FIRST CONSIDERATIONS ON ENVIRONMENTAL FRIENDLY SOLUTIONS TO PROTECT THE SOUTHERN ROMANIAN COAST

Albert **MONCLÚS i BORI**[1], Irina **DINU**[2], Manuel **GARCÍA-LEÓN**[3], Jue **LIN-YE**[3], Vicente **GRÀCIA**[4], Adrian **STĂNICĂ**[2]

[1]Department of Civil and Environmental Engineering, Polytechnic University of Catalonia (DECA-UPC),
Campus Diagonal Nord, Building C2, 1-3 Jordi Girona St., 08034 Barcelona, Spain
[2]National Institute of Marine Geology and Geo-Ecology (GeoEcoMar), 23-25 Dimitrie Onciul St., 024053 Bucharest, Romania
e-mail: irinadinu@geoecomar.ro
[3]International Centre for Research of Coastal Resources (CIIRC), 1-3 Jordi Girona St., Mòdul D1, Campus Nord, 08003 Barcelona, Spain
[4]Laboratory of Maritime Engineering, Polytechnic University of Catalonia (LIM-UPC),
Campus Diagonal Nord, Building D1, 1-3 Jordi Girona St., 08034 Barcelona

---

Abstract. The aim of this work is to assess the effect of a nature-based solution for reducing wave heights on the Southern Romanian coast. Apart from investigating the presence of seagrass from the environmental point of view, there is also a need to assess its impact on the coastal hydrodynamics. The impact on the wave heights of a seagrass meadow located on the Southern Romanian coast, has been analyzed by means of a wave model. In this purpose, several numerical simulations have been performed, both for low and average offshore wave conditions, available from a previous wave climate study, which used a 30 years climate data set. A first set of simulations have been performed in the absence of seagrass. Then a seagrass meadow has been added to our grid and the wave model has been run in the same offshore wave conditions. The differences in computed nearshore wave heights reach around 4% for moderate energy waves. These results show that, on the Southern Romanian coast, seagrass could be regarded as an additional measure for nearshore wave attenuation.

Key words: Southern Romanian coast, seagrass, Zostera noltei, numerical model, simulation, wave height, attenuation

---

1. INTRODUCTION

Many of the coastal defense structures, such as groynes, seawalls and detached breakwaters, along the Southern Romanian coast are in poor condition, as they are approaching or have already exceeded their lifetime. For this reason, in many places, the effectiveness of the coastal structures for controlling beach erosion and protecting the coast is significantly reduced. Therefore, the need for major capital works to improve or replace the damaged structures becomes critical (Halcrow UK *et al.*, 2011-2012).

New approaches concerning green solutions for coastal protection have been developed in recent years, to be more sustainable with the climate change scenarios. Apart from the existing hard structures, green measures are also taken into account for coastal protection against the increasing intensity of storms, where appropriate (Borsje et al, 2011; Narayan *et al.*, 2016; Pontee *et al.*, 2016).

In recent years, around the world, there is interest in seagrass as a green measure (Ondiviela *et al.*, 2014; Sierra *et al.*, 2017), mostly as it is considered as an appropriate habitat for some species. It is also considered as an indicator of the quality of the marine environment (Marin *et al.*, 2013). Nevertheless, the efficiency of wave height reduction in the case of a green solution, based on numerical modelling, has not been assessed for the Romanian coast so far.

Available information on the Southern Romanian coast mentions the presence of seagrass in the area of Mangalia city (Marin *et al.*, 2013; Niță *et al.*, 2014). Our study focuses on a specific area on the Southern Romanian coast, located north of Mangalia city, between the Venus and Saturn resorts. This area has been chosen as there are no coastal structures.

The main purpose of this study is to analyze the impact of a seagrass meadow on the wave heights, by means of a wave model. The wave model was first run in the absence of a seagrass meadow, for low and average wave conditions. Then we added a seagrass meadow and ran the model again, for the same wave conditions. Finally, the results were compared in order to assess the efficiency of the seagrass meadow on wave attenuation. Differences in wave heights reach around 4% for moderate energy waves. This suggests that, even if specific vegetation is considered an indicator of a good quality of the marine environment, in what concerns wave attenuation it could be seen only as an additional measure.

2. METHODOLOGY

2.1. Specific vegetation

Zostera noltei (Dwarf Eelgrass) is a widely studied seagrass catalogued by the IUCN Red List as a Least Concern in the Threatened Species scale. All the specifications of the seagrass can be found in Short *et al.*, 2010, as well as a distribution map, showing that this species is present on most of the Western Europe coasts, on the western half of the Mediterranean, and on the whole Black Sea and Caspian Sea coasts.

Our main interest is to assess the effect of a Zostera noltei meadow on the waves on a specific area of the Southern Romanian coast. There are studies about the transplantation of the Zostera noltei as its population is considered in decrease in the Black, Caspian and Aral Seas (Short *et al.*, 2010; Marin *et al.*, 2013).

Our study relies on the work of Niță *et al.*, 2014, who discuss the possibility for transplantation of these species in the coastal area close to Mangalia city, in order to regenerate the specific submerged vegetation along the Romanian coast. Moreover, in this scientific publication, creation of "nurseries" is discussed, in order to grow this specimen in controlled ecosystems to later transplant them on desired locations.

In 1982, Fonseca *et al.*, 1982 published an observational study on the influence of seagrass on current flow, followed by Fonseca and Cahalan, 1992, where various types of seagrass and salt marshes were tested in a wave tank. The damping effect of seagrass has been demonstrated, being comparable to the effect of salt marshes when water depth is scaled to plant size. The same statement can be found in Blackmar *et al.*, 2013 and Christianen *et al.*, 2013. In more recent studies (Manca *et al.*, 2012; Koftis *et al.*, 2013), Posidonia oceanica (or Mediterranean tapeweed), which is a seagrass endemic of the Mediterranean Sea, has been used.

In 1993, Kobayashi *et al.*, 1993 went one step above, analyzing this effect using the continuity and linearized equations and comparing them with experimental tests runs. Möller *et al.*, 1999 introduced the numerical modelling on the damping effect of seagrass, and also suggested the necessity of maintaining or even growing salt marshes as part of coastal set-back or shoreline realignment schemes.

Fig. 1. The Romanian coast with the location of the study area

Möller, 2006 shows that wave attenuation due to vegetation goes up to a threshold value. As a consequence, the damping effect does not keep up for high wave heights values that can occur in some storm events. But this is not really well understood, as stated by Kirwan and Megonigal, 2013; Bouma *et al.*, 2014. There is strong indication of vegetation causing considerable wave attenuation, even when water levels and waves are higher than the average, but these can flatten and break vegetation stems, and thereby reduce dissipation (Möller *et al.*, 2014) so it is not the optimal situation. It is a combined effect of stems bending and breaking progressively, which reduces wave attenuation, but at the same time it still attenuates as the vegetation is lower, but denser.

Ondivela *et al.*, 2014 have searched in submerged vegetation a possible solution to mitigate the future changing climate effects to the coast, concluding that seagrass meadows cannot protect shorelines in every scenario and finding optimal conditions in shallow waters and low wave energy environments. Sierra *et al.*, 2017 have analyzed the efficiency of seagrass meadow to attenuate the impact of Sea Level Rise on breakwater overtopping, through numerical modelling, in two harbours on the Catalan coast. Their results indicate that the presence of seagrass may compensate overtopping increases for moderate values of Sea Level Rise, for a high density of 100 stems/m^2.

