Influence of Hydrometeorological Hazards and Sea Coast Morphodynamics onto Development of the Cephalanthero rubrae-Fagetum (Wolin Island, the Southern Baltic Sea)~~Influence of Hydrometeorological Hazards and Sea Coast Morphodynamics onto Unique Coastal Vegetation Sites Development – *Cephalanthero rubrae - Fagetum* on Wolin Island (the Southern Baltic Sea)~~

Jacek Tylkowski[1], Marcin Winowski[1], Marcin Hojan[2], Paweł Czyryca[1], Mariusz Samołyk[1]

[1] Institute of Geoecology and Geoinformation, Faculty of Geographical and Geological Sciences, Adam Mickiewicz University, Krygowski 10, 61-680 Poznan, Poland
[2] Institute of Geography, Department of Landscape Geography, Kazimierz Wielki University, Koscieleckich Square 8, 85-033 Bydgoszcz, Poland

Correspondence to: Jacek Tylkowski (jatyl@amu.edu.pl)

Abstract: Climate changes, sea transgression and sea coast erosion observed today cause dynamic changes in coastal ecosystems. In the elaboration, cause and effect interrelations between abiotic hazards (hydrometeorological conditions and sea coast morphodynamics) and biotic (*Cephalanthero rubrae – Fagetum* phytocoenosis) components of natural environment have been defined. An up-to-date phytosociological analysis of a very valuable *Cephalanthero rubrae – Fagetum* site on cliff tableland was conducted in the context of hitherto temporal variability of climatic conditions and the rate of cliff coast recession. Also, the development prognosis of the researched site in the 21st century is provided, with respect to the expected climate changes and cliff's morphodynamics. The conducted research actions revealed the influence of global hazards (e.g., climate changes, sea transgression and sea coast erosion) onto changes in natural environment on regional scale (with the example of the site of *Cephalanthero rubrae – Fagetum* on cliff coast of Wolin Island in Poland). It has been established that in the 21st century, a relatively larger hazard to the functioning of the researched site are climate changes (i.e. mostly changes in thermal and precipitation conditions) not the sea coast erosion.~~It has been established that in the 21st century, a relatively larger hazard to the functioning of the researched site are climate changes, not the sea coast erosion.~~

Key words: hydrometeorological hazards, climate change, sea coast morphodynamics, coastal vegetation

1 Introduction

Contemporary researches confirm dynamic climate changes, which are evidenced mainly in rise of temperatures (Sillmann et al., 2013). The result of thermal climate changes is the rise of sea level by approximately 2 mm yr^{-1} (Church et

Z komentarzem [JT1]: ANONYMOUS REFEREE (line 1): The title was shortened

Z komentarzem [JT2]: ANONYMOUS REFEREE (line 13): spaces have been removed

Z komentarzem [JT3]: MR. WOLSKI
the sentence was completed as suggested

al., 2013). The temporal variability of hydrometeorological conditions is decisive for the sea coast erosion dynamics and causes changes in coastal phytocoenoses (Strandmark et al., 2015). A particular role in this respect is reserved for extreme hydrometeorological events (Tylkowski and Hojan, 2018). Intensification of geomorphological processes, in the majority of cases, results in degradation of coastal vegetation sites (Feagin et al., 2005). Exceptionally rapid and intensive changes of natural environment are present in poorly resistant to erosion, moraine cliff coasts of the Baltic Sea (Kostrzewski et al., 2015). That is why empirical researches on the influence of abiotic conditions onto determination of current state, threats and development perspectives of ~~valuable,~~all coastal phytocoenoses are particularly important.

