Chapter 1
Assessing Ecological Quality on the Rocky Coast of Abalo Beach, Portugal

Teresa Mouga

Abstract Portugal's rich marine biodiversity, home to approximately 550 seaweed species, is distributed across biogeographical regions influenced by Atlantic and Mediterranean climates. Human-induced stressors, including habitat degradation, pollution, and climate change, have impacted seaweed ecosystems, changed the distribution patterns and promoting the invasion of alien species. This paper evaluates the ecological dynamics of seaweed communities on the rocky coast of Abalo Beach, Portugal, using the Marine Macroalgae Assessment Tool (MarMAT) in 2022 and 2023. The MarMAT methodology, endorsed by the Portuguese Environment Agency, assesses the ecological quality of coastal areas based on taxonomic composition, diversity, and biomass of macroalgae. The assessment revealed different percentages of late-successional species (ESGI) and annual (ESGII) seaweeds, indicating a subtle decrease in late-successional species. Of concern is the increase in invasive species from one in 2009 to six in 2023, suggesting a potential threat to ecosystem integrity. Comparative analysis with previous studies confirms the ongoing ecological quality and resilience of Abalo Beach. The article underscores the importance of continuous monitoring amid environmental changes and the rise of invasive species.

Keywords MarMAT index · Seaweeds · Species richness · Biodiversity assessment · Water framework directive

1.1 Introduction

Portugal boasts rich biodiversity, particularly in its marine environment. Regarding seaweeds, the country is home to approximately 550 species, categorized into three distinct biogeographical regions: the Mediterranean, the Atlantic, and, within the Azores and Madeira archipelagos, Macaronesia [1]. The mainland coast exhibits a

T. Mouga (✉)
MARE-Marine and Environmental Sciences Centre/ARNET-Aquatic Research Network, ESTM, Polytechnic University of Leiria, Peniche, Portugal
e-mail: mougat@ipleiria.pt

P. S. Duque de Brito et al. (eds.), *Proceedings of the 4th International Conference (ICoWEFS 2024)*, Springer Water, https://doi.org/10.1007/978-3-031-81817-2_1

latitudinal gradient from north to south, fostering a coexistence of cold waters north Atlantic, with Lusitanian species, along with warm waters southern species [2].

In recent decades, the cumulative impacts of human activities, including habitat degradation, organic pollution, the introduction of alien species, and ocean warming, have weakened the resilience of seaweed ecosystems, leading to a decline in biomass. These challenges persist today. Climate change is prompting the northward migration of cold-water species along the Portuguese coast, notably large kelp species (*Laminaria* spp.) [3]. The rising addition of organic compounds to seawater has also notably increased the abundance of opportunistic species, such as *Ulva* spp. [4]. Additionally, the introduction of alien seaweed species has had a significant impact on communities, ecological processes, and ecosystem services [5].

This disturbance has reshaped the distribution patterns of canopy-forming species responsible for marine forest formation. Simultaneously, simpler species from warmer waters and calcareous algae are on the rise, contributing to ecosystem degradation and creating conditions conducive to invasive alien species [6, 7]. To address these challenges, the Water Framework Directive (WFD) and the Marine Strategy Framework Directive in Europe aim to sustain coastal marine waters and habitats. Monitoring, especially using macroalgae as ecological indicators, is crucial for assessing biodiversity changes and ecosystem structure [8].

Within this framework, macroalgae have a long history of use in ecological assessments due to their ecological importance and sensitivity to stress. Thus, rocky shore macroalgae are widely considered to be good ecological indicators for evaluation, monitoring and impact assessment studies [9]. In Portugal, a comprehensive methodology, known as the Marine Macroalgae Assessment Tool (MarMAT), has been developed to evaluate the ecological quality of coastal areas. MarMAT fulfils the WFD requirements for abundance and taxonomic composition, since the metrics are based on selected attributes of macroalgae, specific composition, diversity between Chlorophyta, Rhodophyta and Phaeophyceae (green, red and brown seaweeds, respectively) and biomass or percentage of some taxa, allowing these communities to be characterized. MarMAT focuses on the seaweed's communities within the rocky intertidal zone, providing a systematic approach to assess and classify the environmental health of these ecosystems. The assessment involves distinguishing between two Ecological Status Groups (ESG): perennial or late-successional species (ESG I) and annual or opportunistic species (ESG II).