2.2. Wave Climate

The Wave Climate data used is from the European Centre for Medium Range Weather Forecasts (ECMWF) reanalysis of 38 years wave data (Onea and Rusu, 2017).

Lin-Ye *et al.*, 2018 produced a hindcast and forecast of this data set, using SWAN (Booij *et al.*, 1999) and a generalized additive model. In this work, the SWAN outputs have been validated against the ERA-interim reanalysis model available for the northwestern Black Sea, for the period 1979 – 2016. This study focused on the northwestern part of the Black Sea, spanning along a part of the Ukrainian coast, the Danube delta coast, and a part of the Romanian coast south of the Danube delta, the southern limit being close to the Eforie resort. The data set used in our study is from the southernmost point available from this work, which is the closest one to the Southern Romanian coast.

The Wave Climate data set is more than a hundred years, due to the reanalysis with hindcast and forecast performed. The data corresponding only to 30 years (1988-2018) have been used in order to derive the average waves to be used as input for our SWAN simulations. This decision has been taken mainly for capacity reasons, but also because the precision of the Wave Climate derived for this period is considered more than enough.

The waves that would not reach the coast have been eliminated from the data set. So the remaining directions are from 11.25 ° to 191.25 °, covering the NNE, NE, ENE, E, ESE, SE, SSE, and S directions. Figure 2 shows the wave roses for the significant wave heights and associated wave periods corresponding to these directions.

The next step to perform is to calculate the H_{morf}, that synthesizes the wave information, in order to represent an average surge, as the extremal scenarios (or storms) are not of our interest.

The H_{morf} is defined as:

$$H_{morf} = \sqrt{\frac{\sum H_i^2 f_i}{\sum f_i}},$$

where i is the number of a registered wave height between certain limits, H_i is the wave height and f_i is its rate of occurrence.

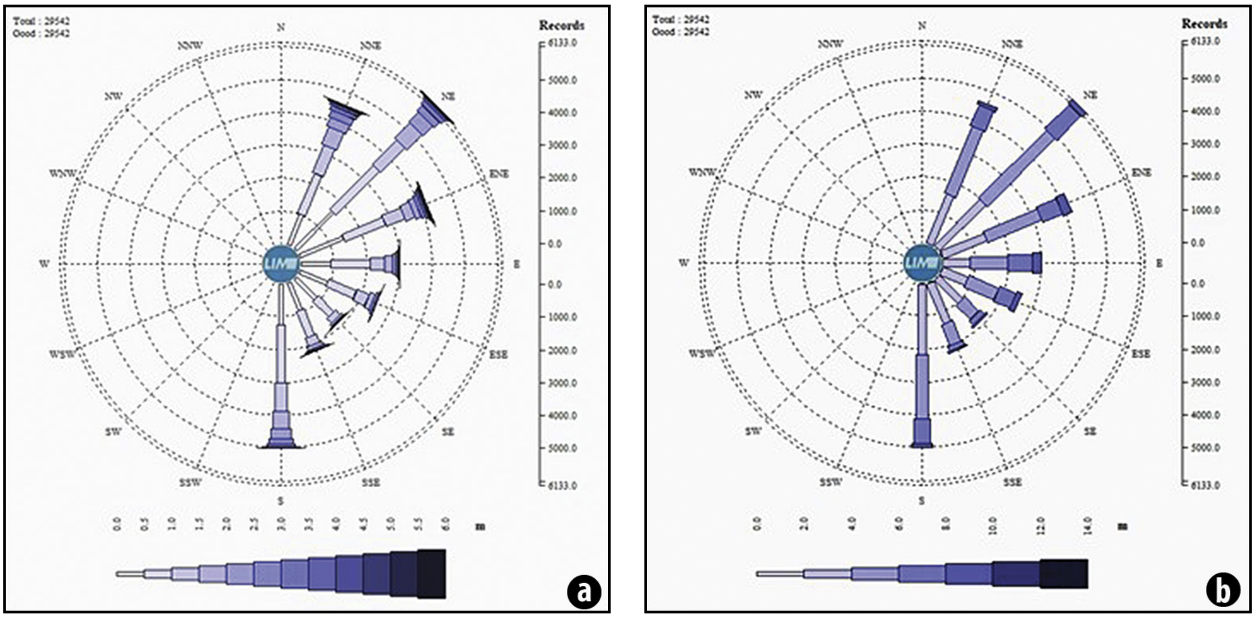


Fig. 2. Wave rose of the significant wave heights (**a**) and wave periods (**b**) for the analyzed directions

Details concerning the calculation of H_{morf} can be found in Monclús i Bori, 2018.

A low and a moderate wave energy spectrum have been selected for our analysis, the one with wave periods between 4 and 6 s (average 5 s), and the one with wave periods between 8 and 10 s (average 9 s). Very low periods and wave heights are not a concern for the coast.

As the intention was to evaluate the feasibility of the submerged vegetation as a green coastal protection measure, three wave directions have been selected for our analysis: NE, E, SSE.

The highest wave height is for NE direction, for the wave period of 9 s. The lowest wave height is for the E direction, for the average wave period of 5 s. The SSE direction is a moderate one, with a high H_{morf} for the average wave period of 5 s, and a low H_{morf} for the average wave period of 9 s. Table 1 summarizes the H_{morf} values for the analyzed directions.

Table 1. H_{morf} for the average wave periods of 5 s and 9 s for the analyzed directions

Wave Direction	H_{morf} (m)	Average Wave Period T (s)
NE	1.15	5
NE	3.43	9
E	0.85	5
E	2.33	9
SSE	1.21	5
SSE	1.63	9

2.3. Bathymetry data and grids

The bathymetry data (Fig. 3) for this study have been collected from electronic navigational charts (www.navionics.com). The bathymetry data used herein goes until 50 m depth, on a 28 km wide alongshore strip.

Nesting was used in order to avoid high computational cost. Therefore, two domains with different extents and resolutions, have been defined. The larger domain is denoted as DOM1, while the smaller one, which includes the seagrass field, is finer and denoted as DOM2 (Fig. 4).

The grids have been generated using the Kriging method. Both domains consist in regular meshes with equal grid spacing in the *x* and *y* directions. The spacing is 80 m in DOM1 and 15 m in DOM2. DOM1 covers 476 km^2 and goes roughly until 50 m deep. DOM2 covers around 49 km^2 and goes roughly until 35 m deep.

2.4. The SWAN model

The SWAN (Simulating WAves Nearshore) model (Booij *et al.*, 1999; The SWAN Team, 2018) is a third generation, phase-averaged, open source numerical model based on the so called "action-balance equation".

The SWAN theory is based on two main concepts:

1. the random-phase/amplitude model, which describes the wave propagation based on statistics obtained through observations and, in our case, observations plus hindcast;
2. the linear wave theory, also called Airy wave theory (Airy, 1841), describing the generation, propagation and dissipation of the waves.

The spectral energy balance equation, which describes the evolution of the energy density spectrum, is the consequence of the combination of these two concepts.