Unique in the world are the sites of coastal thermophilous ~~stenothermal coastal~~ orchid beech wood, *Cephalanthero rubrae-Fagetum (Cr-F)*, which are found only in Poland, on cliff coast of Wolin island, in Wolin National Park. *Cr-F* grows on specific soils and is a peculiar type of beech wood, recognised as separate regional association~~complex~~ (Matuszkiewicz, 2001, 2014). The uniqueness of this ~~phytocoenosis~~ plant community stems from endemic and specific character of ~~site~~ habitat formation. *Cr-F* occurs on the top of the cliff (the so-called 'cliff top') and on cliff tableland, where unique, rich in calcium carbonate soils in the form of cliff naspa were formed. Naspa's accumulation level consists in interbeddings of fine-grain sand and dust drifted by wind from eroded cliff slopes, and rich in humus, dark-grey organic accumulation laminas (mainly leaves of *Fagus sylvatica*). The cliff naspa is a soil with reaction close to neutral, rich in calcium carbonate and characterised by high porosity and efficient humification of organic remains. That is why naspa is a fertile soil. Naspa is deposited on the fossil podzolic soil. Naspa has the following sequence of soil levels: A0 litter level; A1I accumulation level of sand and organic matter layers; A1 (fos) accumulation level of fossil podzolic soil; A2 (fos) eluvial level of fossil podsolic soil; B (fos) iluvial level of fossil podzolic soil; C (fos) parent rock of fossil podzolic soil (Prusinkiewicz, 1971). ~~(Prusinkiewicz, 1971).~~ Therefore, the prerequisite for the development of this phytocoenosis is its non-episodic, aeolian supply of mineral material from clayey and sandy cliff slopes. Moreover, the dynamics of cliff coast recession may not be too extensive, as spatial reach of *Cr-F*, counted from cliff top, is 150 m at maximum (Piotrowska, 1993). The average rate of aeolian deposition in the *Cr-F* habitat was 3-5 mm y^{-1}, and the maximum point value was 8-10 mm y^{-1} (2000-2019).

Cephalanthera rubra and *Epipactis atrorubens* are indicator species for *Cr-F* (Matuszkiewicz, 2020). Both species found in the 6 studied *Cr-F* habitats, but *Cephalanthera rubra* was the dominant one. Non-indicator species, e.g. *Cephalanthera damasonium* and *Epipactis helleborine*, have been found in *Cr-F* habitats too. The researches on *Cr-F* conducted up to now (among others, Czubiński and Urbański, 1951; Piotrowska, 1955, 1993) were concentrated mainly on qualitative floristic and ~~phytocoenotic~~ phytosociological analysis. On the other hand, the main aim of this elaboration was the up-to-date evaluation of the ~~reach~~ plant richness and floristic composition of *Cr-F*, and possible growth of this exceptional association~~phytocoenosis~~, in the context of climate changes and morphodynamics of cliff coast expected to take place in this century.

2 Study Area and Methods

Z komentarzem [JT4]: ANONYMOUS REFEREE (line 32): exchange word from valuable to all

Z komentarzem [JT5]: ANONYMOUS REFEREE (line 33): exchange word from stenotermal coastal to coastal thermophilous

Z komentarzem [JT6]: ANONYMOUS REFEREE (line 35): exchange word from complex to association

Z komentarzem [JT7]: ANONYMOUS REFEREE (line 36): exchange word from phytocoenosis to plant community

Z komentarzem [JT8]: ANONYMOUS REFEREE (line 36): exchange word from site to habitat

Sformatowano: Czcionka: Kursywa

Z komentarzem [JT9]: ANONYMOUS REFEREE (line 76-80): sentence was moved as recommended. Soil genetic levels added

Z komentarzem [JT10]: MR. KOZŁOWSKI added values for aeolian deposition

Sformatowano: Czcionka: Kursywa

Sformatowano: Indeks górny

Sformatowano: Indeks górny

Z komentarzem [JT11]: ANONYMOUS REFEREE (line 41). The text was supplemented in accordance with the comments of the reviewer

Sformatowano: Czcionka: Kursywa

Sformatowano: Czcionka: Kursywa

Z komentarzem [JT12]: ANONYMOUS REFEREE (line 42): exchange word from phytocoenotic to phytosociological

