

THE ROLE OF MANGROVE FOREST IN COASTAL WAVE ATTENUATION: CASE STUDY OF HAU LOC, VIETNAM

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Abstract: Among the soft solutions to protect the coast from wave impacts, the effectiveness of mangrove forests mainly depends on the mangrove belt width, species of mangroves, the density and the tree age. This study evaluates the ability of two popular mangrove species in the North of Vietnam, *S. caseolaris* and *K. obovata*, in dissipating monsoon waves affecting Hau Loc coast in Vietnam using the SWAN model. The study found that *S. caseolaris* is more effective in attenuating waves, showing 72%–82% wave height reduction (considering a mangrove belt width of 350 m, plant aged 5-9 years and a survival rate of 80%). The calculated results are compatible with the study of Bao (2011). In the sea-level rise condition, the forest reduces over 60-70% of incoming wave height; the wave height behind the mangrove forest rises by 2.3 cm. Therefore climate change should be considered when mangroves forests are planted to stabilize the local coastline.

Keywords: mangrove forest; wave attenuation; sea-level rise, SWAN model, Hau Loc.

1. INTRODUCTION

Mangrove forests play an important role in riverbanks and coastlines protection and climate regulation. Vietnam has a long coastline and suitable conditions for mangrove development. In the early 20th century, local inhabitants of the

northern Vietnam coast planted mangroves species, such as *Sonneratia caseolaris* (Vietnamese name: Bần chua) and *Kandelia obovata* (Vietnamese name: Trang), to protect the shore and coastal dikes.

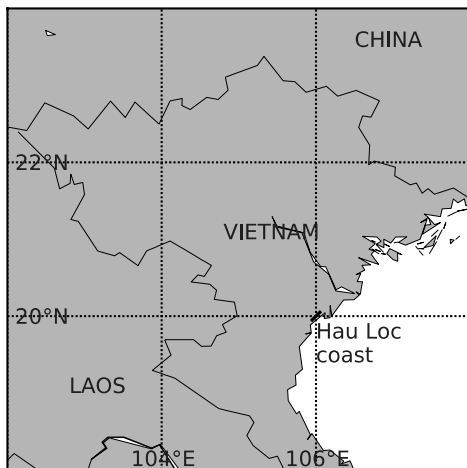


Figure 1. The study area in northern Vietnam coast and Google Earth image of the area

Located in Thanh Hoa Province, the coast of

Hau Loc (20.0°N, 106.0°E) stretches between the Len and Lach Truong rivers. The area is affected by storm yearly, and a 22 km-long sea-dike route had been built to protect the hinterland from flooding. In addition, a

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mangrove forest belt, containing mostly *S. caseolaris* and *K. obovata* species, had been planted to support the sea dike. The role of mangroves in wave attenuation has early been realised by the local people, especially from the experiences of typhoons No. 7 in 2005 and No. 5 in 2007. The sections of the dike being protected by mangroves were not destroyed by high waves, while those unprotected sections were broken because waves directly attacked the dike slope. Similarly, during typhoon Frankie (July 1996) landed on the nearby Thai Binh Province, the sea dikes in Tien Hai were severely damaged as a result of the mangrove deforestation to make shrimp ponds.

Therefore it is clear that planting mangrove forests is an effective solution to maintain and strengthen the Hau Loc dike system lying behind. However, as *S. caseolaris* trees were planted in 2009 with a density of only 1600 ha⁻¹, the mangrove plants remain quite sparse and are inadequate to protect the sea-dike.

The paper will present the capability in reducing waves of the local mangrove belt, while examining various vegetation parameters affecting wave reduction. Also, the impact of climate change on the mangrove forest and estimation of the wave attenuation, taking into account the sea-level rise, will be dealt with.

2. MATERIAL AND METHODS

2.1. The general approach

The workflow can be roughly defined as a series of the following steps:

- Data collection: bathymetry, wind, wave, tide and mangrove locations and features
- Run a nearshore wave model to obtaining nearshore wave characteristics
- Run a wave-vegetation interaction module to get the wave parameters behind the mangrove belt
- Establish a relationship between wave reduction and parameters of the mangrove belt
- Select an optimal plan for mangrove belt planting based on the design wave height in front of the dike / close to the shore.