The spectral energy balance models can be extended to shallow water implementing some corrections to account for those phenomena that occur when waves approach the

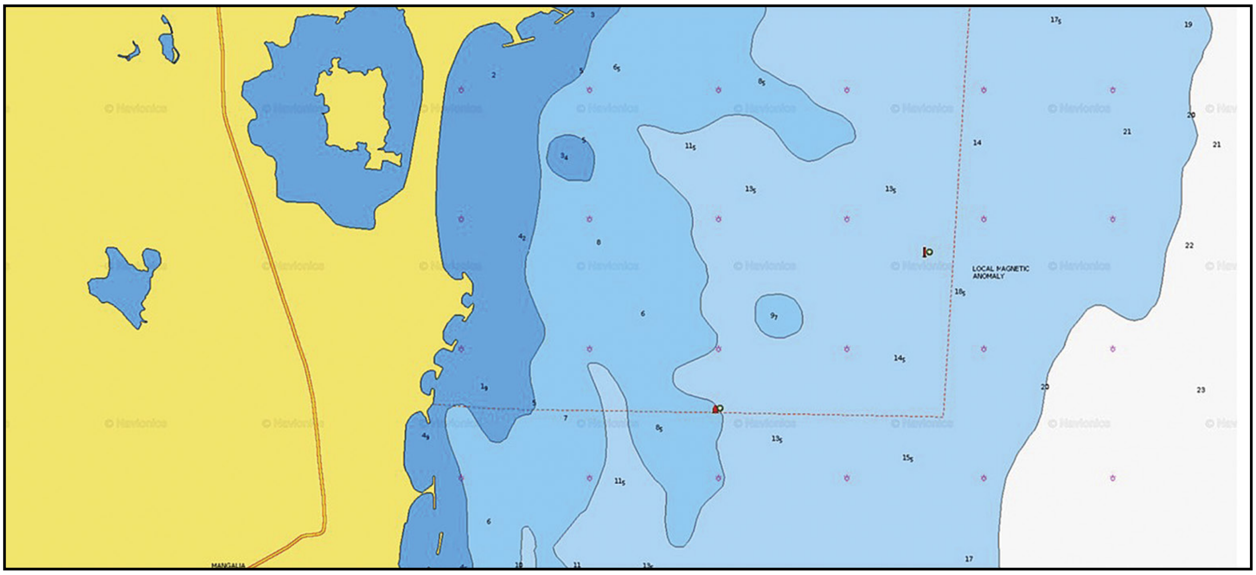


Fig. 3. Bathymetry in the study area (source: www.navionics.com)

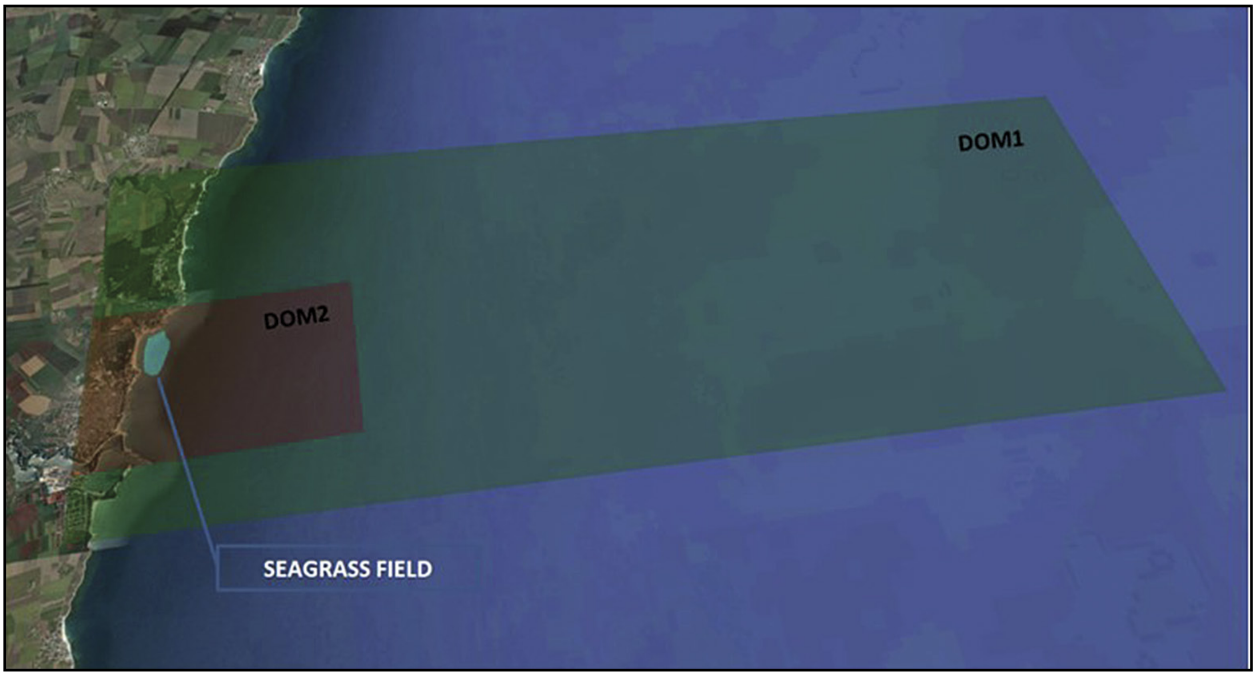


Fig. 4. Representation of the two domains of the nesting

coastline (refraction, shoaling, diffraction), achieving quite good estimations of the significant wave height, period and mean wave direction (Holthuijsen, 2007).

Some references of publications that use SWAN and are related to our study are Blackmar *et al.*, 2013; Suzuki *et al.*, 2012; Sierra *et al.*, 2017; Lin-Ye *et al.*, 2018.

2.5. The Vegetation model

This area, of approximately 1 km^2, has been defined taking into account the Zostera noltei limitations and the bathymetry of the coastal zone between Venus and Saturn (Fig. 5). The vegetation is a limitation due to its minimum and maximum deep where it can live. As stated by Short *et al.*, 2010, the Zostera noltei species range is from 1 to 10 m deep. In a previous study on Zostera noltei species on the Southern Romanian coast, the maximum depth is considered 6 m (Niţă *et al.*, 2014).

In our model the vegetation meadow has been placed starting with 2 m deep, to avoid disturbing swimmers and tourists, and extends up to 6 m deep (Fig. 5).

The plant height and section area values are extracted from Short *et al.*, 2010 and Niţă *et al.*, 2014. Similar studies (Fonseca and Cahalan, 1992; Kobayashi *et al.*, 1993; Koftis *et al.*, 2013; and Castell, 2018) have determined a commonly accepted range of density between 50 and 100 stems/m^2.

In our case the density of 100 stems/m^2 is chosen, as this place is catalogued as very suitable for Zostera noltei to develop (Niţă *et al.*, 2014). However, a higher density value didn't seem reasonable for this location.

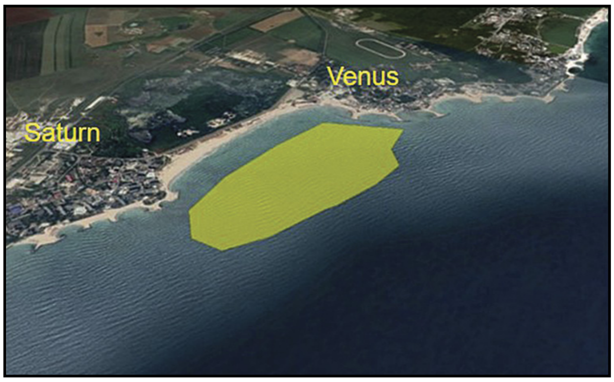


Fig. 5. Position of the vegetation meadow

The stem height was considered 20 cm in all the simulations, corresponding to a good development of this species. According to Surugiu, 2008, Zostera noltei may reach no more than 20 cm.

Finally the drag coefficient has been calculated following Myrhaug and Holmedal, 2011. Its value is 0.095.

2.6. Simulations – actual wave conditions and with vegetation mask

For our analysis, the actual state of the wave propagation from deep waters to shallow waters was first taken into account. Then it was compared to the new state of the wave propagation, with the vegetation meadow. Therefore, a Baseline Scenario and a Vegetation Scenario have been developed for each direction analyzed.