Z komentarzem [JT13]: ANONYMOUS REFEREE (line 43): exchange word from reach to plant richness

Z komentarzem [JT14]: ANONYMOUS REFEREE (line 44): exchange word from phytocoenosis to association

Z komentarzem [JT15]: ANONYMOUS REFEREE (line 46-56): Historical aspects of Cr-F were removed as suggested

~~The known history of *Cr-F* growth on Wolin Island dates back to the end of the 18th century, when natural beech and oak sites had been cut down (with the exception of a small number of the so-called 'parents of family') and pine monoculture was introduced. Such an unfavourable action led to unification of tree sites, acidification and impoverishment of the soil (Piotrowska, 1993), as well as decay of the primary *Cr-F* site. Then, as an outcome of aeolian supply of mineral matter from the cliff slope onto cliff top, a soil started to develop in the form of cliff naspa (Prusinkiewicz, 1971). Accumulation of naspa mechanically destroyed pine forest ground cover and created conditions for re-settlement of species with more extensive trophic demands (including neutrophils) and favoured growth of beech share within pine sites. Current age of beeches in *Cr-F* sites is 150–185 years (Piotrowska, 1993). Thus, the oldest of the currently existing beeches grew in the beginning of naspa accumulation period. Natural expansion of the beech advanced and catered for re-establishment of *Cr-F* (Piotrowska 1993), which occurs until the present day. It should be stressed that paleogeographical sediments record of the 'primary' *Cr-F* site from before the 18th century is not available, as this part of the cliff coast was subject to coastal erosion.~~

The section of cliff coast, in which *Cr-F* occurs, was developed as a result of undercutting Wolin end moraine by the transgressing Baltic Sea. Ultimately, orchid beech wood sites have been developed on hinterland of moraine cliffs. Moraine cliffs at *Cr-F* sites are characterised by high morphological (height of 20–95 m, dominant NW exposition, inclinations op to 1° on cliff top, and up to 88° on clayey slopes) and lithological (sandy sections, clayey or mixed — sandy and clayey) differentiation. The analysed section of cliff coast with the length of merely 3 km features various morphodynamic ~~functions~~ states (erosion or stagnation). The researched site type is rich in species characteristic for, both, forest and non-forest phytocoenoses. Forest species, ~~typical~~ characteristic for *Fagetalia* and *Querco-Fagetea* as well as meadow species with *Molinio-Arrhenatheretea* occur in large numbers (Piotrowska, 1993). The high flow of light to the ground from the sea direction~~Increased light supply from the coastal direction~~ favours the occurrence on the top cliff of many heliophilous species, characteristic for meadows and psammophilous short-grass swards.~~characteristic for sandy meadows and turfs.~~ Gramineous species prevail in the herb layer~~ground cover~~, among others: *Brachypodium sylvatica*, *Dactylis glomerata*, *Poa Nemoralis*~~, *Dactylis glomerata*~~. The most valuable are orchid species, *Cephalanthera damasonium*, *Cephalanthera rubrae*, ~~*Cephalanthera damasonium*,~~ *Epipaptis atrorubens*, which prefer fertile soils with reaction close to neutral (Piotrowska, 2003). There are, however, no of the numerous species characteristic for *Fagetalia* ~~*silvaticae*~~ *sylvaticae* order (~~*Acetea*~~ *Actaea spicata*, *Daphne mezereum*, *Lathyrus vernus*, *Mercurialis perennis*) and *Querco-Fagetea* class (*Aegopodium podagraria*, *Campanula trachelium*, *Corylus avellana*) that feature considerable share in all other *Cephalanthero-Fagenion* forests~~orchid beech woods~~, which evidences the distinction and uniqueness of the *Cr-F* association ~~complex~~ (Matuszkiewicz, 2001). The source of Latin names of plant species and plant communities are the publications Jackowiak et al. (2007) and Matuszkiewicz (2020). ~~Aside of climatic conditions, the main factor conditioning the occurrence of the said site is the cliff coast erosion and cliff naspa formation.~~

The current reach and floristic composition of *Cr-F* has been determined on the basis of a few phytosociological mapping conducted on 6 study sites over 2018 and 2019 vegetative seasons. All in all, 10 detailed phytosociological images were taken with the use of Braun–Blanquet method, and *Cr-F* habitats ~~sites~~ reach chart on Wolin island was drafted (Fig. 1).

