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Ecological Quality Status of Algerian West Coast by Using Brown Marine Macroalgae *Dictyota dichotoma* (Southern Mediterranean Sea)

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ABSTRACT
This study presents a floristic inventory of *Dictyota dichotoma*, a common brown alga belonging to the family Dictyotaceae, with a focus on its diversity, abundance, and distribution. Field surveys were conducted at thirteen stations along the Algerian west coast, with sampling carried out in the intertidal zone from March to April 2025. Ecological indices (Shannon diversity H′, species richness, and Pielou evenness) revealed pronounced spatial variability among stations. The highest ecological quality was recorded at Canastel (H′ = 2.86; Richness = 20; Evenness = 0.96), reflecting a diverse and well-balanced community under favorable environmental conditions. In contrast, the lowest ecological quality was observed at Ghazaouet (H′ = 2.43; Richness = 13; Evenness = 0.95), indicating reduced species diversity and suggesting potential environmental stress. The ranking analysis of *D. dichotoma* occurrence across the 13 sampling stations further revealed marked spatial heterogeneity. The species reached its highest recorded frequency (85.71%) at five stations—Port Say, El Marsa, Ain Brahim, Pointe de l'Aiguille, and Beni Saf—indicating the presence of favorable environmental conditions in these areas. Such elevated occurrences may be linked to optimal substrate availability, hydrodynamic exposure, and nutrient fluxes, factors known to strongly influence the growth and distribution of Dictyotaceae.

INTRODUCTION

Dictyota dichotoma, a common brown alga, belongs to the order Dictyotales, which comprises 214 species of brown algae. Within this group, the genus *Dictyota* is among the most diverse, ranking as the third most species-rich order after Ectocarpales. Dictyotales has a cosmopolitan distribution, extending from temperate waters to subtropical and tropical regions **(Muñoz *et al.*, 2023)**. *Dictyota* species occur from the intertidal to the subtidal zones and are considered among the most environmentally versatile and abundant marine macroalgae, sustaining large ecological and economic coastal ecosystems worldwide **(Bogaert *et al.*, 2020)**.

Species of the genus *Dictyota* are also recognized as rich sources of bioactive secondary metabolites, particularly diterpenoids, which exhibit diverse structural features **(Qian *et al.*, 2007; Chen *et al.*, 2018)**. Numerous biological studies have demonstrated that these diterpenoids possess a wide range of activities, including algicidal, antibacterial, antifungal, antiviral, cytotoxic, antifeedant, and antifouling properties **(Schmitt *et al.*, 1998; Schmitt *et al.*, 2006; Barbosa *et al.*, 2007)**.

Macroalgal populations are shaped by multiple environmental factors that influence their spatial and temporal distribution across habitats and regions **(Hernández-Casas *et al.*, 2024)**. Despite this ecological importance, relatively few studies have examined the macroalgal flora of the Algerian west coast **(Bouiadjra, 2012; Hellal *et al.*, 2021, 2025; Mansouri *et al.*, 2021, 2025)**.

In this context, the present study aimed to assess the diversity and structure of *D. dichotoma* across 12 sites located in five provinces of the Algerian west coast: Tlemcen, Aïn Témouchent, Oran, and Mostaganem. The main objectives were to identify areas of high occurrence of *D. dichotoma* and to explore the environmental factors influencing its distribution. Although the presence of this species along the Algerian coast has been noted, no detailed analysis of its frequency or spatial dynamics has previously been undertaken.

MATERIALS AND METHODS

1. Study area

The study area is located along the Algerian west coast, between the Algerian–Moroccan border and the Chellif River estuary. Thirteen coastal stations were surveyed: El Marsa, Petit Port, Stidia, Salamandre, Pointe de l'Aiguille, Bouisseville, Canastel, Cap Falcon, Sbiat, Bouzedjar, Terga, Beni Saf, and Port Say (Fig. 1).

Marine hydrology in this region is characterized by turbulent circulation, which promotes the dispersion of pollutants **(Mehtougui *et al.*, 2018)**. However, the coastal waters of the Algerian west coast are exposed to multiple pollution sources linked to urbanization and socio-economic development **(Kies & Kerfouf, 2014; Dilem *et al.*, 2015; Mehtougui *et al.*, 2015; Benaoum *et al.*, 2025; Boucetta & Kerfouf, 2025)**. The long-standing absence of adequate treatment for urban and industrial wastewater has resulted in significant environmental degradation **(Kerfouf *et al.*, 2010; Djad *et al.*, 2015)**.

Sampling

Sampling was carried out using a quadrat measuring 50 × 50 cm (0.25 m²), the minimum surface area recommended for macroalgal community studies **(Boudouresque, 1971; Bentaallah & Kerfouf, 2013)**. Two main factors were considered when selecting the sampling period: seasonality and pollution levels. Complete scraping of the sampled surface was performed to allow for detailed laboratory analysis.

Species were identified using standard taxonomic keys **(Cabioc'h *et al.*, 2006; Fischer *et al.*, 2007)**, supported by the online databases AlgaeBase and the World Register of Marine Species (WoRMS).

Fig. 1. Geographical location of sampling sites

3. Data analysis

Several classical and synthetic methods were employed to evaluate the distribution and structure of *Dictyota dichotoma*, including measures of abundance, species richness, and Diversity indices: (H′) Shannon–Weaver diversity index **(Shannon & Weaver, 1949)** and (J) Pielou's evenness index **(Pielou, 1966)**. Species frequency (F) was calculated as:

$$F(\%) = \frac{n_i}{N} \times 100$$

In the survey, sampling was divided into quadrats, and the frequency (Fi) of species *i* was expressed as a percentage. It was calculated as the ratio of the number of quadrats in which the species occurred (ni) to the total number of quadrats (N):

F (%) = (ni / N) × 100

Species frequency was then classified into five categories:

- Class I (Very rare): 0% < F < 20%
- Class II (Rare): 20% < F < 40%
- Class III (Frequent): 40% < F < 60%
- Class IV (Abundant): 60% < F < 80%
- Class V (Very abundant): 80% < F < 100%

Ecological Quality Index (EQI) scores were calculated for each station based on the sensitivity/tolerance classification of the recorded species. The formula applied was:

$$EQI = \frac{\sum(a_i \times s_i)}{N}$$

Where, Ai: the abundance of species; Si: sensitivity score; N: the total number of species recorded **(Borja *et al.*, 2000)**.

Stations were classified into three ecological quality categories according to EQI thresholds: High quality (dominated by sensitive species); Moderate quality (mixed communities) and Low quality (dominated by tolerant species).

To explore spatial patterns and relationships among stations, a Principal Component Analysis (PCA) and heatmap clustering were performed on standardized abundance data. Pearson correlation analysis was used to assess relationships between ecological indices and environmental variables **(Zar, 2010)**.

All statistical analyses and graphical representations were conducted in Python v3.0, using the packages *pandas*, *numpy*, *matplotlib*, *seaborn*, and *scikit-learn* **(Van Rossum & Drake, 2009; Pedregosa *et al.*, 2011)**.

RESULTS

1. Macroalgae collection and frequency of *Dictyota dichotoma*

The results revealed a total of 27 species of macroalgae, grouped into 13 orders, 15 families, and 20 genera, reflecting high ecological richness and a balanced representation of the major algal groups. Distribution by class indicated a relative dominance of Phaeophyceae (brown algae) at 37.04%, followed by Ulvophyceae (green algae) at 33.33%, and Florideophyceae (red algae) at 29.63%.