The Baseline Scenarios of wave propagation have been conducted in our first domain (DOM1) with the corresponding boundary conditions. Then, for every analyzed direction, the computed data were stored in points that surround the second domain (DOM2).

The stored data are used as the new boundary conditions both for the Baseline Scenario and the Vegetation Scenario in DOM2.

A total number of 18 simulations have been performed. For every direction and level of energy (*Hmorf* value), a first simulation has been performed on DOM1, then a second simulation in DOM2, and later, a simulation with vegetation mask in DOM2.

Figure 6 illustrates the scenarios and the nesting performed for our analysis.

Finally, for every direction, the results for the Baseline and the Vegetation Scenarios were compared using a MATLAB script. The maximum attenuation was reported as the highest difference between the Baseline and the Vegetation significant heights in all the points of the grid. For the average attenuation, all the points with non-zero difference have been used. The maximum and average attenuation have also been determined as percentages with respect to the Baseline significant height in every point of the grid.

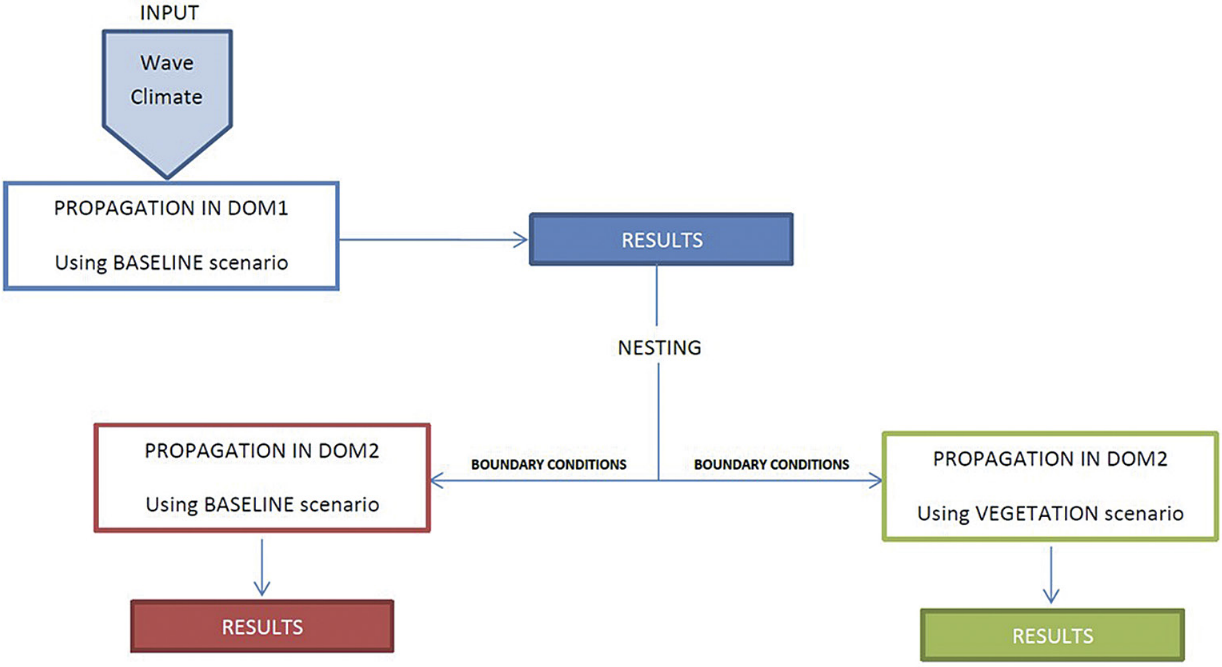


Fig. 6. General outline of the nesting performed in the project.

3. RESULTS AND DISCUSSION

The SWAN output has been plotted using a MATLAB script.

The following figures show the spatial distribution of the wave heights provided by SWAN, in the DOM1 and DOM2 domains, in the absence of the seagrass meadow, as well as the distribution of the wave height difference, for all the wave forcings considered. The horizontal and vertical coordinates, as well as the color scales, are in meters. The bathymetry lines (m) are also reported on the figures.

3.1. NE waves

The results for the NE low energy waves are illustrated in figures 7 and 8. The results for the NE moderate energy waves are illustrated in figures 9 and 10.

3.2. E waves

The results for the E low energy waves are illustrated in figures 11 and 12. The results for the E moderate energy waves are illustrated in figures 13 and 14.

3.3. SSE waves

The results for the SSE low energy waves are illustrated in figures 15 and 16. The results for the SSE moderate energy waves are illustrated in figures 17 and 18.

For all the three directions, one can notice an increase of the wave height difference for the moderate energy waves (Figs. 8 vs. 10, 12 vs 14, 16 vs 18).

Table 2 shows the maximum and average attenuation determined for every direction and level of energy considered in our analysis.

Following their experiments, Koftis *et al.*, 2013 stated that wave attenuation increases with the wave period. This is the

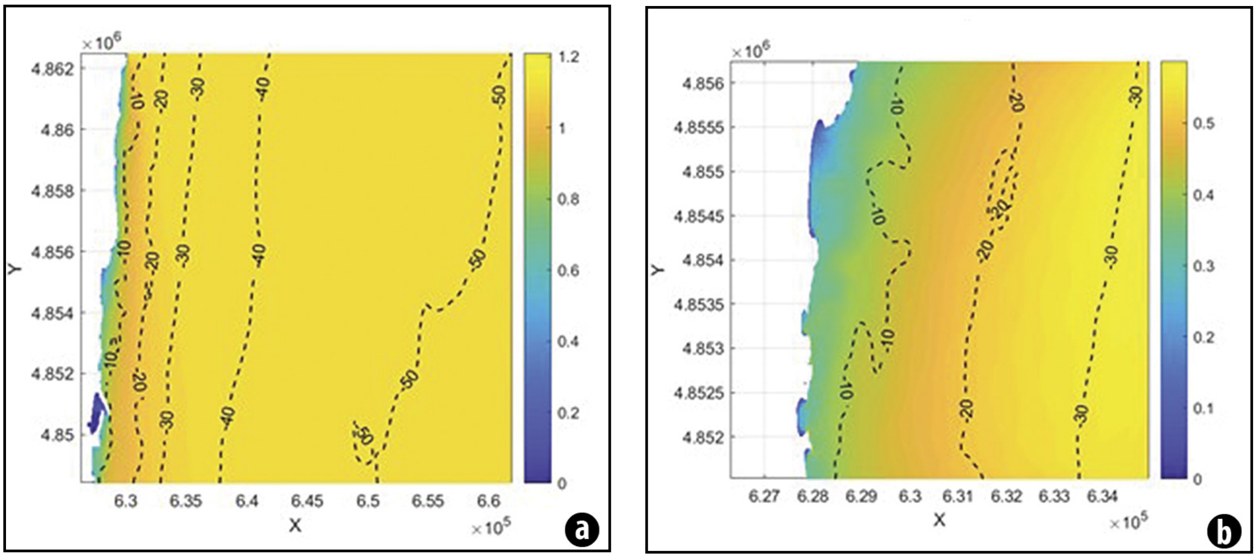
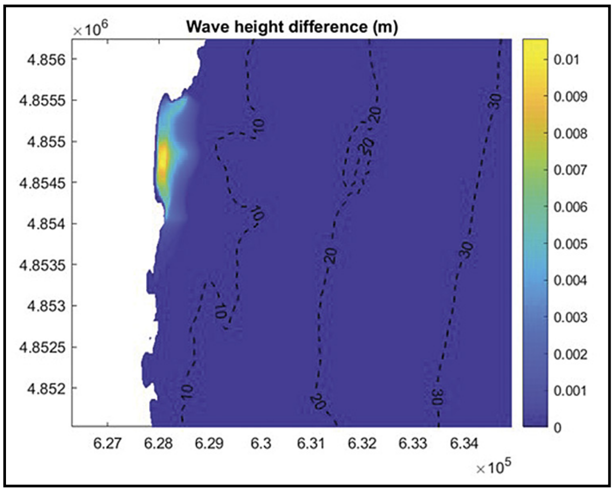