Sformatowano: Wcięcie: Pierwszy wiersz: 1 cm

Z komentarzem [JT16]: ANONYMOUS REFEREE (line 63): exchange word from typical to characteristic

Z komentarzem [JT17]: ANONYMOUS REFEREE (line 64-65): sentence changed as suggested

Z komentarzem [JT18]: ANONYMOUS REFEREE (line 65): exchange word from ground cover to herb layer

Z komentarzem [JT19]: ANONYMOUS REFEREE (line 66): alphabetical order

Z komentarzem [JT20]: ANONYMOUS REFEREE (line 70): exchange word from orchid beech woods to Cephalanthero-Fagenion forests

Sformatowano: Czcionka: Kursywa

Z komentarzem [JT21]: ANONYMOUS REFEREE (line 71): exchange word from complex to association

Z komentarzem [JT22]: ANONYMOUS REFEREE (line 71-72): Sentence removed. It was already on lines 35-39

Z komentarzem [JT23]: ANONYMOUS REFEREE (line 45): Text added as suggested. Source of Latin names

Z komentarzem [JT24]: ANONYMOUS REFEREE (line 75): exchange word from site to habitats

An assumption was adopted that *Cr-F* site reach is determined by soil conditions. ~~,~~ The cliff naspa determines the occurrence of *Cephalanthera rubra* and *Epipactis artorubens*, which are species regionally characteristic of *Cephalanthero rubrae-Fagetum*~~,as the cliff naspa conditions occurrence of some of *Orchidaceae* family species. Naspa's accumulation level consists in interbeddings of fine-grain sand and dust drifted by wind from eroded cliff slopes, and rich in humus, dark grey organic accumulation laminas (mainly leaves of *Fagus Silvatica*). The cliff naspa is a soil with reaction close to neutral, rich in calcium carbonate and characterised by high porosity and efficient humification of organic remains. That is why naspa is a fertile soil (Prusinkiewicz, 1971).~~ The site's reach limits are indicated on the basis of occurrence of *Cephalanthera rubra*~~,~~ ~~that is an indicatory species for *Cr-F* complex~~.