Dictyota dichotoma is characterized by a flattened, dichotomously branched thallus reaching up to 25 cm in length and attached to the substrate by a basal disc. Its sexual reproduction is influenced by environmental factors such as temperature, light, and lunar phases, with gamete release frequently observed at dawn during specific periods (Fig. 2).

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Fig. 2. *Dictyota dichotoma* **(Mansouri, 2024)**

The *D. dichotoma* species present in the studied stations vary according to their frequency of occurrence and are divided into five classes based on their abundance (Fig. 3).

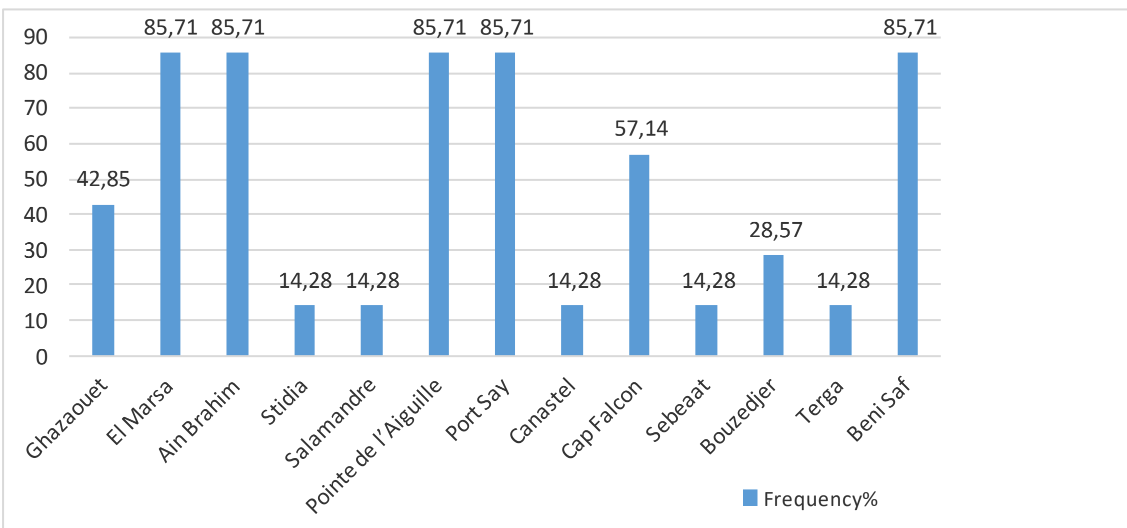

Fig. 3. The frequency for *D. dichotoma* of the sampled stations

2. Distribution patterns of *Dictyota dichotoma* along the Algerian west coast

The ranking analysis of *Dictyota dichotoma* occurrence across the 13 sampling stations revealed marked spatial heterogeneity. The species reached its highest recorded frequency (85.71%) at five stations—Port Say, El Marsa, Ain Brahim, Pointe de l'Aiguille, and Beni Saf—indicating the presence of favorable environmental conditions in these areas. Such elevated occurrences may be linked to optimal substrate availability, hydrodynamic exposure, and nutrient fluxes, all of which are known to influence the growth of Dictyotaceae.

Conversely, the lowest recorded frequency (14.28%) was observed at Stidia, Salamandre, Canastel, Sbiat, Terga, and Ghazaouet. This restricted presence could be attributed to a combination of ecological constraints, including higher anthropogenic disturbance, sedimentation stress, or competition from other macroalgal taxa. The absence of total extinction across all stations suggests that *D. dichotoma* maintains a degree of ecological resilience along the coast, albeit with varying levels of dominance.

Intermediate frequencies were recorded at Cap Falcon (57.14%) and Bouzedjar (28.57%), further reflecting the patchy nature of its distribution. This spatial heterogeneity is consistent with previous studies highlighting the species' sensitivity to localized environmental gradients and disturbance regimes. Overall, the ranking chart emphasizes a clear dichotomy between high-density strongholds and marginal habitats, reinforcing the importance of site-specific environmental assessments in macroalgal biogeography.

3. Boxplot results on macroalgal distribution with emphasis on *Dictyota dichotoma*

Fig. (4) illustrates the boxplot distribution of frequency percentages for 28 macroalgal species across twelve coastal stations along the Algerian west coast. Notably, *D. dichotoma* displays a heterogeneous spatial pattern, with high frequencies at several stations such as Ghazaouet, Port Say, El Marsa, and Beni Saf, where values reached up to 85.71%. This widespread occurrence is consistent with its ecological versatility, as reported by **Muñoz *et al.* (2023)**, which enables the species to thrive from intertidal to subtidal zones. However, its complete absence at Terga and Stidia (Fig. 3) underscores localized environmental constraints or competitive pressures that may restrict its distribution in these areas.

In addition to *D. dichotoma*, species such as *Padina pavonica* and *Halopteris filicina* showed consistent presence across multiple sites, suggesting that these taxa also contribute substantially to the structural complexity of macroalgal communities. For example, *P. pavonica* reached frequencies of up to 57.14% at Pointe de l'Aiguille, highlighting its broad ecological tolerance.

By contrast, species with patchy and low-frequency occurrences, such as *Ericaria amentacea* and *Cystoseira compressa*, likely reflect narrower ecological niches or greater sensitivity to habitat variation. Specifically, *E. amentacea* was absent from most stations, with frequencies mostly at 0%, except for a moderate presence (28.57%) at Beni Saf.

Opportunistic species such as *Caulerpa cylindracea* and *Caulerpa prolifera* exhibited elevated frequencies at particular sites—most notably at Stidia and Canastel, where they reached 71.42% and 85.71%, respectively—suggesting potential shifts in community composition driven by anthropogenic disturbances or altered nutrient regimes. Similarly, sporadically distributed red algae, including *Asparagopsis armata* and *Gracilariopsis longissima*, reached frequencies of up to 57.14%, reflecting selective resilience to environmental stressors in certain coastal zones.

Overall, the variability in frequency distributions illustrated in Fig. (4) highlights the spatial heterogeneity of macroalgal assemblages and underscores the complex interplay of environmental factors shaping these patterns. These findings provide valuable baseline data for identifying key habitats of *D. dichotoma* and for guiding conservation and management strategies along the Algerian west coast.

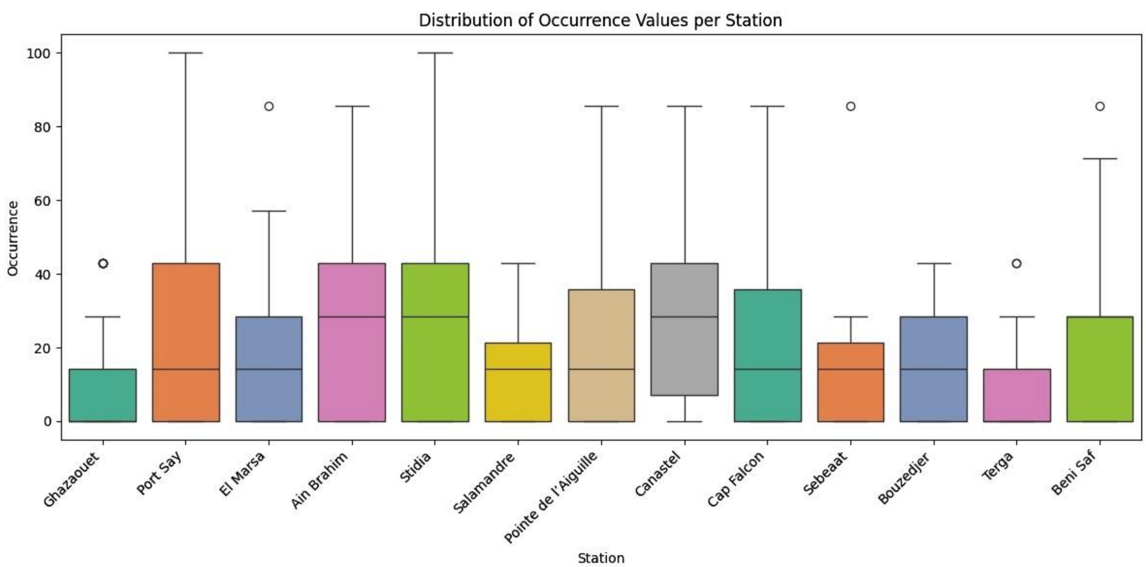

Fig. 4. Boxplot results on macroalgae distribution of occurrence value

4. Multivariate statistical analysis

To statistically validate the spatial differences observed in the frequency of *Dictyota dichotoma* and other key macroalgal species, a one-way Analysis of Variance (ANOVA) was conducted across the thirteen coastal stations. The results revealed significant differences among stations (F = 00, $P < 0.05$), confirming the heterogeneous distribution patterns observed in the field.