Fig. 7. NE low energy waves ($H_{morf} = 1.15$ m, T = 5 s). Caption of the propagation in DOM1 (**a**) and its nesting in the absence of the seagrass meadow in DOM2 (**b**)



◂ **Fig. 8.** NE low energy waves ($H_{morf} = 1.15$ m, T = 5 s). Comparison between the Baseline and the Vegetation scenarios

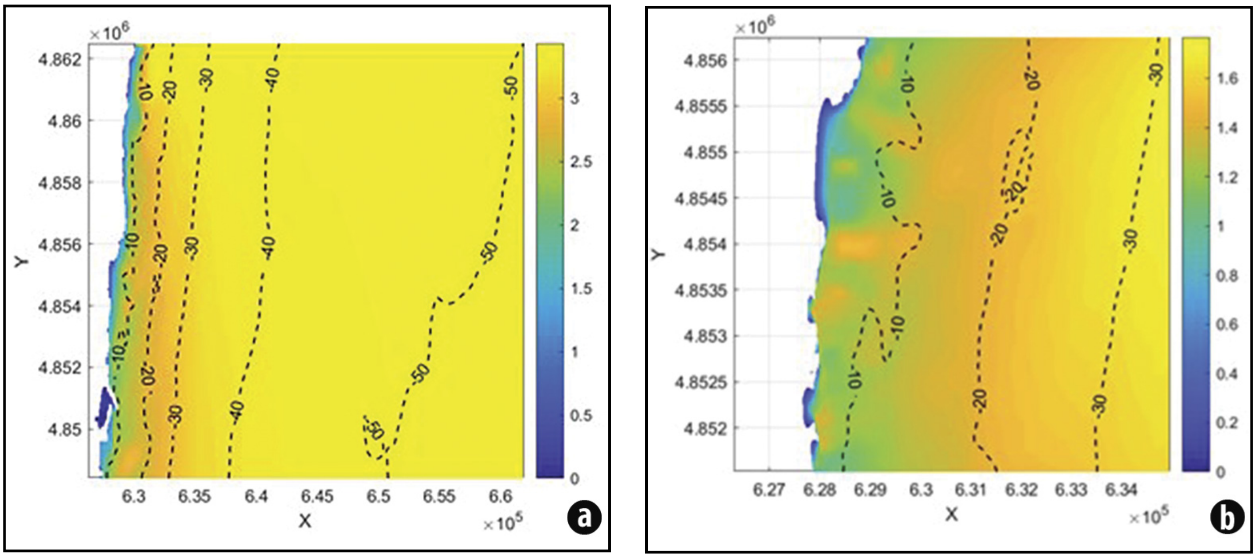


Fig. 9. NE moderate energy waves ($H_{morf} = 3.43$ m, T = 9 s). Caption of the propagation in the DOM1 (**a**) and its nesting in the absence of the seagrass meadow in DOM2 (**b**)

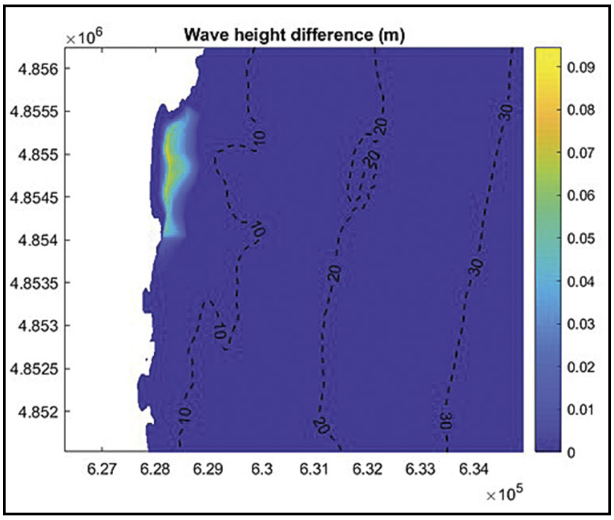


Fig. 10. NE moderate energy waves ($H_{morf} = 3.43$ m, $T = 9$ s). Comparison between the Baseline and the Vegetation scenarios

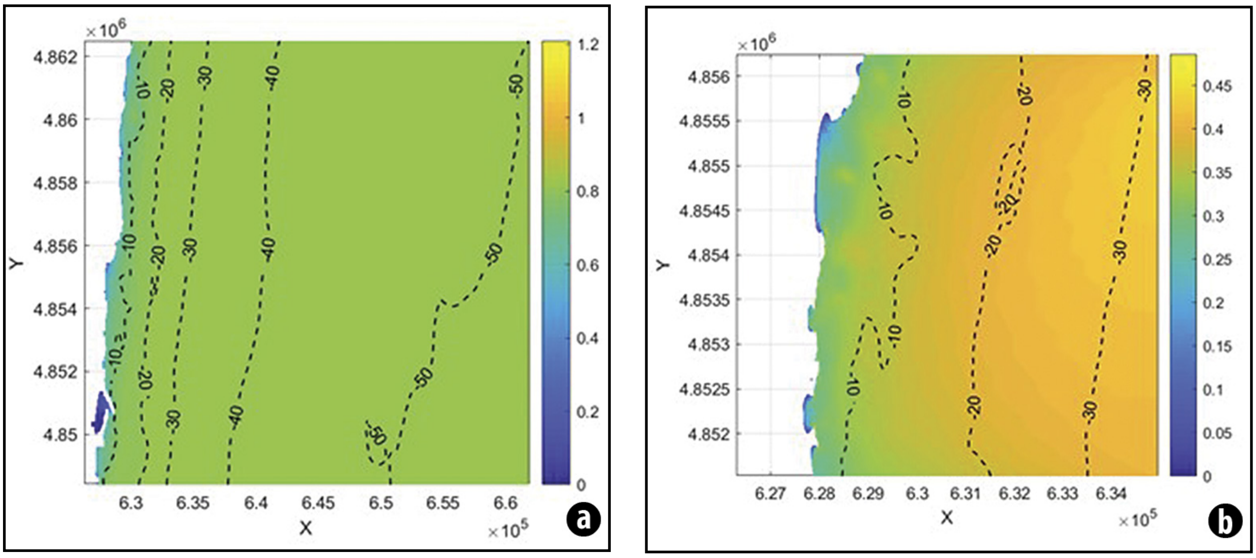


Fig. 11. E low energy waves ($H_{morf} = 0.85$ m, $T = 5$ s). Caption of the propagation in DOM1 (**a**) and its nesting in the absence of the seagrass meadow in DOM2 (**b**)