According to Rasmeemasuang and Sasaki

(2015), a mangrove forest provides three main mechanisms to attenuate waves propagating through it: a) drag force on wind due to branches and leaves, b) drag force on waves due to trunks and roots, and c) bed friction. Of which, both drag force components are difficult to estimate, and often wave attenuation are evaluated based on the cross-shore distribution of wave height. This approach has been used in physical scale modelling (Tuyen and Hung, 2009) and field surveys (Mazda et al. 2006; Bao 2011).

In this paper, the wave attenuation is calculated using SWAN model – a third-generation wave model for obtaining realistic estimates of wave parameters in coastal areas, lakes and estuaries from given bathymetry data, wind, tidal water level, and offshore wave conditions. The model is based on the wave action balance equation with sources and sinks (Holthuijsen et al., 2006). Within SWAN model, the SWAN-VEG module calculate wave dissipation due to vegetation, in which mangroves are modelled as cylindrical obstacles (Suzuki, 2011). The vegetation drag force causes energy loss, which is represented by an energy dissipation term. This term is added to the original SWAN model.

2.2 Data for wave simulation

The bathymetry data of the study area was obtained from the Institute of Mechanics, surveyed in 2010. Wave data were extracted from the NOAA Wave Watch III database at the nearest sampling location (19.5°N, 106.5°E). Wind data were derived from the online service ‘WindFinder’ (Windfinder, 2018). The average wind speeds in summers and winters are almost similar, about 3 m/s. The water level data was collected in 2015 at the Sam-Son gauging station (19°45’N, 105°54’E), which is near the study area.

The conditions for planting mangroves are detailed in a guideline by VAWR (2011). For two local species – *S. caseolaris* and *K. obovata* - the water level should be low enough for the plants to be exposed more than 6 hours per day.

In the study site, the designed bed level for planting mangroves is from -0.6 m to -0.1 m. The width of the designed mangroves belt is 350 m. The tree density is also given. Another model parameter is the tree height; it corresponds to the age of the mangrove (5-year-old and 9-year-old trees) and its values are shown in Table 3.

2.3 Wave model set-up

The computation domain of the wave model is rectangular, which is 24,200 m alongshore and 26,100 m cross-shore. The grid is rotated by 45°. The grid cell size is 50 m × 100 m. The water depth along the offshore boundary may reach 20 m. Wave simulation is performed for the typical long-term hydro-meteorological conditions: wave, wind and water level parameters corresponding to SE monsoon (SCN1) and NE monsoon (SCN2).

Offshore boundary and forcing

Based on the measured data series, the water levels input data for SCN1 corresponding to high tide in summers and SCN2 representative for winters are determined (see Table 1).

The offshore wave parameters include significant wave height H_s , wave period T_p and incident wave angle θ . It can be identified, from the long-term wave statistics, that there are two dominant wave directions: ENE (corresponding to the NE monsoon) and SE (corresponding to the SE monsoon). For each direction, the total effect of different classes of wave heights can be quantified using a representative “morphological wave height” (H_{mor}) (De Vriend et al., 1993):

$$H_{mor} = \left(\frac{\sum(p_i H_i)^{2.5}}{\sum p_i} \right)^{0.4} \quad (1)$$

Thus for ENE waves, $H_{mor} = 1.08$ m, and for SE waves, $H_{mor} = 0.86$ m (see Table 1).

The wave periods are estimated from the morphological wave heights (H_{mor}) through their bivariate relationship, which results in 5.5 s (for ENE waves) and 5 s (for SE waves).

Waves entering SE boundary of the model conform to a JONSWAP spectrum, with wave directions being 67.5° (ENE waves) and 135° (SE waves).

Table 1. Input data for wave simulation using the SWAN model

Input parameters	SCN1	SCN2
	Summer monsoon	Winter monsoon
Water level (m)	1.36	1.79
Sig. wave height, H_{mor} (m)	0.86	1.08
Wave direction (°)	135	67.5
Wave period (s)	5.0	5.5
Wind velocity (m/s)	3	3
Wind direction (°)	135	45

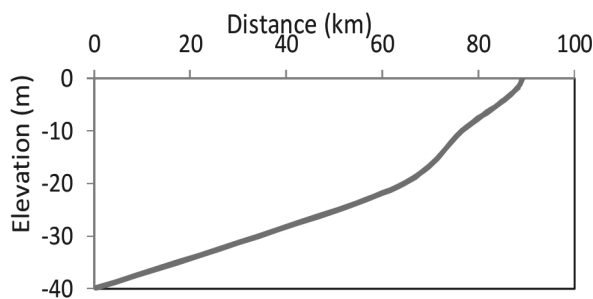


Figure 2. Bed profile (B-B') for SWAN-VEG simulation

Calculation is performed using SWAN model in stationary mode. The vegetation parameters are referred to (Thuong, 2018). The appropriate density for planting *K. obovata* is from 2500 ha⁻¹ to 10000 ha⁻¹, and for *S. caseolaris*, from 1600 ha⁻¹ to 5000 ha⁻¹ (VAWR, 2011).