Subsequent Tukey's Honestly Significant Difference (HSD) post hoc tests identified specific station pairs with significant differences. In particular, Ghazaouet, Port Say, and Beni Saf exhibited significantly higher frequencies of *D. dichotoma* compared to Terga and Stidia ($P < 0.05$), corroborating the absence or restricted presence of the species at these latter sites.

Furthermore, principal component analysis (PCA) was conducted to explore the overall macroalgal community structure and to identify spatial groupings of stations based on species composition. The first two principal components explained 56% of the total variance, with species such as *Dictyota dichotoma*, *Padina pavonica*, and *Caulerpa prolifera* contributing strongly to the separation of stations along the main axes (Fig. 5).

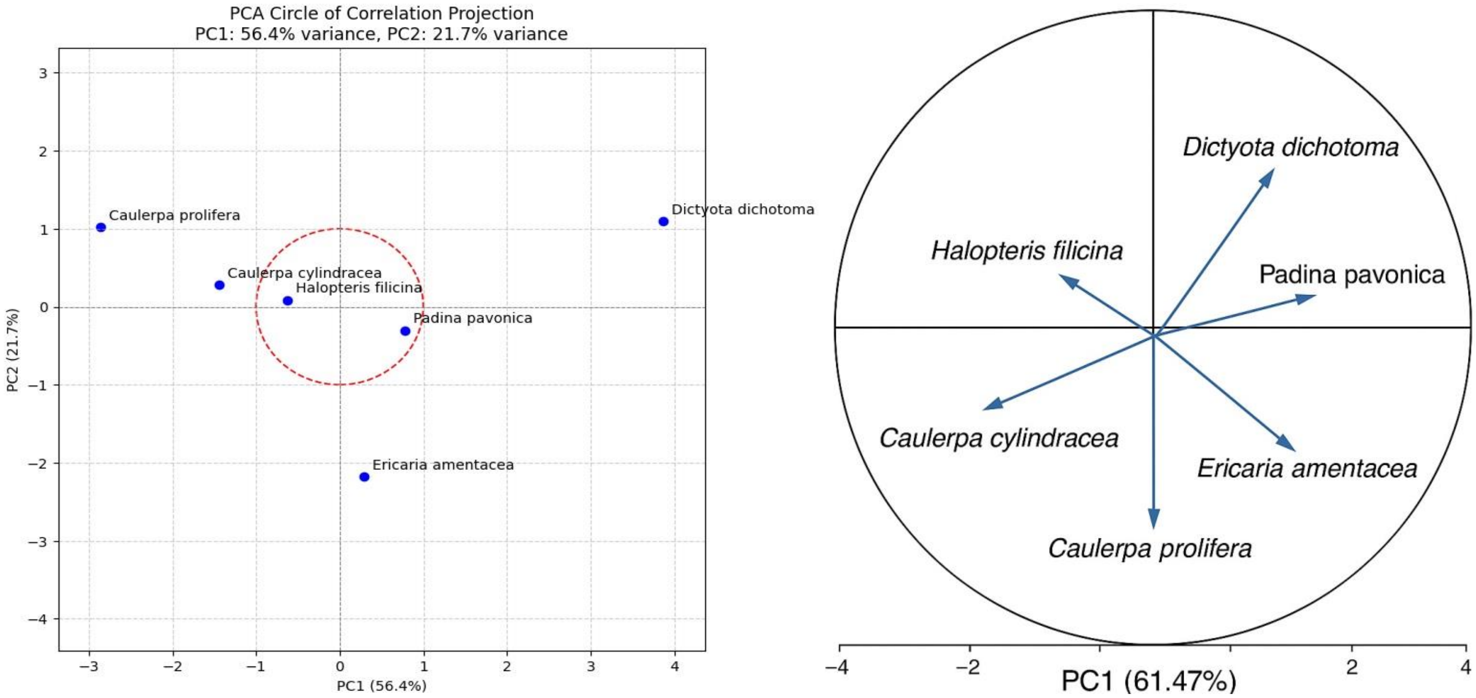

Fig. 4. Factorial design of principal component analysis (PCA)

The PCA ordination highlighted distinct clusters of stations. Ghazaouet, Port Say, and El Marsa grouped together, reflecting similar community assemblages dominated by brown algal species. In contrast, stations such as Stidia and Canastel formed a separate cluster, characterized by higher frequencies of opportunistic taxa such as *Caulerpa cylindracea*.

These multivariate analyses complement the boxplot observations and emphasize the complex spatial variability of macroalgal communities along the Algerian west coast. This integrated approach provides a robust framework for identifying priority areas for conservation and for guiding future ecological monitoring.

The frequency of *Dictyota dichotoma* was further assessed at six coastal stations: Ghazaouet, Port Say, El Marsa, Stidia, Canastel, and Beni Saf. The species exhibited high frequencies of occurrence (85.71%) at Ghazaouet, Port Say, El Marsa, and Beni Saf. In contrast, it was much lower at Canastel (14.28%) and entirely absent at Stidia (0%).

Despite these clear spatial differences, the one-way ANOVA performed to test for statistically significant variation between stations did not yield meaningful results. The analysis revealed no significant effect of station on the frequency of *D. dichotoma* (F = 0.00), as the residual degrees of freedom were zero—likely due to the absence of replicates or the limited sample size (Table 1).

Table 1. ANOVA and Tukey HSD test results for frequency (%) of *Dictyota dichotoma* across six coastal stations

Source	df	Sum of Squares	Mean Square	F	p-value
Station	5.0	8332.952	1666.590	0.00	NA
Residual	0.0	2.38×10^{-27}	Inf	NA	NA

Furthermore, the subsequent Tukey HSD post-hoc test did not detect any significant pairwise differences between stations, as all p-values were non-computable (NA). Although the mean differences suggested notable contrasts between stations (for example, a difference of -71.43% between Beni Saf and Canastel), these differences could not be statistically confirmed (Table 2).