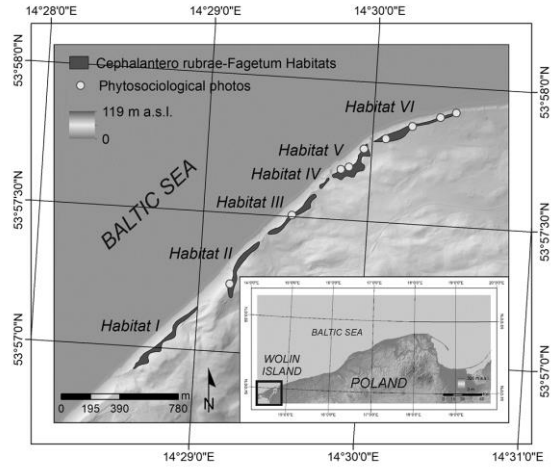
Sformatowano: Czcionka: Kursywa

Sformatowano: Czcionka: Kursywa

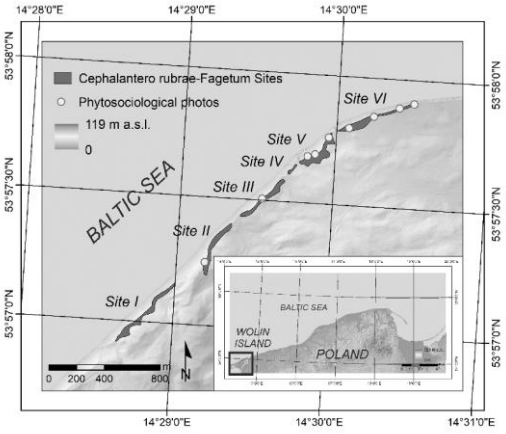
Sformatowano: Czcionka: Kursywa

Z komentarzem [JT25]: ANONYMOUS REFEREE (line 76-77): sentence changed as suggested

Z komentarzem [JT26]: ANONYMOUS REFEREE (line 81): the sentence was shortened



104



105

106 **Figure 1.** *Cr-F* ~~Sites~~ habitats~~of *Cr-F*~~, localisation of phytosociological mapping on Wolin Island.

Z komentarzem [JT27]: exchange word from site to habitats

Figure 2. *Cr-F* habitat II on Wolin Island.

Detailed recognition of hydrometeorological conditions and the recession rate of the cliff top are vastly important for the functioning of *Cr-F* ~~site~~habitats. Thermal and precipitation conditions determine, e.g. on water and heat resources and duration of vegetative season. On the other hand, extreme storm surges may generate intensive cliff erosion and consequently reduce the spatial extent of coastal plant communities. Therefore, unfavorable hydrometeorological conditions may limit the development of the *Cr-F* habitats. For the purpose of defining long-term trend for thermal and precipitation conditions and sea level, daily hydrometeorological data in the period of 1960–2019, collected in measurement station in ~~Swinoujscie~~Świnoujście, were used. The data were provided by the Polish Institute of Meteorology and Water Management. The meteorological and mareographical station in ~~Swinoujscie~~ Świnoujście is located 15 km from the research area and provides homogeneous ~~credible, uniform~~ and complete series of actual data.

In the elaboration, a number of especially useful climatic indicators were calculated and their values compared with threshold values adequate for *Fagus* ~~*Silvatica*~~ *sylvatica* given by Budeanu et al. (2016): ~~(Budeanu et al., 2016):~~

- De Martonne ~~aridity~~ Aridity ~~index~~Index IA=P/(T+10), ~~(AI) (~~where *P* is the amount of the annual precipitation, *T* is the average annual temperature (De Martonne, 1926); with optimal thresholds for beech wood in the range of 35–40 (Satmari, 2010~~),~~); De Martonne Aridity Index - classification by Tabari et al., (2014): IA<5 extremely arid, 5<IA<10 arid, 10<IA<20 semi-arid, 20<IA<24 mediterranean, 24<IA<28 semi-humid, 28<IA<35 humid, 35<IA<55 very humid, 55<IA extremely humid.
- ~~-~~Ellenberg Quotient EQ=Tw/Px1000,~~(EQ)~~ where *Tw* is the temperature of the warmest month of the year, *P* is the annual precipitations (Ellenberg, 1988); with optimal threshold beneficial for beech growth of below 30 and its recession threshold of above 40 (Stojanovic et al., 2013),
- ~~-~~Forestry Aridity Index ~~(~~FAI=100x($T_{VII\text{-}VIII}$/($P_{V\text{-}VII}$+$P_{VII\text{-}VIII}$), where $T_{VII\text{-}VIII}$ is the average temperature of the months July and August, $P_{V\text{-}VII}$ is the amount of precipitations during May-July and $P_{VII\text{-}VIII}$ is the amount of precipitations during July-August;~~)~~ with climatic conditions favouring beeches of below 4.75 (Führer et al., 2011),

Sformatowano: Wyrównany do środka

Z komentarzem [JT28]: MR. KOLANDER, MRS. KIJOWSKA an overview photo of the habitat has been added