Sea-level rise scenario

The input data of mangrove forest in a sea-level rise scenario is limited to 9-year old *S. caseolaris* plants, with a density of 2500 ha⁻¹ and a survival rate of 80%. (This 80% is chosen

based on the result from the previous scenarios, SCN1 and SCN2, and represents a typical value of survival rate for the range (55%,100%) that can be observed from Figure 7.) The forest belt width is about 350 m. Due to climate change and the sea-level rise, the total water depth increases and incoming waves grow. Also, the mangrove forest belt migrates landward so the area for mangroves decreases because of the existing sea dike. However, for simplicity, the change in wave parameters is not taken into account.

Water levels in the climate change context based on different emission scenarios are presented in the guideline by MONRE (2016). In both scenarios, a sea-level rise of 0.30 m is considered.

Assessing the wave reduction

Wave attenuation coefficients K_t and R are used for quantitative analysis. K_t represents the total energy dissipation and R the energy dissipation that is caused by only mangroves.

$$K_t = H_x / H_0 \quad (2)$$

where H_x = wave height at the location x behind mangrove belt and H_0 = wave height at the front edge of the mangrove belt.

$$R = (H_{0x} - H_x) / H_{0x} \quad (3)$$

where H_{0x} = wave height at the location x in case without mangroves.

3. RESULTS AND DISCUSSION

3.1 Results

SWAN wave model. The resulting wave field for scenario SCN2 is shown in Figure 3. The location of the mangrove belt is also shown. The NE monsoon scenario, SCN2, exhibits a larger offshore wave height, but due to strong wave refraction around the Day river delta, the nearshore wave heights are smaller than those of SE monsoon scenario, SCN1.

In addition to a stationary wave field, the output data are extracted at a typical location B (19.85°N, 106.05°E), offshore the Hau Loc mangrove forest belt. Such wave characteristics at B are chosen as boundary conditions for SWAN-VEG modelling along the B-B' profile (see Figures 2 and 3).

SWAN-VEG module. Wave attenuation is calculated for two main cases with 5-year-old and 9-year-old plants. The densities are maximal for each type of mangroves based on VAWR (2011) with a survival rate of 80%. The results are shown in Table 2 and Figure 4.

Table 2. Wave attenuation corresponding to scenarios SCN 1 and 2

Type	SCN1		SCN2	
	$1 - K_t$	R	$1 - K_t$	R
5-yr <i>S. caseolaris</i>	74%	73%	73%	72%
9-yr <i>S. caseolaris</i>	82%	81%	82%	82%
5-yr <i>K. obovata</i>	67%	66%	58%	57%
9-yr <i>K. obovata</i>	76%	75%	78%	78%

Based on the results presented in Table 2 (in which $1 - K_t$ is used instead of K_t for easier comparison to R), some remarks can be made:

- Mangrove is the decisive factor in wave reduction (across the width 350-m of the mangrove belt), compared to other factors such as wave breaking, refraction and dissipation.

- Wave attenuation increases when the tree gets older.

- *S. caseolaris* is the better species of mangroves in terms of wave attenuation.

Factors influencing wave reduction

Wave attenuation is calculated with 9-year-old *S. caseolaris*. The mangrove belt width is 350 m. From the results (Figures 5–7), some remarks can be made:

- The mangrove forest with a width of 250 m can reduce more than 60% wave height compared to the case without mangroves. When the mangrove belt width increases, the wave attenuation coefficient does not change much.

- The mangrove forest with density of 2000

ha^{-1} can reduce 50% wave height compared to the case without mangroves.

- A survival rate over 55% can ensure >60%

wave reduction. For a range in survival rate 55%-100%, the wave reduction changes much more slowly (60%-68%).