To gauge the impact of human activities on ecosystems, the methodology identifies and quantifies pressures, leading to the calculation of an Ecological Quality Ratio (EQR). This ratio forms the basis for determining the Ecological Quality Status (EQS), which is classified into qualitative categories such as "Excellent," "Good," "Fair," "Poor," and "Bad". Each classification reflects the deviation from characteristic values expected in the absence of anthropogenic disturbances.

This method, endorsed by the Portuguese Environment Agency, is the recommended approach for evaluating the biological quality element of rocky substrate macroalgae in coastal waters, aligning with the requirements of the WFD [10].

This paper outlines the application of the MarMAT methodology on the rocky coast of Abalo Beach, situated on the Peniche Peninsula in Portugal. The surveys

625431_1_En_1_Chapter ☑ TYPESET ☐ DISK ☐ LE ☑ CP Disp.:9/5/2025 Pages: 12 Layout: T1-Standard

occurred within the context of field trips conducted as part of the Marine Botany course, an integral component of the Bachelor's degree program in Marine Biology, during the years 2022 and 2023. The primary objective of these field trips was to evaluate the ecological quality of the rocky platform at Abalo Beach and subsequently draw comparisons with data collected in 2012 and in 2009 for the identical area.

1.2 Methods

1.2.1 Location

Abalo Beach (39° 22′ 14.113″ N; 9° 23′ 6.222″ W) stands as a unique beach nestled into the cliffs of the Peniche Peninsula (Fig. 1.1). Located along the western coast of Portugal, on the North-East Atlantic (NEA) region, typology NEA 1 (WFD, 2000/60/EC), it is formally classified type A5 in the national categorization, denoting an exposed coast, Abalo Beach experiences semidiurnal tides, featuring a spring tidal range of 3.8 m. This coastal environment is marked by high-energy hydrodynamics, making it susceptible to storms from the North Atlantic, particularly during the period from October to March. The dominant wave direction is from the West and Northwest, occasionally influenced by southwestern occurrences [11].

The water temperature experiences a seasonal variation, ranging between 15 and 18 °C in summer, with a potential drop to as low as 12 °C in winter. The air temperature

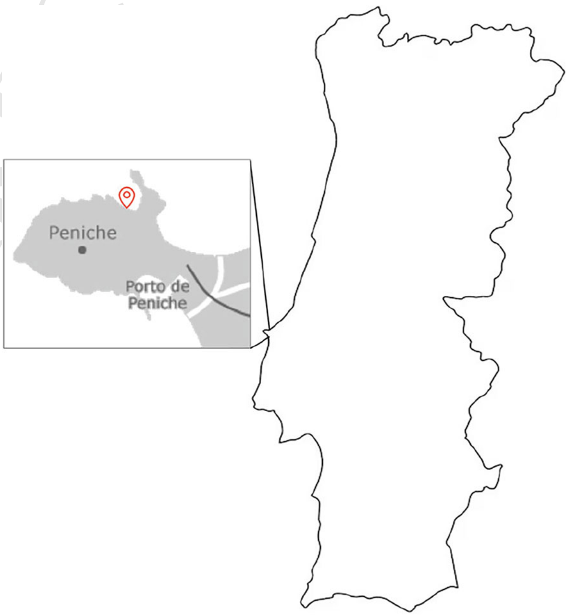

Fig. 1.1 Peniche Península and Abalo Beach

remains moderate, not exceeding 25 °C, and the winds prevail from north-northwest [1, 12].

1.2.2 Surveys and Seaweeds Identification

In May of both 2022 and 2023 (on the 16th and 8th, respectively), surveys were conducted during low tide. The coast was described by filling in the details in a specific classification table. The evaluation of macroalgal species richness involved traversing a randomly chosen path across the rocky ground and tide pools, spanning from the lowest tide level to the highest intertidal level. All identified species along this route were meticulously photographed, harvested, and placed into appropriately labeled plastic bags. The assessment of opportunist coverage required the random collection of four samples, each measuring 20 × 20 cm, from distinct rock surfaces (higher infralittoral, lower mediolittoral, higher mediolittoral, lower supralittoral). The rocks were carefully scraped with a chisel, and all gathered seaweeds were then stored in labeled plastic bags. The bags were promptly transported to the laboratory, where the biomass underwent freezing at −20 °C until the identification process.