Sformatowano: Wcięcie: Pierwszy wiersz: 1,25 cm

Sformatowano: Czcionka: Kursywa

Z komentarzem [JT29]: ANONYMOUS REFEREE (line 84-86): the text has been completed as suggested

Z komentarzem [JT30]: ANONYMOUS REFEREE (line 88): text corrected as suggested

Sformatowano: Odstęp Przed: 0 pkt

Z komentarzem [JT31]: ANONYMOUS REFEREE (line 90): corrected citation

Sformatowano: Akapit z listą, Wcięcie: Z lewej: 0 cm, Wysunięcie: 0,25 cm, Odstęp Przed: 0 pkt, Punktowane + Poziom: 1 + Wyrównanie: 0,63 cm + Wcięcie: 1,27 cm

Sformatowano: Czcionka: Kursywa

Sformatowano: Czcionka: Kursywa

Sformatowano: Czcionka: Kursywa

Sformatowano: Indeks dolny

Sformatowano: Indeks dolny

Sformatowano: Indeks dolny

Sformatowano: Czcionka: Kursywa

Sformatowano: Czcionka: Kursywa, Indeks dolny

Sformatowano: Czcionka: Kursywa

Sformatowano: Czcionka: Kursywa, Indeks dolny

Sformatowano: Czcionka: Kursywa

Sformatowano: Czcionka: Kursywa, Indeks dolny

Sformatowano: Indeks dolny

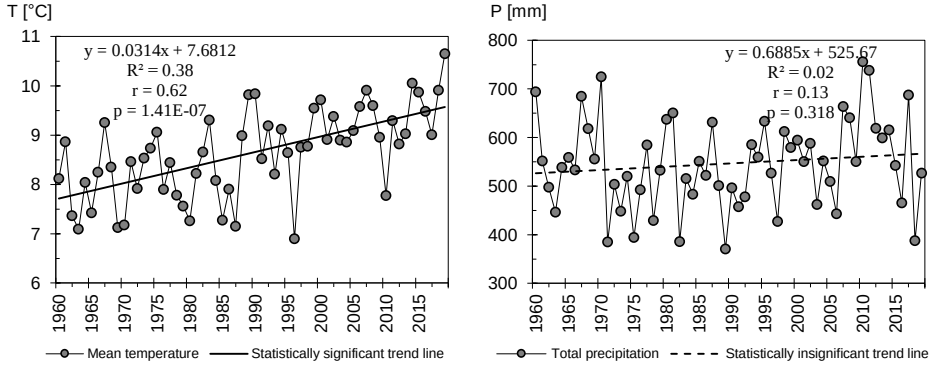
Mayr Tetratherm: MT=(T_{V}+T_{VI}+T_{VII}+T_{VIII})/4, where T_{V}-T_{VIII} represent the mean temperature for the May-August period ~~and Mayr Tethraterm (MT),~~ (Mayr, 1909); with optimal thermal conditions for beech wood of 13–18 °C (Satmari, 2010).

The main zone of *Cr-F* occurrence is the cliff top, which changes its location as a result of, among others, mass movements, water erosion and aeolian erosion. Thus, the cliff's morphodynamics is decisive for spatial reach of *Cr-F*. Annual measurements of the recession rate of cliff top and evolution of slope forms have been conducted since 1984 on four orchid beech wood sites (Fig. 1), (Kostrzewski et al., 2015; Winowski et al., 2019). Geomorphological changes in the cliff coast were registered a few times over a year, based on geodetic measurements, geomorphological mapping, photographic documentation collected with the use of photo-traps and drones.