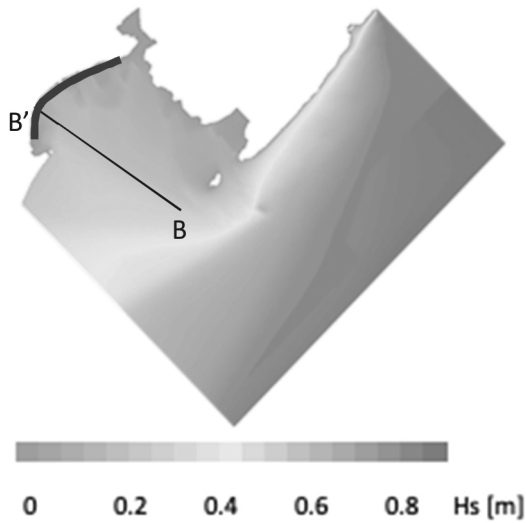


Figure 3. Distribution of wave height in SCN2 scenario (The forest belt is shown as a thick curve.)

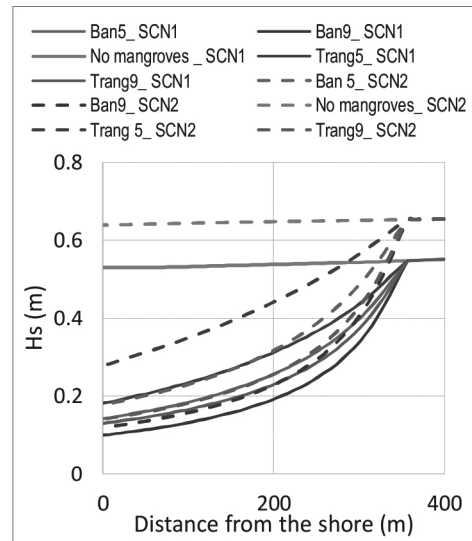


Figure 4. Wave height through mangrove forest for two scenarios

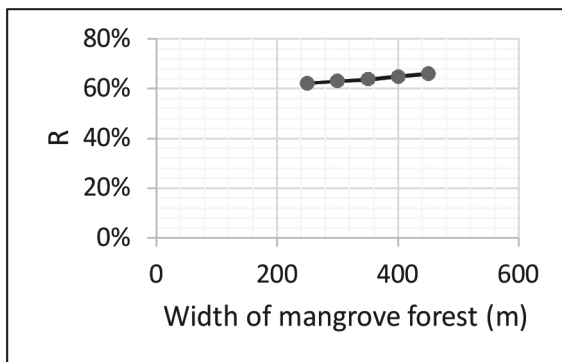


Figure 5. Relationship between mangrove forest width and wave attenuation

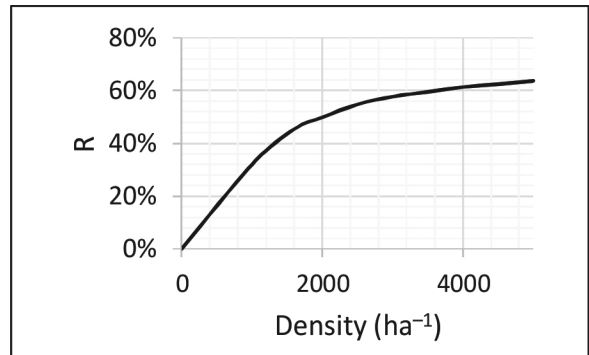


Figure 6. Relationship between tree density and wave attenuation

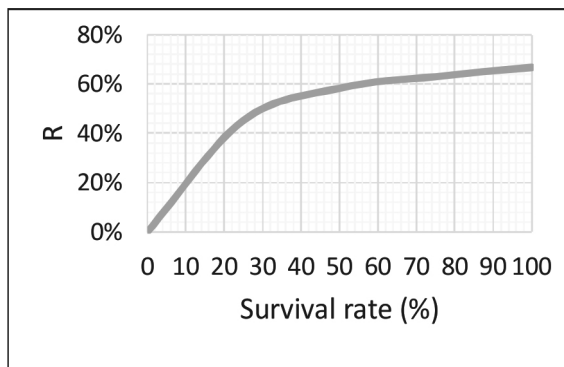


Figure 7. Relationship between survival rate and wave attenuation

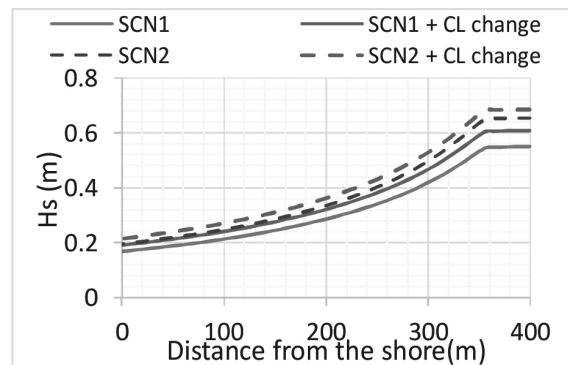


Figure 8. Wave height through mangrove forest: comparison with and without climate change

Climate change scenarios

In context of climate change when the sea level rises, there are growths in both the incident wave and the wave behind the mangrove belt. As shown in Figure 8, when the sea level rises by 30 cm, the wave height behind the mangrove forest increases only from 1.9-2.3 cm corresponding to SCN2 and SCN1. This shows the effect of the mangrove band, which reduces over 60-70% the incoming wave height.

3.2 Discussion

For SWAN wave modelling, the effect of river flow is neglected. The major river mouth, Ninh Co, may influence NE wave propagation only during flood season but has very limited effect otherwise. Also, the lack of an extensive data survey constrained the domain extent of model reaching only water of about 23 m depth, and refraction of NE waves may not be accurately accounted for.

The above limitations in modelling need to be improved in the future for more accurate and complete wave simulations. At present, the

model allows only one species in each scenario and the plant parameters are average values for the whole computational area.

Due to limited observed data, the calculation results are calibrated against Bao (2011)'s formula of wave height reduction:

$$b = 0.048 - 0.0016 TH - 0.00178 \ln(N) - 0.0077 \ln(CC)$$

$$H_{\text{behind}} = (0.9899 H_i + 0.3526) \exp(b \times B_w)$$

