem [71]. Evidence on the suitability of algae as bioindicators of effects against different pollution gradients is known and undoubted [23, 73]. Moreover, the application of Macroalgae in biological quality elements to be used for the biomonitoring of the ecological status of coastal waters in the the European Water Framework Directive context has supported such a capacity. Furthermore, in recent years, important advances in the development of specific indices for evaluation of this element using different approaches have been carried out [6, 63, 64, 82].

4.3. Algae as Bioindicator

According to Bulent et al (2013), Bioindicator organisms can be used to identify and qualify the effects of pollutants on the environment. Bioindicator species can tell us about how long a problem may persist and the cumulative effects of different pollutants in the marine ecosystem. However, the biotic parameters have many advantages in seawater bio-monitoring [48, 65]. Among these marine biotas, Macroalgae are good bio-monitors of pollutants, especially heavy metals and have been included in European coastal monitoring programs.

Therefore, Macroalgae species have a unique ability to be used as biomonitors to evaluate metals pollution in marine environments. Around the world, the Macroalgal species have been used as the metal biomonitor agent [39]. In the Aegean Sea, Akcali and Kucuksezgin (2011) have introduced the brown algae *Cystoseira* and the green algae *Ulva* and *Enteromorpha* species as a biomonitoring model for heavy metals toxicity. Moreover, Bioindicator organisms can be any biological species that respond to a number of characteristics of the environment, according to Bulent et al. (2013), algae are known to be good indicators of pollution of many types for the following reasons:

1) They are easier to detect and sample.
2) Marine Macroalgae response quickly to the charges in the marine environment due to significant pollution.
3) Macroalgae are diverse group of organisms found in large quantities and they are very abundant.
4) Many algal species are available all the year during the four seasons.

5) The presence of some Macroalgae is well correlated with particular type of pollution particularly to organic pollution.
6) Macroalgae have wide temporal and spatial distribution.

5. Conclusion

This review gave an insight about the marine pollution in general and an update to the information about recent works on macroalgae biomonitoring in Morocco. The valorization of the Moroccan macroalgae species in the biomonitoring programs still a necessity in order to develop more the monitoring studied techniques in other regions on the Atlantic coast of Morocco but also the Mediterranean Sea and worldwide.

To rationally manage and control marine pollution in the Atlantic coast of Morocco, it is necessary to study everything related to the inputs, distribution and destiny of contaminants, including land-based heavy metals that flow into aquatic ecosystems. It is essential to address their effects on seaweed biodiversity, especially at Safi city where the growth of phosphate industry is accelerating.

As a perspective for future research, we aim to develop the following axes:

1. Develop the monitoring studied techniques in more other regions in the Atlantic coast of Morocco but also the Mediterranean and worldwide.
2. Littoral geomorphology for better understanding of algal distribution using recent technologies.

Additionally, we sugget a protocol in order to monitor effectively with low cost and efforts the marine ecosystem. We would start by an overview on the algal species. Once we detect a significant decrease in the marine seaweed species, we will make an inventory of the brown species that are the most sensitive.

For the abiotic parameters that could be the origin of the pollution, we should do a research on the study sites in order to target the key parameters to analyse. This will allow us to gain more time and money.

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