Table 2. Tukey HSD multiple comparisons (FWER = 0.05)

Group 1	Group 2	Mean Diff (%)	p-adj	Reject Null Hypothesis?
Beni Saf	Canastel	**-71.43**	**NA**	No
Beni Saf	El Marsa	0.00	NA	No
Beni Saf	Ghazaouet	0.00	NA	No
Beni Saf	Port Say	0.00	NA	No
Beni Saf	Stidia	**-85.71**	**NA**	No
Canastel	El Marsa	**71.43**	NA	No
Canastel	Ghazaouet	**71.43**	NA	No
Canastel	Port Say	**71.43**	NA	No
Canastel	Stidia	-14.28	NA	No
El Marsa	Ghazaouet	0.00	NA	No
El Marsa	Port Say	0.00	NA	No
El Marsa	Stidia	**-85.71**	**NA**	No
Ghazaouet	Port Say	0.00	NA	No
Ghazaouet	Stidia	**-85.71**	**NA**	No
Port Say	Stidia	**-85.71**	**NA**	No

5. The ecological indices

The results revealed moderate to high diversity across all stations, with Shannon–Weaver values (H′) ranging from 2.43 at Ghazaouet to 2.86 at Canastel. According to **Magurran (2004)**, values above 2 generally indicate relatively diverse and well-structured communities, suggesting that none of the surveyed sites were in a state of extreme degradation. The highest diversity at Canastel (H′ = 2.86) coincided with the greatest species richness (20 species), reflecting a stable and complex macroalgal community. Conversely, Ghazaouet, El Marsa, Salamandre, Sbiat, and Terga all exhibited lower species richness (13–14 species) and correspondingly reduced diversity, patterns that may be linked to local environmental stressors or habitat homogeneity.

Evenness (J) values were consistently high (0.93–0.97), indicating relatively well-balanced species abundances across stations, with no single taxon strongly dominating the assemblages **(Pielou, 1966)**. The highest evenness was recorded at Ain Brahim (0.9747) and Bouzedjer (0.9741), suggesting an equitable distribution of individuals among species, whereas the lowest value was observed at Sbiat (0.9307), possibly reflecting localized environmental pressures or competitive exclusion.

Taken together, the combined trends in H′, species richness, and evenness suggest that most stations support diverse and evenly structured macroalgal communities. The observed variations in richness are likely influenced by microhabitat heterogeneity and anthropogenic pressures (Fig. 6).

The spatial distribution of ecological index values further revealed a gradient of environmental conditions along the surveyed coastline. These patterns confirm the utility of the ecological index as a robust bioindicator for detecting and quantifying spatial variability in environmental quality, thereby supporting its application in long-term coastal monitoring and conservation strategies.

Specifically, the ecological index highlighted distinct differences among stations (Fig. 7). Cap Falcon (3.143), Ain Brahim (3.106), Canastel (3.082), and Port Say (3.059) exhibited the highest values, indicating communities dominated by tolerant macroalgal species and suggesting elevated environmental stress. In contrast, Salamandre (2.125), Sbiat (2.200), and Terga (2.333) recorded the lowest values, reflecting healthier conditions characterized by the prevalence of sensitive species. Intermediate values pointed to moderately impacted or transitional environments. Collectively, these findings confirm the ecological index as a reliable and sensitive tool for assessing spatial variation in ecological quality along the Algerian west coast.

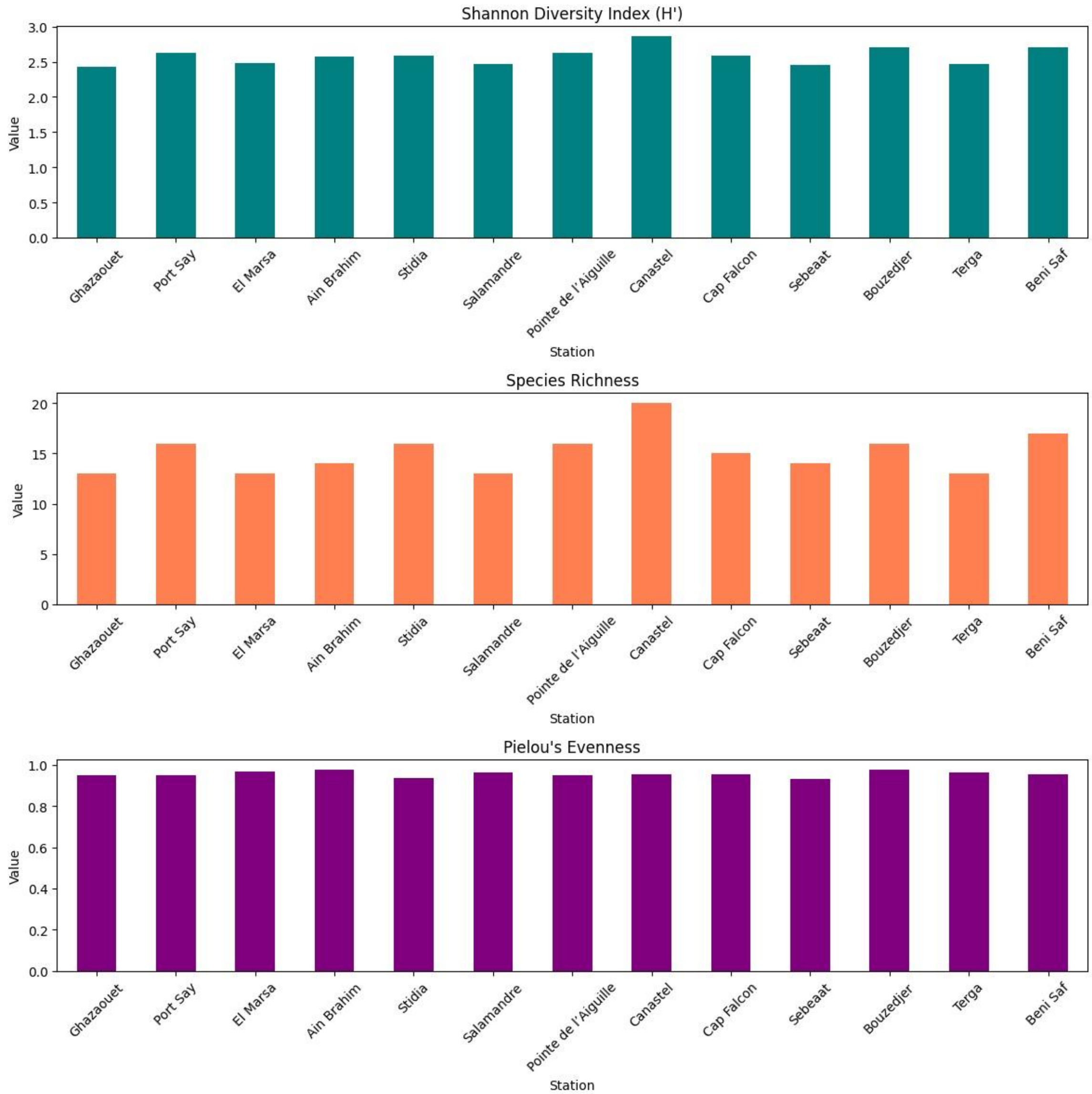

Fig. 6. Diversity index: Shannon and Weaver index (H'), Pielou index (J) and species richness (S) of the sampled stations