where H_{behind} : sea wave height behind the forest belt [cm], H_i : incident sea wave height [cm], TH: average tree height [m], N : tree density [ha^{-1}], CC: canopy closure [%], B_w : forest belt width [m]. We consider eight scenarios, shown as eight rows in Table 3. The scenarios are combinations of two plant ages, two densities, and two wave heights. The fixed parameters are $B_w = 350$ m and $CC = 72\%$. The tree height is taken as the sum of trunk height, root length, and half the branch length (Thuong, 2018). The mangrove parameters are used as input for SWAN model and also for calculating with Bao's Eq. (4).

Table 3. Comparison results of wave height behind mangrove to Bao (2011)'s study

Type, age (yr.)	N (ha^{-1})	TH (m)	H_i (cm)	H_{behind} (cm)	
				Bao (2011)	SWAN
<i>S. caseolaris</i> , 5	5000	2.11 m	65 cm	19.2 cm	18 cm
<i>S. caseolaris</i> , 9	5000	3.36 m	65 cm	9.5 cm	12 cm
<i>K. obovata</i> , 5	10000	1.16 m	65 cm	21.3 cm	28 cm
<i>K. obovata</i> , 9	10000	1.70 m	65 cm	15.8 cm	14 cm
<i>S. caseolaris</i> , 5	5000	2.11 m	55 cm	16.3 cm	14 cm
<i>S. caseolaris</i> , 9	5000	3.36 m	55 cm	8.1 cm	9.8 cm
<i>K. obovata</i> , 5	10000	1.16 m	55 cm	18.0 cm	18 cm
<i>K. obovata</i> , 9	10000	1.70 m	55 cm	13.3 cm	13 cm

From Table 3, it can be seen that the results of calculation of wave height behind mangrove forest by SWAN are compatible with the study by Bao (2011). The mean relative error is only 3%.

For simplicity we would assume the canopy closure as the canopy cover – the percentage in area occupied by the vertical projection of tree crowns, which can be conveniently determined from remotely sensed data (Paletto and Tosi,

2009). Although ground-truthing is not available to determine CC, it can be seen through a sensitivity analysis, that the variability of CC does not affect much the result. When CC is varied from 70% to 75% (around the chosen value $CC=72\%$), the mean relative error between H_{Bao} and H_{SWAN} changes from +5% to -13% and this error margin is acceptable.