Subsequently, in the following week, the biomass was meticulously identified to the species level, apart from filamentous brown and red seaweeds, which were classified only to the family level, as required. The examination of smaller algae was carried out in the laboratory using a Stereo Microscope (LaStemi305, Zeiss, Germany) and a Light Microscope (Primostar1, Zeiss, Germany).

1.2.3 Ecological Assessment

The data on taxonomic composition (presence/absence of species) recorded at the site is compared with a Reduced List of Indicator Taxa (RTL), specific to Portuguese coast, created based on the macroalgae species present under different levels of pressure, outlined by Neto et al. [8] and Gaspar et al. [13].

All MarMAT metrics except the "Proportion of Opportunistic species" are calculated based on this RTL. Taxa that are not assigned in the RTL are not included in the calculations [8]. The following indicators were applied:

$$\text{Specific richness} = \text{total number of indicator species recorded} \qquad (1.1)$$

$$\text{Proportion of green species (Chlorophyta)} = \frac{\text{no. of green species}}{\text{total no. indicator species recorded}} \qquad (1.2)$$

625431_1_En_1_Chapter ✓ TYPESET ☐ DISK ☐ LE ✓ CP Disp.:9/5/2025 Pages: 12 Layout: T1-Standard

$$\text{Number of red species(Rhodophyta)} = \text{total number of red indicator species} \quad (1.3)$$

$$\text{Ratio of opportunistic species} = \frac{\text{no. of pportunistic species}}{\text{no. perennial or late} - \text{successional species(ESG I)}} \quad (1.4)$$

$$\text{Proportion of opportunistic species} = \frac{\text{no. opportunistic species}}{\text{total no. indicator species recorded}} \quad (1.5)$$

$$\text{Coverage of opportunistic species} = \frac{\%\text{area covered by opportunistic species}}{\%\text{area covered by the total algal flora}} \quad (1.6)$$

$$\text{Description of the coast (scores retrieved from Table 2)} \quad (1.7)$$

According to Neto et al. [8] each indicator is assigned five value ranges, each of which corresponds to an ecological status with a different value, as shown in Table 1.1. Ultimately, the sum of the values obtained will be converted into Ecological Quality Status (EQS).

Table 1.1 Scores assigned to the different MarMAT Index metrics and the conversion of EQR values into ecological quality status (EQS)

Metrics	Bad	Poor	Moderate	Good	High
Species Richness*	0–6	7–13	14–20	21–27	>28
Proportion of Chlorophyta	0.32–1	0.27–0.31	0.21–0.26	0.15–0.20	0–0.14
Number of Rhodophyta	0–3	4–8	9–12	13–17	18–33
Number of opportunists/ESG I	≥1.23	1.01–1.22	0.80–1.00	0.58–0.79	<0.58
Proportion of opportunists	0.59–1	0.47–0.58	0.35–0.46	0.23–0.34	0–0.22
Coverage of opportunists (%)*	72–100	59–71	4–58	33–45	0–32
Shore Description	–	15–18	12–14	8–11	1–7
Corresponding score to metrics class	**0**	**1**	**2**	**3**	**4**
Sum of scores	0–7	8–14	15–21	22–28	29–36
EQR	0–0.20	0.21–0.40	0.41–0.60	0.61–0.80	0.81–1
EQS	Bad	Poor	Moderate	Good	High

Metrics with an asterisk (*) are counted twice in the sum of scores calculation.

1.3 Results and Discussion

The assessment of biodiversity and species distribution is crucial for comprehending the impact of environmental changes on communities and ecosystems, as well as predicting future transformations. Biological proxies have gained traction as indicators of biodiversity patterns, especially in marine systems where species identification can be complex and field studies are resource-intensive [14]. The MARMAT index, a tool facilitating a swift assessment of ecological status using a limited set of taxa, proves particularly useful in this context.