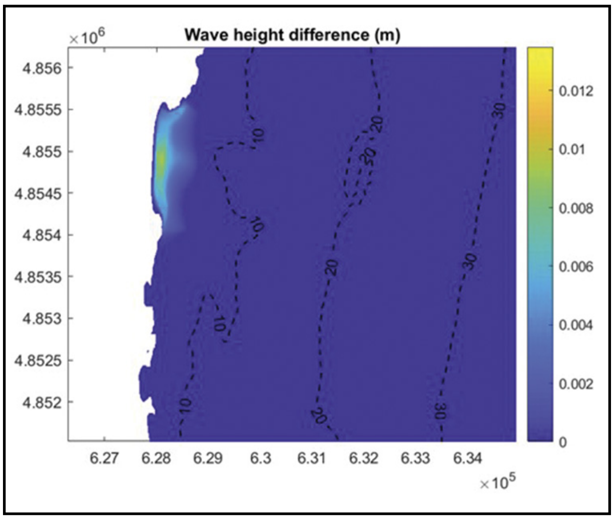


Fig. 12. E low energy waves ($H_{morf} = 0.85$ m, $T = 5$ s). Comparison between the Baseline and the Vegetation scenarios

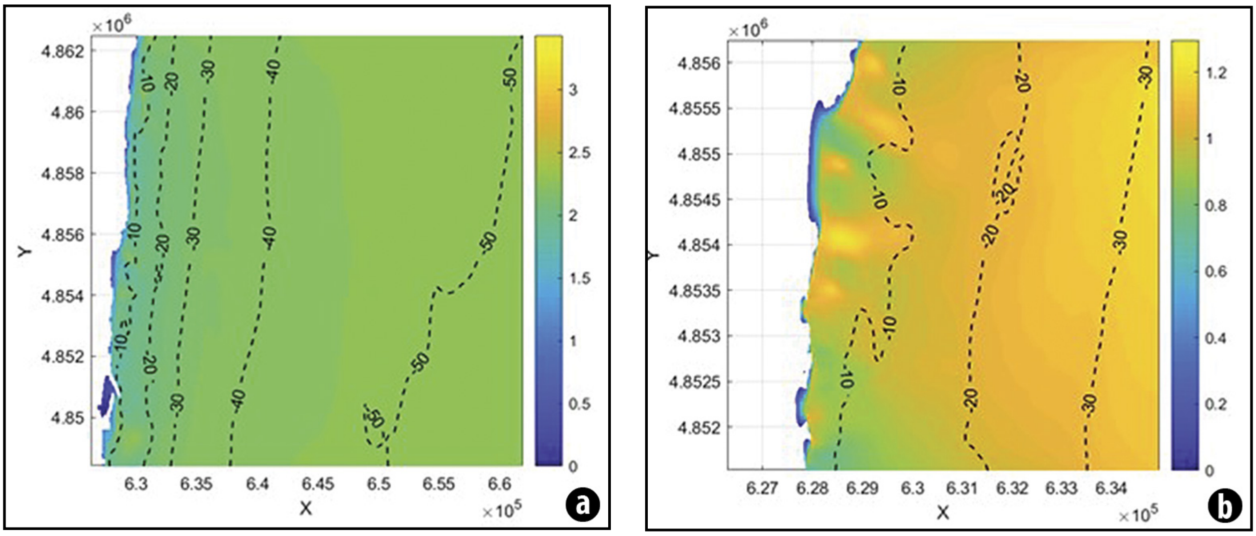


Fig. 13. E moderate energy waves ($H_{morf} = 2.33$ m, T = 9 s). Caption of the propagation in DOM1 (**a**) and its nesting in the absence of the seagrass meadow in DOM2 (**b**)

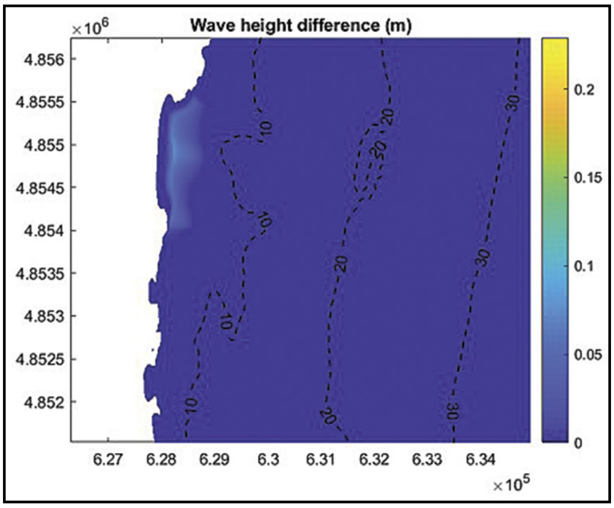


Fig. 14. E moderate energy waves ($H_{morf} = 2.33$ m, T = 9 s). Comparison between the Baseline and the Vegetation scenarios

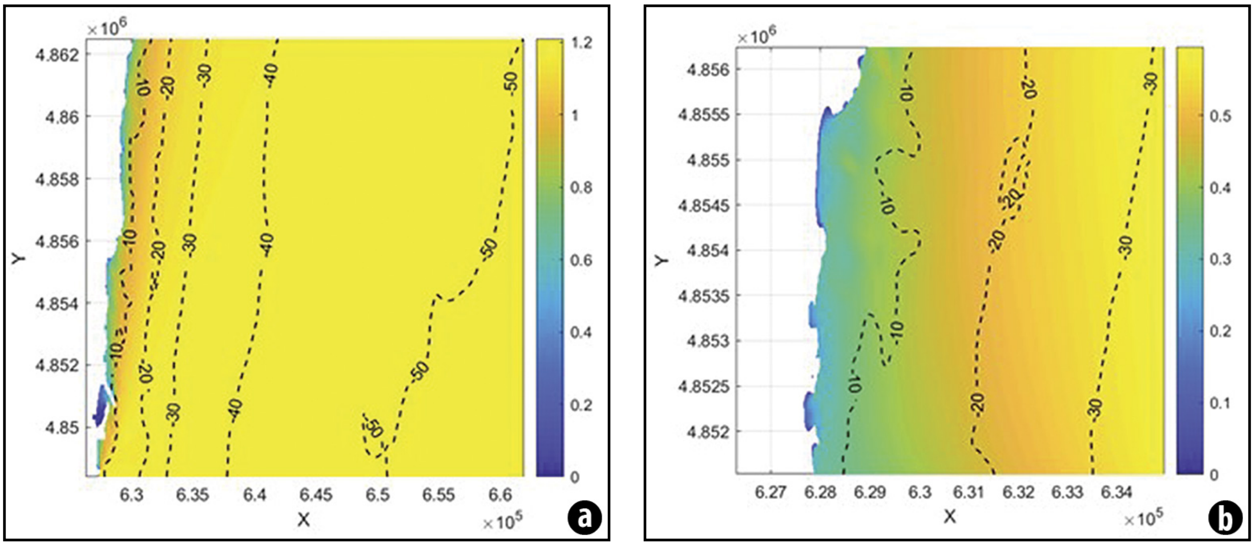
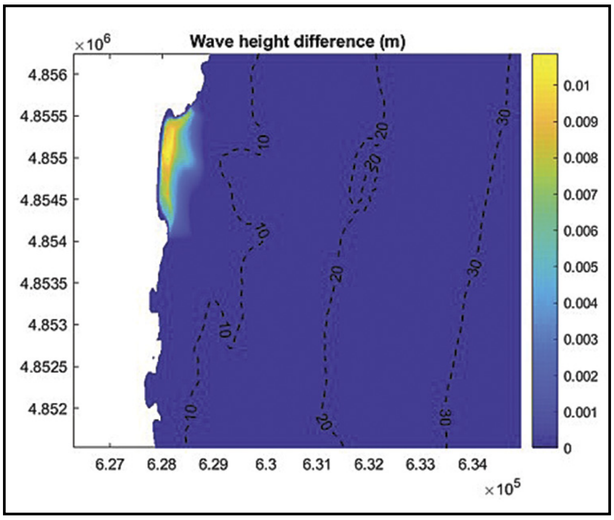