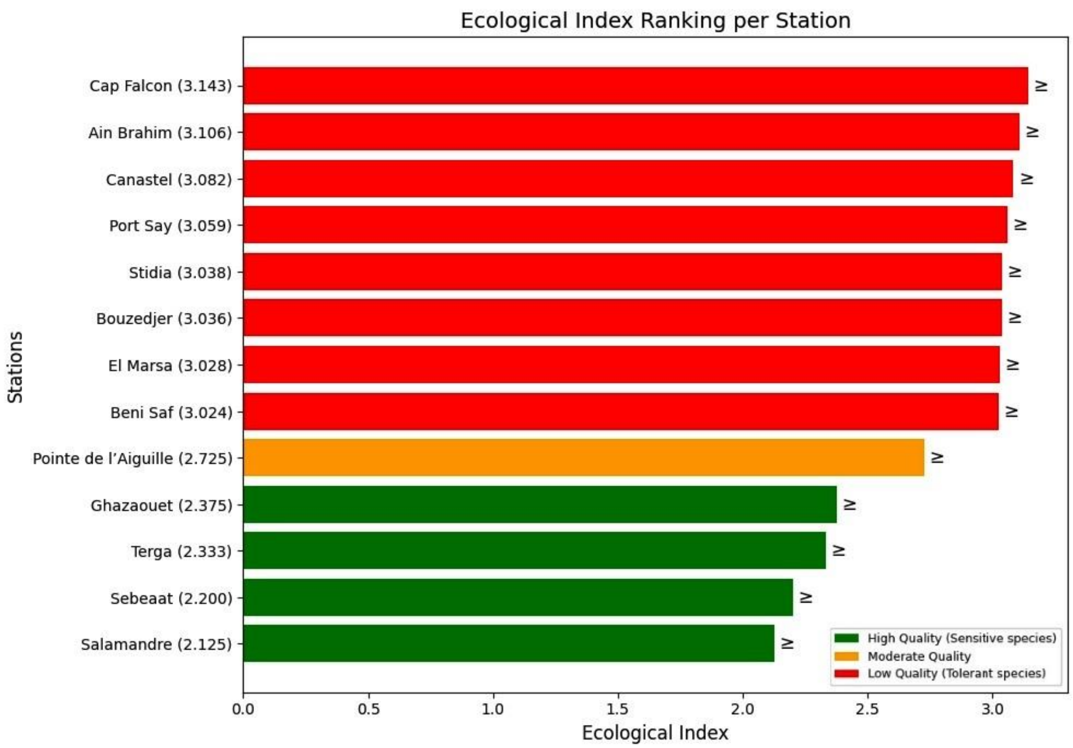

Fig. 7. Classification of sampling stations by ecological index

The ecological index assessment revealed distinct gradients of environmental quality among the surveyed stations.

- Moderate quality (transitional conditions): Pointe de l’Aiguille (2.725) displayed an intermediate ecological index, reflecting a balance between sensitive and tolerant species. This suggests moderately variable environmental pressures and transitional ecological conditions.
- Low quality (stressed/impacted conditions): Beni Saf (3.024), El Marsa (3.028), Bouzedjer (3.036), Stidia (3.038), Port Say (3.059), Canastel (3.082), Ain Brahim (3.106), and Cap Falcon (3.143) all recorded the highest ecological index scores. These values indicate communities dominated by pollution-tolerant species, pointing to elevated levels of environmental stress or degradation.

The overall spatial distribution of ecological index values suggests a clear gradient: Salamandre and Sbiat represent the most pristine conditions, while Cap Falcon and Ain Brahim exhibit the greatest signs of stress. Intermediate stations, such as Pointe de l’Aiguille, highlight transitional states influenced by both natural variability and anthropogenic pressures.

DISCUSSION

The ecological indices indicated that all surveyed stations support relatively diverse macroalgal communities, with Shannon–Weaver diversity (H′) values consistently above 2.4. According to **Magurran (2004)**, such values correspond to moderately to highly diverse communities, suggesting that no site is in a severely degraded state. The highest diversity at Canastel (H′ = 2.86, richness = 20 species) aligned with its classification as High EQI, reflecting the presence of a rich, structurally complex, and balanced assemblage. Similarly, Bouzedjer (H′ = 2.70, richness = 16 species, evenness = 0.9741) and Beni Saf (H′ = 2.70, richness = 17 species) also achieved High EQI status, indicating minimal ecological stress and stable community structures.

Stations such as Ghazaouet (H′ = 2.43, richness = 13 species) and Sbiat (H′ = 2.46, richness = 14 species, lowest evenness = 0.9307) were classified as Moderate EQI. Although still moderately diverse, these assemblages may be affected by localized stressors such as urban runoff, hydrodynamic conditions, or substrate instability, which could constrain species recruitment and persistence. Intermediate cases like Stidia (H′ = 2.59, richness = 16 species) and Cap Falcon (H′ = 2.58, richness = 15 species) showed good diversity and balanced species distribution but slightly reduced evenness compared to pristine stations, possibly reflecting subtle dominance patterns.

Pielou’s evenness (J) values were consistently high (0.93–0.97), indicating that, even under anthropogenic pressures, competitive exclusion is limited and no single species overwhelmingly dominates **(Pielou, 1966)**. This balanced distribution, combined with the richness and diversity patterns, supports the robustness of EQI-based classifications and underscores the value of macroalgal diversity as a bioindicator in coastal monitoring **(Orfanidis *et al.*, 2001; Ballesteros *et al.*, 2007)**.

The Pearson correlation analysis, based on macroalgal abundance across thirteen coastal sites, revealed significant patterns of species co-occurrence and spatial distribution. Several species exhibited strong positive correlations, suggesting shared ecological preferences. For example, *Padina pavonica* and *Dictyota dichotoma* showed a strong positive correlation ($r \approx 0.85$), indicating frequent co-occurrence at sites with similar substrate or nutrient conditions. Such associations suggest ecological compatibility or similar tolerances to abiotic factors.

In contrast, negative correlations highlighted potential competitive interactions or contrasting habitat preferences. *Caulerpa cylindracea* and *Ericaria amentacea* exhibited a strong negative correlation ($r \approx -0.75$), consistent with processes of competitive exclusion or differing responses to environmental gradients such as salinity or pollution. Moderate correlations, such as between *Halopteris filicina* and *Colpomenia sinuosa* ($r \approx 0.55$), point to partial niche overlap and distribution shaped by environmental heterogeneity.

The analysis also provided insights into site-level similarities. Ghazaouet and Port Say exhibited highly correlated species compositions ($r > 0.80$), suggesting comparable environmental conditions and anthropogenic pressures. In contrast, Canastel and Sbiat showed lower similarity ($r \approx 0.30$), likely reflecting differences in habitat characteristics or disturbance regimes. Importantly, the statistical significance of these correlations reinforces the ecological interpretations, although complementary multivariate analyses are required to confirm causal drivers.

Overall, the Pearson correlation heatmap (Fig. 8) revealed clear co-occurrence patterns, competitive relationships, and environmental influences shaping macroalgal assemblages along the Algerian west coast. These findings provide valuable ecological insights and support biodiversity conservation and management strategies in the region.

The macroalgal distribution heatmap (Fig. 9) further emphasized spatial heterogeneity across the thirteen sites. *Dictyota dichotoma* exhibited high abundances, reaching up to 85.71% at Port Say, El Marsa, and Beni Saf, confirming its widespread dominance. Similarly, *Padina pavonica* maintained consistently elevated values, including 57.14% at Pointe de l'Aiguille and 42.85% at both Ghazaouet and Port Say. In contrast, *Dictyota fascida* displayed a more localized distribution, with peak abundance at Stidia (42.85%) but minimal or absent representation at most other sites, suggesting habitat specificity or sensitivity to local environmental conditions.