Abalo Beach, characterized by a sandy expanse only revealed during low tide, boasts a distinctive coastal landscape defined by a vast rocky platform, marked by large cravices and small tide pools. Due to challenging accessibility, the beach primarily attracts occasional fishermen, minimizing direct human impact and thus contributing to the preservation of its biodiversity. Table 1.2 provides detailed information on Abalo Beach, including tidal heights, low tide times, and various shore descriptors. The MarMAT equivalent score of 3 emphasizes the shore description score based on this information.

In 2022, Abalo Beach recorded 55 taxa, with distinctive distribution among green, brown and red seaweeds, respectively: Chlorophyta (8 taxa), Phaeophyceae (12 taxa), and Rhodophyta (35 taxa). A similar trend persisted in 2023, with a slight decline in late-successional species: Chlorophyta (7 taxa), Phaeophyceae (12 taxa), and Rhodophyta (29 taxa). Notably, the distribution of these seaweed groups reflects established patterns, with the richness of brown macroalgae being higher in colder waters, while red macroalgae exhibit larger richness in temperate to tropical waters [2].

Figure 1.2 illustrates the percentage of ESGI and ESGII seaweeds for Abalo Beach in 2022 and 2023. The data reveal a decrease in late-successional species from 19 to

Table 1.2 Shore description, according to sampling form of the MarMAT metric

General information	
Shore name: Abalo Beach	Date: 2022–05–16 and 2023–05–08 Tidal height: 0.4 m and 0.7 m Time of low tide: 09 h 25 m and 11 h 05 m
Shore description	
Sand scour = Yes = 0	Non-anthropogenic turbidity = Yes = 0
Dominant shore type Rock ridges/outcrops/platforms = 4	Sub habitats Large crevices = 3
	Basic rockpools
	Other habitats (boulders)
	Total number of sub-habitats = 3
Sum of scores = 10	
Shore description: MarMAT equivalent score = 3	

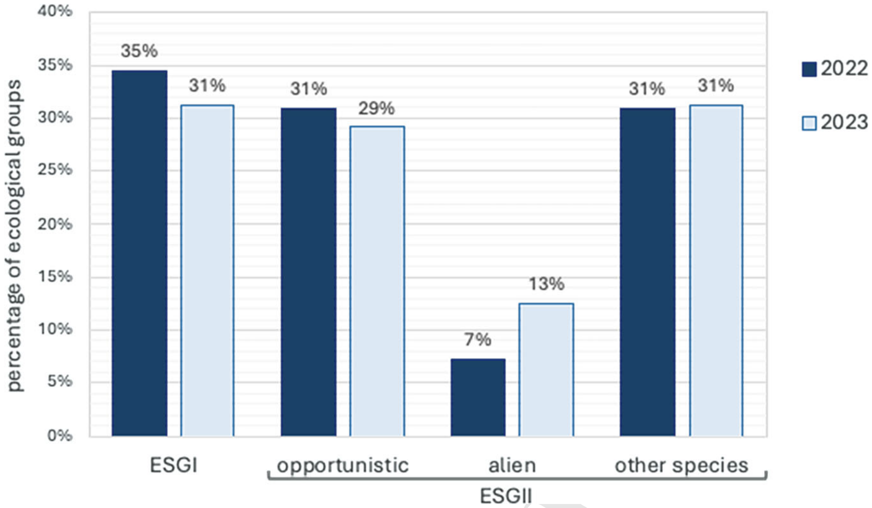

Fig. 1.2 Percentage of ESGI and ESGII seaweeds for Abalo Beach in 2022 and 2023

15 species, albeit still higher than the 9 species recorded in 2011 [15], emphasizing the shift towards the increase in annual species. This decrease brings the number of ESGI species closer to the number of opportunistic species.

The concerning rise in invasive (alien) species, from one in 2012 (*Asparagopsis armata*), to four species in 2022 (*Colpomenia peregrina, Sargassum muticum, Symphyocladia marchantioides*) to six species in 2023 (*Codium fragile*, *Rugolopterix okamurae*), highlights the potential threat to ecosystem integrity, as the introduction of invasive species is generally irreversible and have a major negative impact on ecosystems (Fig. 1.3). Invasions can lead to a complete cover of substrata, modifying environmental conditions and the function of ecosystems, as well as the community structure, causing biotic homogenization. Invasions are, thus, a major contributor to species threat and extinction, strongly affecting native biodiversity and causing the impoverishment of the ecosystems [5, 16, 17]. All the recorded species (except for S. *marchantoides)* have been recognized as aggressive invaders with great ecological impact in Europe [18, 19].