Fig. 15. SSE low energy waves ($H_{morf} = 1.21$ m, T = 5 s). Caption of the propagation in DOM1 (**a**) and its nesting in the absence of the seagrass meadow in DOM2 (**b**)



◂ **Fig. 16.** SSE low energy waves (H_{morf} = 1.21 m, T = 5 s). Comparison between the Baseline and the Vegetation scenarios

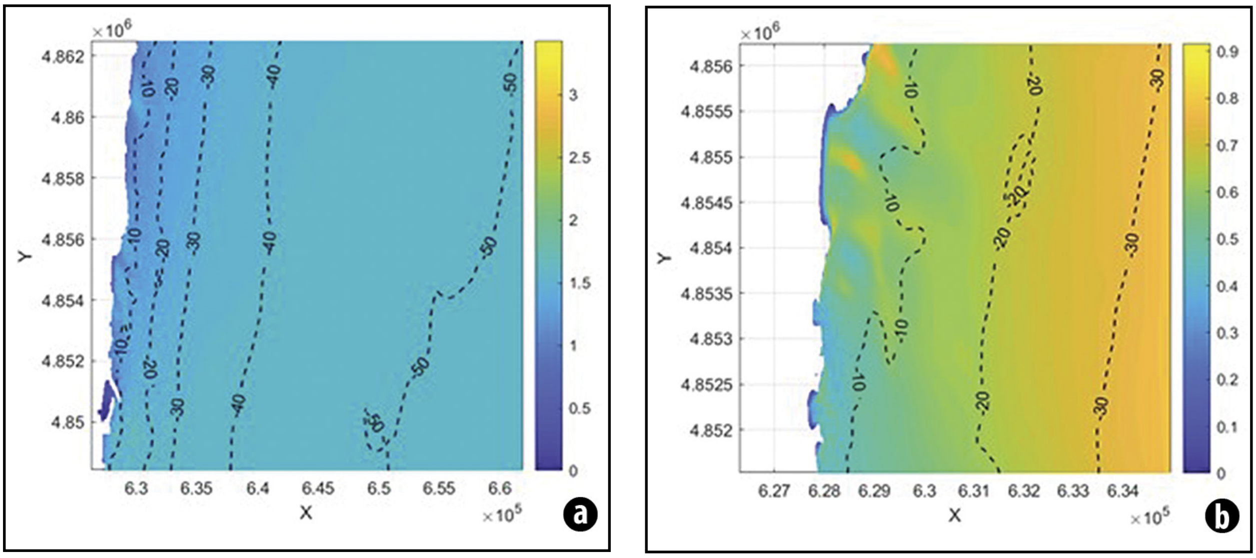
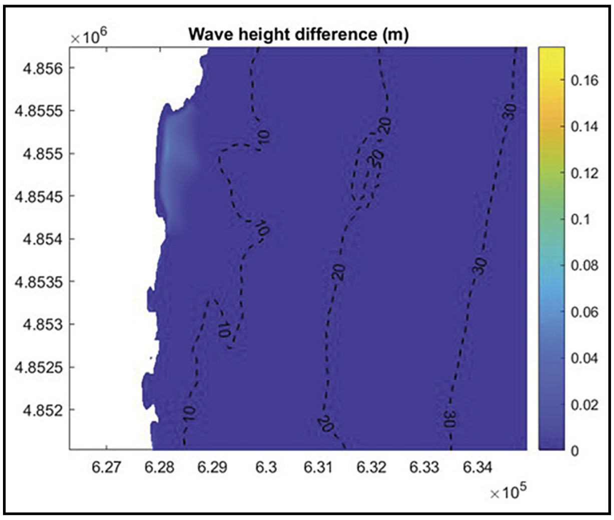


Fig. 17. SSE moderate energy waves (H_{morf} = 1.63 m, T = 9 s). Caption of the propagation in DOM1 (**a**) and its nesting in the absence of the seagrass meadow in DOM2 (**b**)



◂ **Fig. 18.** SSE moderate energy waves (H_{morf} = 1.63 m, T = 9 s). Comparison between the Baseline and the Vegetation scenarios

Table 2. Maximum and average attenuation for every direction and level of energy

Waves	Maximum attenuation		Average attenuation	
	(m)	(%)	(m)	(%)
NE low energy	0.011	3.3	0.007	2.4
NE moderate energy	0.092	6.4	0.063	4.8
E low energy	0.013	3.5	0.008	2.1
E moderate energy	0.220	8.1	0.098	4.5
SSE low energy	0.011	3.2	0.008	2.7
SSE moderate energy	0.169	7.7	0.062	4.0

reason that, in the case of moderate energy waves, hence with higher wave periods, the attenuation is higher. The same result is reached in our case.

To sum up, these numbers indicate a 4 to 8.1 % reduction of the wave height due to the seagrass meadow for moderate energy waves cases, in all the considered directions, and a reduction of 2.1 to 3.5 % for the low energy ones. Overall, for all the analyzed directions, we can consider an average reduction of 4.4 % for the moderate energy waves, and of 2.4 % for the low energy ones.

The maximum attenuation shows the lowest value (6.4 %) for the moderate waves from NE, that have the highest significant wave height. Waves from NE are almost parallel to the breakwater located north of our study area (Fig. 3), so attenuation occurs mainly through the seagrass meadow.

The highest value of the maximum attenuation (8.1 %) occurs for the moderate waves from E. These waves have the shortest distance to travel through the seagrass meadow. But the bathymetry shows an elevated zone, of depths between 3.4 and 5 m, while the surrounding depths are between 7 and 10 m (Fig. 3). This elevated zone is included in DOM2. The offshore E waves travelling towards the coast reach this elevated zone, which is an obstacle leading to attenuation.

The moderate waves from SSE also show slightly higher attenuation (7.7 %), as they have the longest distance to travel through the vegetation meadow.

4. DISCUSSION AND CONCLUSIONS

Specific submerged vegetation, such as Zostera noltei, can help in slight reduction of the wave height in the coastal zone between the Venus and Saturn resorts.

An improvement of this result could be achieved with higher stem height and a larger field, but the Zostera noltei proposed for this project is limited to the conditions used. Taller seagrass could provide an improvement to the results, but there is no information on such seagrass native from this coast. Using other species does not appear to be an option, as we don't know if they can adapt and develop.

From the numerical point of view, the detail of the models meshes could be improved, even adding more nesting steps. A 30 years span of data have been used for the Wave Climate, enough to calculate an accurate approximation at this stage of the study. Taking into account that the available forecast and hindcast cover more than a hundred years, there is room for improvement. Thus, the detail of the work could lead to a more extended and accurate approximation of the reality.

Overall, assessing the effect of a Zostera noltei meadow on the wave heights in our chosen study area opens a subject of interest for the Southern Romanian coast, mostly because the presence of this species is associated to a good ecological state.

Our results show that, from the hydrodynamic point of view, seagrass could be taken into account as an additional coastal protection measure.

ACKNOWLEDGEMENTS

This work has been performed within a bachelor degree thesis. The second author acknowledges the Mobility Projects MC2017-1274 and MC2018-1922, which covered the costs of two recent research visits to the Laboratory of Maritime Engineering, Polytechnic University of Catalonia (LIM-UPC), Barcelona. We acknowledge as well the project PN 18160103. We thank Dr. Marian T. Gomoiu and Dr. Mihaela Mureșan from GeoEcoMar Constanța, Romania, for useful discussions concerning the presence of seagrass along the Romanian Black Sea coast. Last but not least, we thank one of the reviewers, whose comments allowed us to significantly improve the article.