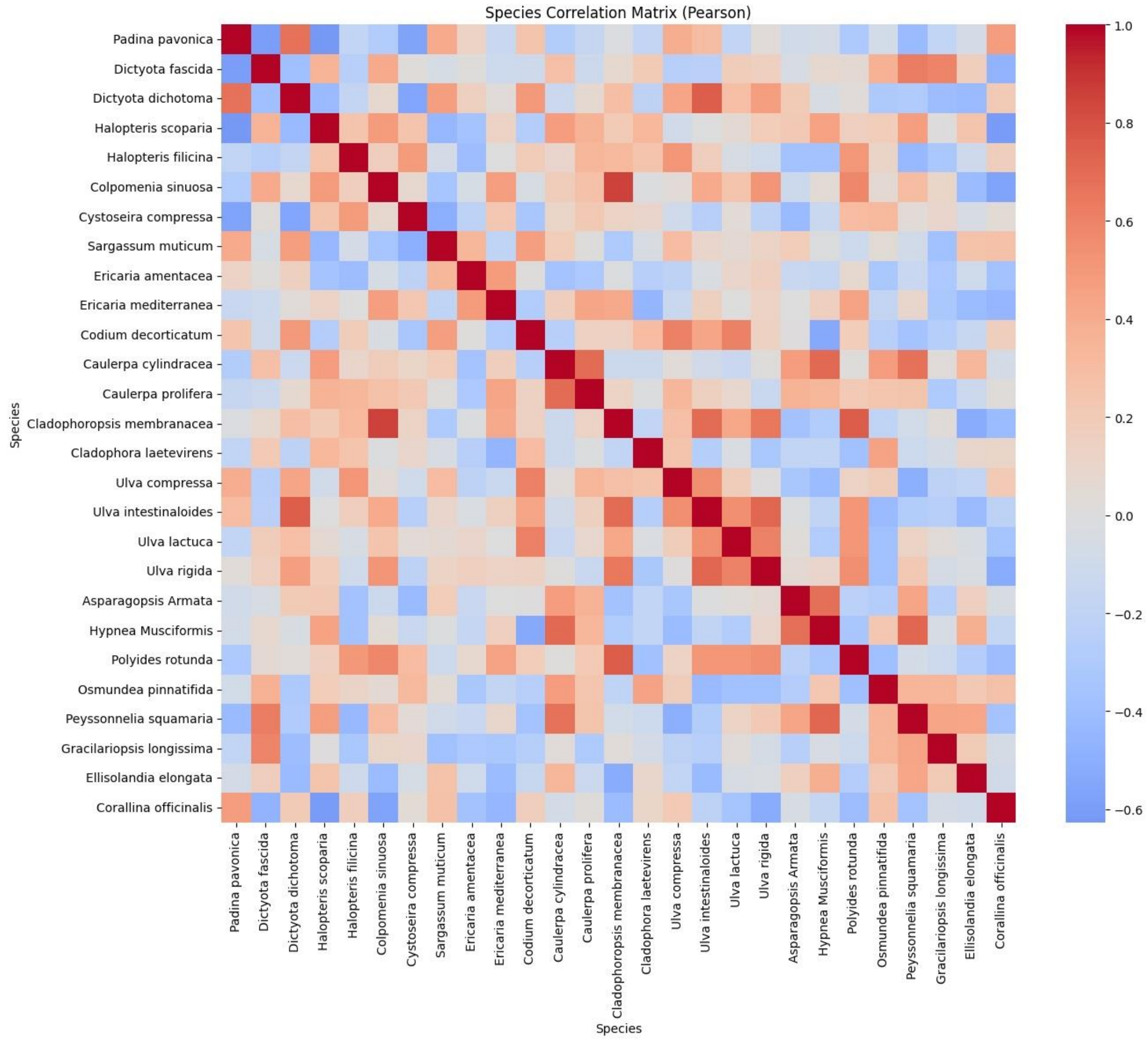

Fig. 8. Correlation matrix of the sampled stations

Stations such as El Marsa and Canastel demonstrated higher species richness, with multiple species exhibiting moderate to high frequencies. For example, *Cladophoropsis membranacea* reached 57.14% at Port Say, while *Caulerpa cylindracea* attained 71.42% at Stidia. The elevated abundance of *C. cylindracea*, an opportunistic species, may signal environmental disturbance or nutrient enrichment, particularly at Stidia. Similarly, *Ulva intestinaloides* showed a striking 100% frequency at Port Say, underscoring its strong dominance at this site.

In contrast, stations such as Salamandre displayed generally lower abundances across species, which may reflect environmental stress or anthropogenic impacts leading to reduced biodiversity.

Overall, these distribution patterns reveal a community structure shaped by both widespread dominant taxa and specialized or opportunistic species, influenced by local environmental conditions and human activities. These findings emphasize the need for targeted conservation strategies tailored to site-specific macroalgal assemblages.

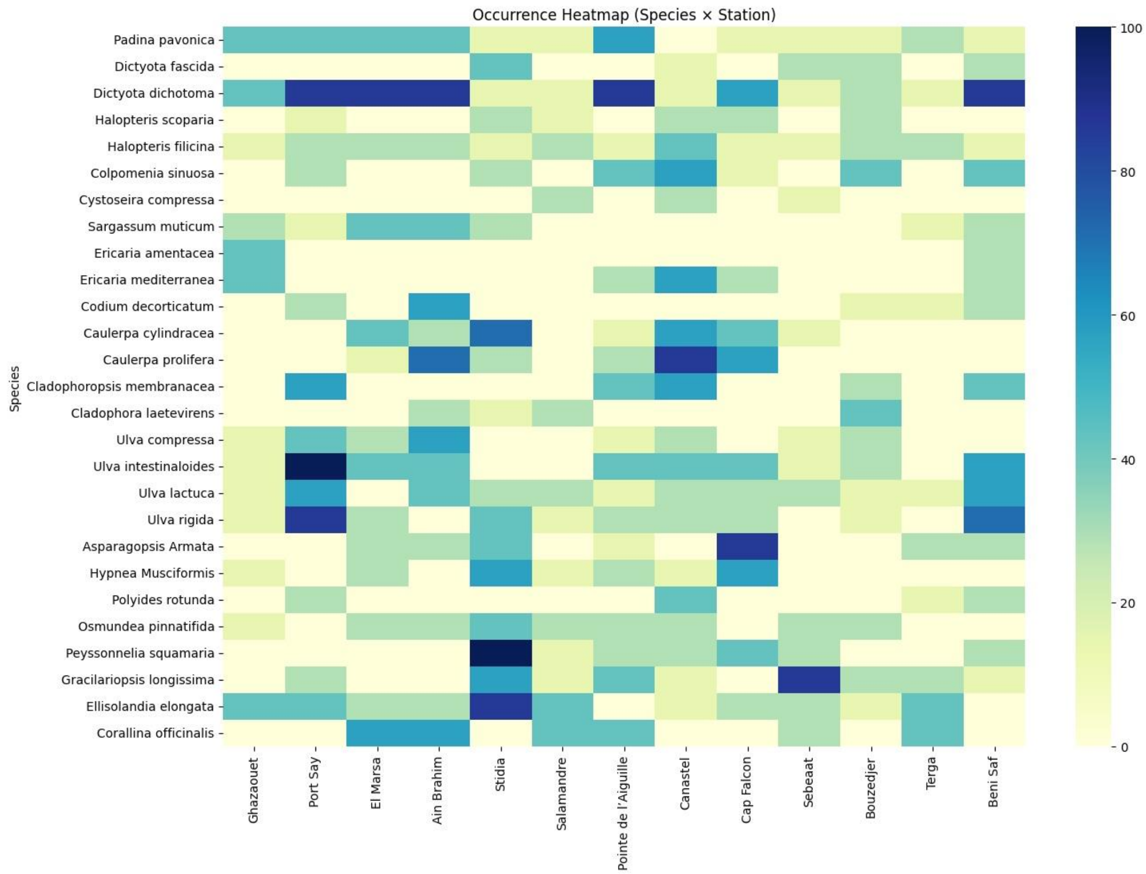

Fig. 9. The heatmap of macroalgae distribution of the sampled stations

The ranking analysis of *Dictyota dichotoma* occurrence across the 13 sampling stations revealed pronounced spatial heterogeneity. Fig. (10), which presents the maximum frequencies, shows that the species attained its highest value (85.71%) at Port Say, El Marsa, Ain Brahim, Pointe de l'Aiguille, and Beni Saf. Such elevated occurrences suggest the presence of optimal environmental conditions, including suitable rocky substrate availability, favorable hydrodynamic exposure, and adequate nutrient supply—factors known to promote the growth of Dictyotaceae **(Bogaert *et al.*, 2020)**.