Table 1.3 provides a comparative analysis of MarMAT metrics for Abalo Beach in 2022 and 2023, alongside data from Peniche in 2009 published by Neto et al. [8], and Portinho da Areia Norte Beach in 2012 published by Lima et al. [15]. It is important to note that the species richness recorded in the table represents a condensed list rather than the absolute numbers found during the field trip, as previously discussed.

Despite minor fluctuations, Abalo Beach consistently exhibits high species richness and Rhodophyte numbers, aligning with the observations of Lima et al. [15] and Neto et al. [8].

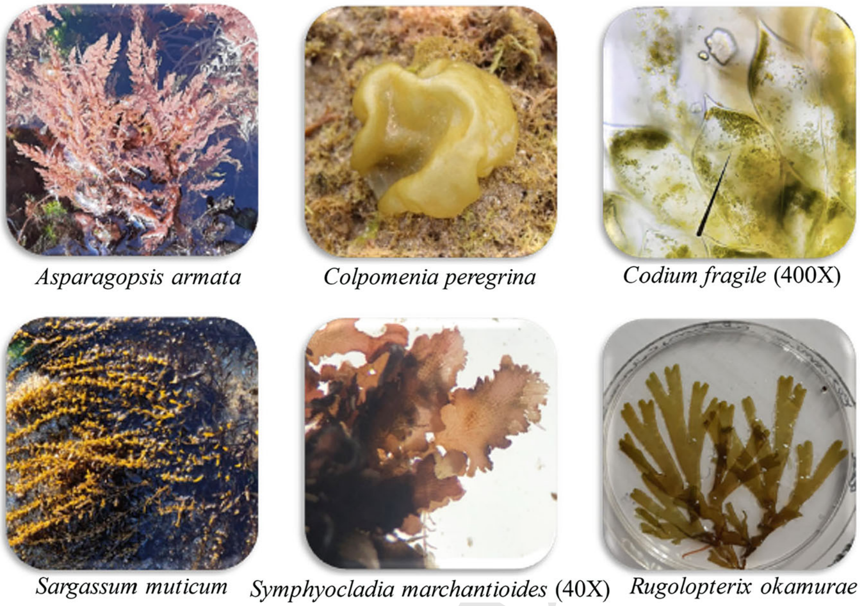

Fig. 1.3 Invasive species present in Abalo Beach in 2023

Lima et al. [15] reported lower values for Chlorophytes, opportunist taxa, and late-successional perennial species, whereas our recent data closely resemble the 2009 findings, confirming the sustained high quality of the study area since 2009.

In favorable environmental conditions, the dominance of green algae species is typically limited, with their biomass relatively low. However, environmental degradation prompts a shift, allowing opportunistic green species to thrive, ultimately dictating the decline of other species, and altering the species richness dynamics. In our study the number of green seaweeds in Abalo Beach has not increased since 2009, denoting the current good environmental quality. Brown algae species decrease in the presence of warmer waters, indicative of declining environmental quality. As the dominant group, the number of red species is expected to decrease with increasing disturbances, affecting overall diversity and species richness [13]. Again, the number of brown and red seaweeds has not decreased significantly since 2009.

However, anticipating the successive warming of ocean waters, a northward shift of temperate and warm-water species is expected, coinciding with a decline in cold-water species. Additionally, as is being occurring in other seashore lines, as organic pollution increases, the proportion of green species is projected to increase in worsening environmental conditions, given their opportunistic nature, while late-successional brown and red species are likely to decline [14].