REFERENCES

Airy G.B., 1841. Tides and waves. In Rose, H.J., *et al.*, 1817-1845. Encyclopædia Metropolitana, *Mixed Sciences*, **3**.

Blackmar P.J., Cox D.T., Wei-Chang W., 2013. Laboratory observations and numerical simulations of wave height attenuation in heterogeneous vegetation. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, **140**(*1*), 56-65.

Booij N., Ris R.C., Holthuijsen L.H., 1999. A third-generation wave model for coastal regions, Part I, Model description and validation. *Journal of Geophysical Research*, **104** (*c4*), 7649-7666.

Borsje B.W., van Wesenbeeck B.K. , Dekker F., Paalvast P., Bouma T.J. , van Katwijk M.M., de Vries M., 2011. How ecological engineering can serve in coastal protection. *Ecological Engineering*, **37**(*2*), 113-122.

Bouma T.J., van Belzen J., Balke T., Zhu Z., Airoldi L., Blight A.J., Davies A.J., Galvan C., Hawkins S.J., Hoggart S.P.G., Lara J.L., Losada I.J., Maza M., Ondiviela B., Skov M.W., Strain E.M., Thompson R.C., Yang S., Zanuttigh B., Zhang L., Herman P.M.J., 2014. Identifying knowledge gaps hampering application of intertidal habitats in coastal protection: Opportunities & steps to take. *Coastal Engineering*, **87**, 147-157.

Castell X., 2018. Estudio del uso de praderas submarinas como medida de protección costera. Master thesis, Universitat Politècnica de Catalunya.

Christianen M.J.A., van Belzen J., Herman P.M.J., van Katwijk M.M., Lamers L.P.M., *et al.*, 2013. Low-Canopy Seagrass Beds Still Provide Important Coastal Protection Services. *PLoS ONE* **8**(*5*): e62413. doi:10.1371/journal.pone.0062413

Fonseca M.S., Fisher J.S., Zieman J.C., Thayer G.W., 1982. Influence of the seagrass, Zostera marina L., on current flow. *Estuarine Coastal and Shelf Science*, **15**(*4*), 351-358.

Fonseca M.S., Cahalan J.H., 1992. A preliminary evaluation of wave attenuation by four species of seagrass. *Estuarine, Coastal and Shelf Science*, **35**(*6*), 565-576.

Halcrow UK *et al.*, 2011-2012. Master Plan 'Protection and Rehabilitation of the coastal zone'.

Holthuijsen L.H., 2007. *Waves in Oceanic and Coastal Waters*. New York, NY: Cambridge University Press.

Kirwan M. L., Megonigal J. P., 2013. Tidal wetland stability in the face of human impacts and sea-level rise. *Nature*, **504**, 53-60.

Kobayashi N., Raichle A.W., Asano T., 1993. Wave attenuation by vegetation. *Journal of Waterway, Port, Coastal and Ocean Engineering*, **119**(*1*), p. 30-48.

Koftis T., Prinos P., Stratigaki V., 2013. Wave damping over artificial Posidonia oceania meadow: a large-scale experimental study. *Coastal Engineering*, **73**(*1*), 71-83.

Lin-Ye J., García-León M., Gràcia V., Ortego M.I., Stănică A., Sánchez-Arcilla A., 2018. Multivariate Hybrid Modelling of Future Wave-storms at the Northwestern Black Sea. *Water* 2018, **10**(*2*), 221, doi:10.3390/w10020221.

Manca E., Caceres I., Alsina J.M., Stratigaki V., Townend I., Amos C.L., 2012. Wave energy and wave-induced flow reduction by full-scale model Posidonia oceania seagrass. *Continental Shelf Research*, **50-51**(*1*), 100-116.

Marin O., Abaza V., Sava D., 2013. Phytobenthos - Key Biological element in shallow marine waters. *Cercetări Marine*, **43**, 197-218.

Möller I., Spencer T., French J.R., Leggett D.J., Dixon M., 1999. Wave Transformation Over Salt Marshes: A Field and Numerical Modelling Study from North Norfolk, England. *Estuarine, Coastal and Shelf Science*, **49**(*3*), 411-426.

Möller, I., 2006. Quantifying saltmarsh vegetation and its effect on wave height dissipation: Results from a UK east coast saltmarsh. *Estuarine, Coastal and Shelf Science*, **69**(*3-4*), 337-351.

Möller I., Kudella M., Rupprecht F., Spencer T., Paul M., van Wesenbeeck B.K., Wolters G., Jensen K, Bouma T.J., Miranda-Lange M., Schimmels S., 2014. Wave attenuation over coastal salt marshes under storm surge conditions. *Nature Geoscience*, **7**(*10*), 727-731.

Monclús i Bori A., 2018. Environmental friendly measures to protect the Romanian coast. Final Degree Thesis. Department of Civil and Environmental Engineering, Polytechnic University of Catalonia (DECA-UPC), Barcelona, Spain

Myrhaug D., Holmedal L.E., 2011. Drag force on a vegetation field due to longcrested and short-crested nonlinear random waves. *Coastal Engineering*, **58**, 562-566.

Narayan S., Beck M.W., Reguero B. G., Losada I. J., van Wesenbeeck B., Pontee N., Sanchirico J. N., Ingram J. C., Lange G. M., Burks-Copes K. A.. 2016. The Effectiveness, Costs and Coastal Protection Benefits of Natural and Nature-Based Defences. *PLoS ONE* **11**(*5*), e0154735.

Niță V., Micu D, Nenciu M., 2014. First attempt of transplanting the key-species Cystoseira barbata and Zostera noltei at the Romanian coast. *Cercetări Marine*, **44**, 147-163.

Ondiviela B., Losada I.J., Lara J.L., Maza M., Galván C., Bouma T.J., van Belzen J., 2014. The role of seagrasses in coastal protection in a changing climate. *Coastal Engineering*, **87**, 157-168.

Onea F., Rusu L., 2017. A long-term assessment of the Black Sea wave climate. *Sustainability*, **9**(*10*), 1875.

Pontee N.I., Narayan S., Beck M., Hosking A.H., 2016. Building with nature: Lessons from around the world. *Maritime Engineering*, **169**, *1*, 29-36.

Short F.T., Carruthers T.J.R., Waycott M., Kendrick G.A., Fourqurean J.W., Callabine A., Kenworthy W.J., Dennison W.C., 2010. *Zostera noltei*. The IUCN Red List of Threatened Species 2010: e.T173361A6999224.

Sierra J.P., García-León M., Gràcia V., Sánchez-Arcilla A., 2017. Green measures for Mediterranean harbours under a changing climate. *Proceedings of the Institution of Civil Engineers - Maritime Engineering*, **170**(*2*), 55-66.

Surugiu V., 2008. On the Occurrence of *Zostera noltei* Hornemann at the Romanian Coast of the Black Sea. *Analele ştiinţifice ale Universităţii "Al. I. Cuza" Iaşi*, **LIV**, fasc. *2*, s.II a. Biologie vegetală, 2008.

Suzuki T., Zijlema M., Burger B., Narayan S., 2012. Wave dissipation by vegetation with layer schematization in SWAN. *Coastal Engineering*, **59**, 64-71.

The SWAN Team, 2018. Scientific and technical documentation. SWAN Cycle III version 41.20A. Delft University of Technology.