The wave attenuation results agree with the study by Vinh (2015), who reported the

following reduction factors for Hai Phong mangrove area: 0.15-0.6 during mild weather conditions. That author also remarked that effective wave reduction takes place in the outer 300-400 m of the mangrove belt. The parameters of mangrove and drag coefficient are taken from the study in Haiphong. There are similarities between the Haiphong site and the study area, including hydro-meteorological conditions (diurnal tide with spring tidal ranges > 3 m, monsoon climate), geomorphological conditions (flat beach with sediment mainly supplied by rivers and partially sheltered by northeastern islands or river deltas), and biological condition (mangrove species). Therefore, these assumptions are acceptable and the results can be used for planning purposes.

In general, the capacity of mangrove forest in wave attenuation increases when the density of tree increase. However, when mangroves are planted too densely the survival rate will be affected. This study does not consider the correlation among them. Planting mangroves based on natural succession not only sustains the development of forests but also ensures effective wave attenuation for various water levels. Furthermore, it is necessary to study the biological density and the appropriate time for tree cutting to ensure the development of new mangrove belt planting or recently-planted mangroves (for several years).

In the context of climate change, other aspects need to be further considered when calculating the wave height behind mangrove

forest in climate change scenarios, which include the higher incoming waves and the mangrove forest recession.

4. CONCLUSION

The paper presents the relationship between the parameters of the mangroves belt and wave attenuation for two simulation scenarios involving two typical mangrove species. In normal condition, the wave reduction rate ranges from about 60% to 80%.

Regarding wave attenuation performance, *S. caseolaris* species is better than *K. obovata* species in both seasonal monsoon conditions.

Planting a mangrove belt with *S. caseolaris* species, over a width of 350 m, with a density of 2500 ha⁻¹ and the expected survival rate of 80% after 9 years can help the forest effectively reduces the waves, even when the future sea level-rise is accounted for. In normal condition the approaching wave height is about 0.2 m. The survival rate should be at least 30% after 9 years to achieve a wave attenuation ratio of 50%.

A proposal on planting mangroves for the study area would be: at bed elevation from -0.6 m to -0.1 m, the chosen species is *S. caseolaris*, with a density of 2500 ha⁻¹. However, field surveys on planting grounds need to be carefully conducted and some support measures are requested in advance to enhance sediment deposition.

ACKNOWLEDGEMENTS

The first author would like to thank NAGAO foundation for funding this research.

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Tóm tắt:

NGHIÊN CỨU VAI TRÒ GIẢM SÓNG CỦA RỪNG NGẬP MẶN, TRƯỜNG HỢP NGHIÊN CỨU TẠI HUYỆN HẬU LỘC, TỈNH THANH HÓA, VIỆT NAM

Trong các giải pháp xanh bảo vệ bờ, giảm tác động của sóng biển thì hiệu quả giảm sóng của rừng ngập mặn chủ yếu phụ thuộc vào chiều rộng vành đai rừng ngập mặn, loài cây ngập mặn, mật độ và tuổi cây. Bài báo này trình bày kết quả đánh giá khả năng giảm sóng của hai loài cây ngập mặn phổ biến ở miền Bắc Việt Nam là cây Bần (*S. caseolaris*) và cây Trang (*K. obovata*) tại bờ biển huyện Hậu Lộc (có tọa độ 19,93° Bắc, 105,96° Đông) bằng mô hình SWAN. Kết quả tính toán cho thấy cây Bần có hiệu quả giảm sóng tốt hơn cây Trang, với chiều cao sóng tới giảm 72% - 82% (xem xét một dải rừng rộng 350 m, với tuổi cây là 5-9 năm và tỷ lệ sóng sót 80%). Các kết quả tính toán được phù hợp so với nghiên cứu của tác giả Trần Quang Bảo (2011). Trong điều kiện nước biển dâng, rừng vẫn giảm được 60-70% chiều cao sóng tới, chiều cao sóng sau rừng ngập mặn tăng thêm là 2,3 cm. Do đó, biến đổi khí hậu cần được xem xét khi mở rộng việc trồng rừng ngập mặn để ổn định đường bờ địa phương.

Từ khóa: rừng ngập mặn, giảm sóng, biến đổi khí hậu, mô hình SWAN, Hậu Lộc.

Ngày nhận bài: 10/9/2020

Ngày chấp nhận đăng: 31/12/2020