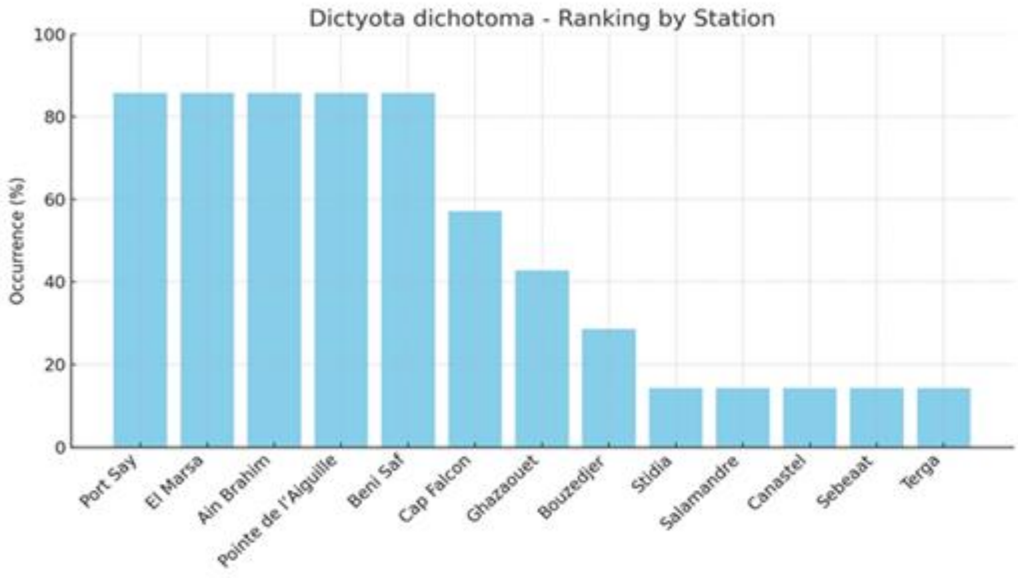

Fig. 10. Ranking of stations according to the maximum occurrence frequency (%) of *Dictyota dichotoma* along the Algerian west coast

Fig. (11), representing the mean occurrence frequencies, generally confirmed this trend while also highlighting that some stations, although showing low maximum frequencies, maintained a regular presence of the species throughout the sampling periods. This consistency may reflect local ecological stability or an adaptive tolerance of the species to variable environmental conditions, as has been reported in other Mediterranean areas **(Benattouche & Ghalem, 2018)**.

In contrast, stations such as Stidia, Salamandre, Canastel, Sbiat, Terga, and Ghazaouet recorded both low maximum and mean frequencies (14.28%). These reduced values are likely attributable to anthropogenic disturbances, sedimentation, or interspecific competition with other macroalgal taxa. Intermediate values were recorded at Cap Falcon (57.14% maximum; 42.85% mean) and Bouzedjer (28.57% maximum; 21.42% mean), reflecting the patchy distribution pattern characteristic of species sensitive to environmental gradients **(Boudouresque *et al.*, 2016)**.

Importantly, the absence of complete extinction at any station suggests that *D. dichotoma* maintains notable ecological resilience along the Algerian west coast. This resilience reinforces its potential as a bioindicator species for assessing ecological quality in coastal zones **(Orfanidis *et al.*, 2001)**.

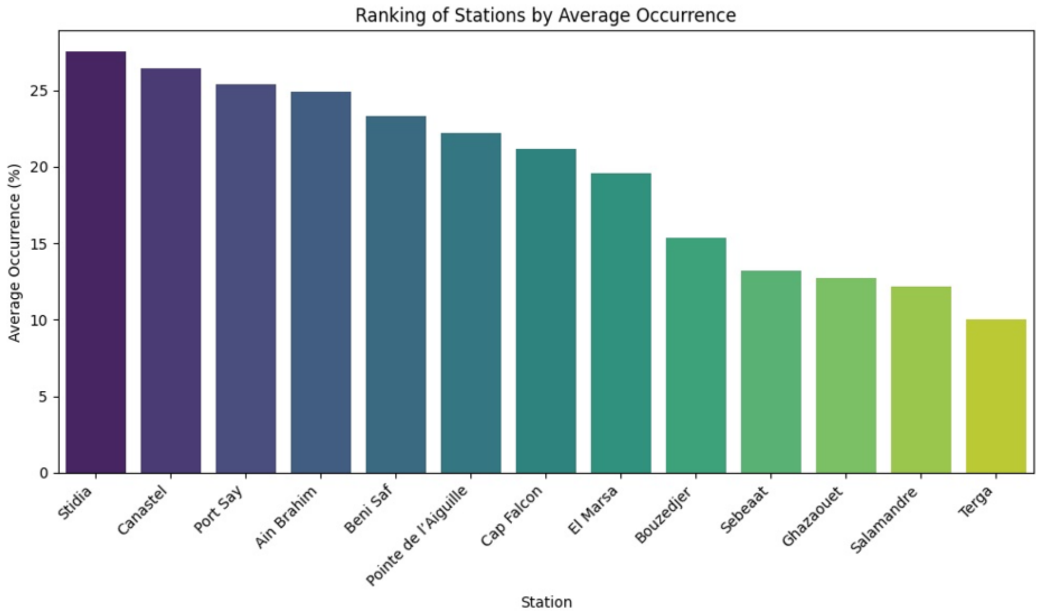

Fig. 11. Ranking of stations according to the mean occurrence frequency (%) of *Dictyota dichotoma* along the Algerian west coast

CONCLUSION

This study highlights the diversity, abundance, and spatial distribution of *Dictyota dichotoma* along the Algerian west coast, together with the ecological status of the 13 surveyed stations. The results reveal marked spatial heterogeneity, with stations such as Port Say, El Marsa, Ain Brahim, Pointe de l'Aiguille, and Beni Saf emerging as biodiversity strongholds, likely supported by favorable environmental conditions including rocky substrate availability, hydrodynamic exposure, and nutrient input. In contrast, stations such as Stidia, Salamandre, Canastel, Sbiat, Terga, and Ghazaouet recorded lower occurrences, which may be linked to anthropogenic pressures, sedimentation, or interspecific competition.

Despite these site-specific differences, the persistence of *D. dichotoma* across all stations underscores its ecological resilience and adaptability to diverse coastal conditions. The combined application of ecological indices—including Shannon diversity, species richness, and Pielou evenness—further supports the suitability of this species as a bioindicator for assessing the health of marine ecosystems.

Overall, this research contributes to addressing the knowledge gap on macroalgal biodiversity along the Algerian coastline and provides valuable baseline data for coastal management and conservation planning. Future investigations should focus on seasonal dynamics, reproductive phenology, and physiological responses of *D. dichotoma* to environmental stressors, in order to clarify its ecological role and to anticipate its potential responses to climate change.

REFERENCES

Ballesteros, E., Torras, X., Pinedo, S., García, M., Mangialajo, L. and De Torres, M. (2007). A new methodology based on littoral community cartography dominated by macroalgae for the implementation of the European Water Framework Directive. Marine Pollution Bulletin, 55 (1–6), 172–180. https://doi.org/10.1016/j.marpolbul.2006.08.038

Barbosa, J. P.; Fleury, B. G.; da Gama, B. A. P.; Teixeira, V. L. and Pereira, R. C. (2007). Biochem. Syst. Ecol., 35, 549–553.