Table 1.3 Summary of the data used in the calculation of the MarMAT index, with the respective score (EQR) and classification (EQS) for Abalo Beach in 2023 (Ab23), in 2022 (Ab22), for Portinho da Areia Norte in 2012 (PAN12) and for Peniche in 2009 (Pen09)

	Ab23	Ab22	PAN12[1]	Pen09[2]
Species Richness	33	34	27	36
Number of Chlorophyta	5	5	3	6
Number of Rhodophyta	18	19	17	20
Number of opportunists	6	6	3	7
Number of ESG1 taxa	9	11	5	12
Number of ESG2 taxa	24	23	20	24
Proportion of Chlorophyta	0.15	0.15	0.11	0.17
Proportion of Rhodophyta	0.55	0.56	0.63	0.56
Proportion of opportunists	0.18	0.18	0.11	0.19
Number of opportunistic/ESGI	0.67	0.55	0.60	0.58
Coverage of opportunists	39.30%	46.80%	45.20%	26.00%
Shore description score	10	10	10	-
MarMAT scores				
Species Richness *	4 (8)	4 (8)	3 (6)	4 (8)
Proportion of Chlorophyta	3	3	4	3
Number of Rhodophyta	4	4	4	4
Number of opportunists/ESG I	3	3	3	3
Proportion of opportunists	4	4	4	4
Coverage of the opportunists (%)*	3 (6)	2 (4)	3 (6)	4 (8)
Shore Description	3	3	3	2
Sum of the scores	31	29	30	32
EQR	**0.86**	**0.81**	**0.83**	**0.89**
EQS	**High**	**High**	**High**	**High**

Metrics with an asterisk (*) were counted twice in the sum of scores calculation
[1]Data from Lima et al. [15]
[2]Data from Neto et al. [8]

1.4 Conclusions

Environmental conditions play a pivotal role in seaweed distribution, with opportunistic green species dominating in degraded conditions. The proportional increase in opportunistic species, decrease in late succession perennial species, highlight the relationship between environmental quality and seaweed diversity. The major concern detected between 2009 and 2023 is the increasing number of alien species. The invasiveness character of these species may endanger the native species, decreasing their biodiversity in time. The comparative analysis of MARMAT scores, EQR, and EQS indicates that Abalo Beach maintains a remarkably high ecological quality over the years, further emphasizing its significance as a valuable study area. The collected data contribute with valuable insights into the dynamics of marine ecosystems, boosting informed conservation and management strategies.

Acknowledgements This work was funded by national funds through FCT—Fundação para a Ciência e a Tecnologia for I.P., within the scope of the project UID/04292/MARE—Centro de Ciências do Mar e do Ambiente and the project LA/P/0069/2020, granted to the Associate Laboratory ARNET.