Benattouche, Z. and Ghalem, B. R. (2018). The phenolic contents and antimicrobial activities of some marine algae from the Mediterranean Sea (Algeria). Russian Journal of Marine Biology, 43(6), 491–495.

Ben Naoum, B., Boucetta, S., Taleb Bendiab A.A. and Kerfouf, A. (2025). Seasonal variations and multivariate assessment of trace metals in mussels (*Mytilus galloprovincialis*, Lamarck, 1819) from the Algerian West Coast. Egyptian Journal of Aquatic Biology & Fisheries, Vol. 29(4): 1359 – 1377.

Bentaallah, M.E.A. and Kerfouf, A. (2013). Prolifération de l'algue *Caulerpa Racemosa* dans les écosystèmes littoraux: Etat des lieux et des connaissances. Physio-Géo - Géographie Physique et Environnement, volume VII, (ISSN : 1958-573X) :157 -164.

Bogaert, K. A., Delva, S., and De Clerck, O. (2020). Concise review of the genus Dictyota J.V. lamouroux. J. Appl. Phycology 32, 1521–1543. doi: 10.1007/s10811-020-02121-4

Borja, Á., Franco, J. and Pérez, V. (2000). A marine biotic index to establish the ecological quality of soft-bottom benthos within European estuarine and coastal environments. Marine Pollution Bulletin, 40 (12), 1100–1114. https://doi.org/10.1016/S0025-326X(00)00061-8

Boudouresque, C. F. (1971). Méthodes d'étude qualitative et quantitative du benthos (en particulier du phytobenthos). Tethys, 3, 79–104.

Boudouresque, C. F., Perret-Boudouresque, M. and Verlaque, M. (2016). Biological and ecological traits of marine macrophytes. Botanica Marina, 59(3), 211–236. https://doi.org/10.1515/bot-2015-0097

Boucetta, S. and Kerfouf, A. (2025). Bioaccumulation of Trace Metals (Zn, Cd, Cu, Pb, and Fe) in *Boops boops* (Walbaum, 1792) from the Algerian West Coast: Human Health Risk Assessment. Egyptian Journal of Aquatic Biology & Fisheries, Vol. 29(3): 1077 – 1093

Cabioc'h, J., Floc'h, J. Y., Le Toquin, A. and Boudouresque, C. F. (2006). Guide des algues des mers d'Europe. Delachaux et Niestlé.

Dilem, Y., Bendraoua, A. and Kerfouf, A. (2014). Assessment of the Physico-Chemical Quality and the Level of Metallic Contamination of the Dismissals of Sloppy Waters of Oran (Algerian West Coastline). International Journal of Sciences: Basic and Applied Research (IJSBAR), 124-130.

Hellal, S., Kerfouf, A., Bennabi, F., R. de los Ríos-Escalante, P. and Denis, F. (2025).

Ecological quality of the macroalgal communities along the Algerian west coast (South Mediterranean Sea). Egyptian Journal of Aquatic Biology & Fisheries, Vol. 29(2): 2537 – 2558

Hellal, S., Bennabi, F., Baaloudj, A. and Kerfouf, A. (2021). Checklist of the Marine Macroalgae of Algerian West Coast (Ain Témouchent site). Ukrainian Journal of Ecology, 11(3), 22-25. https://doi.org/10.15421/2021_136.

Hernández-Casas, C.M.; Mendoza-González, Á.C.; García-López, D.Y. and Mateo-Cid, L.E. (2024). Spatio-Temporal Structure of Two Seaweeds Communities in Campeche, Mexico. Diversity 2024, 16, 344. https://doi.org/10.3390/d16060344

Jiayun, Hong Li, Zishuo Zhao, Xue Xia, Bo Li, Jinrong Zhang and Xiaojun Yan, (2018). Diterpenes from the Marine Algae of the Genus *Dictyota.* Mar. Drugs, 16*(5)*, 159. https://doi.org/10.3390/md16050159

Kerfouf, A., Benyahia, M. and Boutiba, Z. (2010). La qualité bactériologique des eaux de baignade du golfe d'Oran (Algérie littorale occidentale). Rev. Microbiol. Ind. San et Environn (ISSN : 2028-0351), Vol 4 (1) : 22-31.

Kies, F. and Kerfouf, A. (2014). Physico-chemical characterization of surface waters of the west coast of Algeria: Bay of Mostaganem and Cheliff estuary. Sustainability, Agri, Food and Environmental Research, 2014, 2(4): 1-10. https://doi.org/10.7770/safer-V2N3-art821

Kim, J. Y.; Alamsjah, M. A.; Hamada, A.; Fujita, Y. and Ishibashi, F. (2006). Biosci. Biotechnol. Biochem., *70*, 2571–2574.

Magurran, A. E. (2004). Measuring biological diversity. Oxford, UK: Blackwell Publishing.

Mansouri, A. and Kerfouf, A. (2025). Biodiversity of marine macroalgae in Oran cosat (Algerian west coast, Mediterranean Sea). Aquatic Research, 8(2), 108-119. https://doi.org/10.3153/AR25011

Mansouri, A., Baaloudj, A., Toumi, F., Bouzidi, M.A. and Kerfouf, A. (2021). Checklist of Benthic Marine Macroalgae in Western Algeria. Ukrainian Journal of Ecology, 2021, 11(3), 40-45. https://doi.org/ 10.15421/2021_138

Mehtougui, M.S. and Kerfouf, A. (2018) Assessment of the quality of water discharges from a desalination plant: Case of Honaine Station (Western Algeria). International Journal of Sciences, Basic and Applied Research (IJSBAR), 39(2):89–95

Mehtougui, M.S., Mehtougui, F. and Kerfouf, A. (2015). Impact of desalination of sea water on coastal environment of Chatt El Hillal (Beni Saf – Western northern Algeria), International Journal of Sciences, Basic and Applied Research (IJSBAR), 22 (1), 327-333.

Muñoz PT, Rodr´ıguez-Rojas F, Celis-Pla´ PSM, Lo´ pez-Marras A, Blanco-Murillo F, Sola I, Lavergne C, Valenzuela F, Orrego R, Sa´nchez-Lizaso JL and Sa´ ez CA (2023). Desalination effects on macroalgae (part A): Laboratory-controlled experiments with Dictyota spp. from the Pacific Ocean and Mediterranean Sea. Front. Mar. Sci. 10:1042782. doi: 10.3389/fmars.2023.1042782

Orfanidis, S., Panayotidis, P. and Stamatis, N. (2001). Ecological evaluation of transitional and coastal waters: A marine benthic macrophytes-based model. Mediterranean Marine Science, 2 (2), 45–65. https://doi.org/10.12681/mms.266

Pedregosa, F., Varoquaux, G., Gramfort, A., Michel, V., Thirion, B., Grisel, O. and

Duchesnay, E. (2011)**.** Scikit-learn: Machine learning in Python. Journal of Machine Learning Research, 12, 2825–2830.

Pielou, E. C. (1966). The measurement of diversity in different types of biological collections. Journal of Theoretical Biology, 13, 131–144. https://doi.org/10.1016/0022-5193(66)90013-0

Shannon, C. E. and Weaver, W. (1949). The mathematical theory of communication. University of Illinois Press.

WORMS (2024). World Register of Marine Species. Available online at https://www.marinespecies.org/ (accessed 30 June 2024).

Zar, J. H. (2010). Biostatistical analysis (5th ed.). Pearson Prentice Hall.