References

1. Gaspar, R., Pereira, L., Sousa-Pinto, I.: The seaweed resources of Portugal. Bot. Mar. **62**, 499–525 (2019)
2. Lüning, K.: Seaweeds: Their Environment, Biogeography and Ecophysiology. Wiley-InterScience Publication, New York (1990)
3. Franco, J.N., Tuya, F., Bertocci, I., Rodríguez, L., Brezo Martínez, I., Sousa-Pinto, I., Arenas, F.: The 'golden kelp' Laminaria ochroleuca under global change: Integrating multiple eco-physiological responses with species distribution models. J. Ecol. **106**, 47–58 (2018)
4. Teichberg, M., Fox, S.E., Olsen, Y.S., Valiela, I., Martinetto, P., Iribarne, O., Muto, E.Y., Petti, M.A.V., Corbisier, T.N., Soto-Jiménez, M., Páez-Osuna, F., Castro, P., Freitas, H., Zitelli, A., Cardinaletti, M., Tagliapietra, D.: Eutrophication and macroalgal blooms in temperate and tropical coastal waters: nutrient enrichment experiments with Ulva spp. Glob. Chang. Biol. **16**, 2624–2637 (2010)
5. Blanco, A., Larrinaga, A.R., Neto, J.M., Troncoso, J., Méndez, G., Domínguez-Lapido, P., Ovejero, A., Pereira, L., Mouga, T.M., Gaspar, R., Martínez, B., Lemos, M.F.L., Olabarria, C.: Spotting intruders: species distribution models for managing invasive intertidal macroalgae. J. Environ. Manage. **281**, 111861 (2021)
6. Arenas, F., Sanchez, I., Hawkins, S.J., Jenkins, S.R.: The invasibility of marine algal assemblages: role of functional diversity and identity. Ecology **87**, 2851–2861 (2006)
7. Vaz-Pinto, F., Rodil, I., Mineur, F., Olabarria, C., Arenas, F.: Understanding biological invasions by seaweeds. In: Pereira, L., Neto, J.M. (eds.) Marine Algae: Biodiversity, Taxonomy, Environmental Assessment and Biotechnology, pp. 140–177. CRC Press, Boca Raton (2014)
8. Neto, J.M., Gaspar, R., Pereira, L., Marques, J.C.: Marine macroalgae assessment tool (MarMAT) for intertidal rocky shores. Quality assessment under the scope of the European Water Framework Directive. Ecol. Indic. **19**, 39–47 (2012)
9. D'Archino, R., Piazzi, L.: Macroalgal assemblages as indicators of the ecological status of marine coastal systems: a review. Ecol. Indic. **129**, 107835 (2021)
10. Agência Portuguesa do Ambiente: Critérios para a Classificação das Massas de Água, https://apambiente.pt/sites/default/files/_Agua/DRH/ParticipacaoPublica/PGRH/2022-2027/3_Fase/PGRH_3_SistemasClassificacao.pdf. Accessed 25 April 2024
11. Bettencourt, A., Bricker, S.B., Ferreira, J.G., Franco, A., Marques, J.C., Melo, J.J., Nobre, A., Ramos, L., Reis, C.S., Salas, F., Silva, M.C., Simas, T., Wolff, W.: Typology and Reference Conditions for Portuguese Transitional and Coastal Waters. Institute of Marine Research, Lisbon (2004)
12. Agência Portuguesa do Ambiente: Perfil de Água Balnear de Medão-Supertubos, https://apambiente.pt/sites/default/files/_SNIAMB_A_APA/Comunicacao/Epoca_balnear/PerfisAB/ARH_TejoOeste/PerfisAguasBalneares/PENICHE/MedaoSupertubos_PTCF2K.pdf. Accessed 25 April 2024

13. Gaspar, R., Pereira, L., Neto, J.M.: Ecological reference conditions and quality states of marine macroalgae sensu water framework directive: an example from the intertidal rocky shores of the Portuguese coastal waters. Ecol. Indic. **19**, 24–38 (2012)
14. Gaspar, R., Neto. J., Pereira, L.: Searching for ecological reference conditions of marine macroalgae. In: Pereira, L. Neto, J.M. (eds.) Marine Algae—Biodiversity, Taxonomy, Environmental Assessment, and Biotechnology. CRC Press, Boca Raton (2012)
15. Lima, A.L., Gaspar, R., Neto, J.M., Pereira, L.: The identification of macroalgae and the assessment of intertidal rocky shores' ecological statuses in the central western coast of continental Portugal. In: Newton, P. (ed.) Seaweeds: Biodiversity, Environmental Chemistry and Ecological Impacts, pp. 19–84. Nova Science Publishers Inc., New York (2017)
16. Piazzi, L., Balata, D.: Invasion of alien macroalgae in different Mediterranean habitats. Biol. Invasions **11**, 193–204 (2009)
17. Mineur, F., Arenas, F., Assis, J., Davies, A.J., Engelen, A.H., Fernandes, F., Malta, E., Thibaut, T., Van Nguyen, T., Vaz-Pinto, F., Vranken, S., Serrão, E.A., De Clerck, O.: European seaweeds under pressure: consequences for communities and ecosystem functioning. J. Sea Res. **98**, 91–108 (2015)
18. Carlos García-Gómez, J., Sempere-Valverde, J., Roi González, A., Martínez-Chacón, M., Olaya-Ponzone, L., Sánchez-Moyano, E., Ostalé-Valriberas, E., Megina, C.: From exotic to invasive in record time: the extreme impact of Rugulopteryx okamurae (Dictyotales, Ochrophyta) in the strait of Gibraltar
19. Blanco, A., Lemos, M.F.L., Pereira, L., Gaspar, R., Mouga, T., Neto, J.M., Troncoso, J.S., Olabarria, C.: Mapping Invasive Macroalgae in the Western Iberian Peninsula: A Methodological Guide. Servizo de publicacións da Universidade de Vigo, Vigo (2020)