3 Results

3.1 Hydrometeorological Conditions and Hazards

In the researched 60-year period (1960–2019), the mean annual air temperature reached 8.7°C, with statistically significant rising trend of 0.3°C per 10 years (Fig. 2). A cooler period lasted until the end of 1980s. Since 1990s, a considerable warming up may be observed, and especially warm period has been the decade of 2010s. The mean annual precipitation reached 546.7 mm. Annual sum of precipitation has not shown statistically significant long-term trend (Fig. 2). However, for the mean and maximum annual sea level, statistically significant rising trends in their values have been observed. The mean sea level has been rising by 2 cm per 10 years, which correlates with the results of Church et al. (2013). On the other hand, the dynamics in the maximum level rise is twice as high and amounts to 4 cm per 10 years (Fig. 3). Such positive long-term trends evidence a rising threat of cliff coast abrasion in the future. The mean annual sea level in the period of 1960–2019 amounted to 501 cm, but in the last 10 years it reached 508 cm.



Sformatowano: Indeks dolny
Sformatowano: Indeks dolny
Sformatowano: Indeks dolny
Sformatowano: Indeks dolny
Sformatowano: Czcionka: Kursywa
Sformatowano: Czcionka: Kursywa, Indeks dolny
Sformatowano: Czcionka: Kursywa
Sformatowano: Czcionka: Kursywa, Indeks dolny
Z komentarzem [JT32]: MR. WOLSKI, MR. KOZŁOWSKI: formulas for climate indicators have been added
Sformatowano: Akapit z listą, Wcięcie: Pierwszy wiersz: 1,27 cm
Z komentarzem [JT33]: ANONYMOUS REFEREE (line 102): the order of subsections was changed as recommended
Z komentarzem [JT34]: ANONYMOUS REFEREE (line 155): the text has been completed as suggested

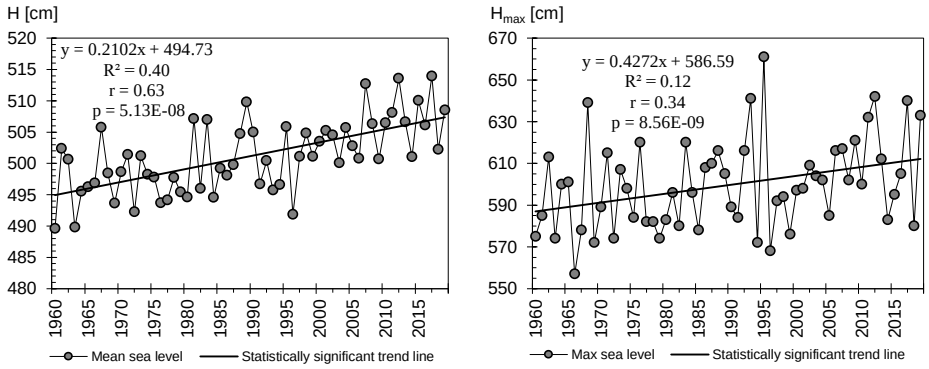


Figure 3. Long-term trends in hydrometeorological conditions: annual mean air temperature (T), annual total precipitation (P), annual mean sea level (H), annual maximum sea level (H_{max}), (Świnoujście, 1960–2019). *(Own study based on raw data from the Institute of Meteorology and Water Management in Warsaw).*

For recognition of thermal conditions of floral growth, a detailed analysis of thermal conditions trend may be presented with the data on vegetative season and heat resources. In Poland, the vegetative season starts, when the man daily air temperature exceeds 5°C. Heat resources in the vegetative season may be presented with the sum of effective temperatures, which are the sum of surpluses of the mean daily temperature exceeding 5°C (Tylkowski, 2015). The vegetative season in the research area lasts, on average, 228 days; it usually starts on March 30 and ends November 12. A statistically significant trend of extending the vegetative season by +3 days per 10 years has been proved (Fig. 4). The mean annual (1960–2019) sum of effective temperatures reached 1,817°C, and annual range of variability amounted to 1,500°C in 1967, and up to 2,254°C in 2018. The indicator of effective temperature sums featured for the researched area a positive trend of heat resource rise by 60°C per 10 years (Fig. 4), which is a favourable condition for the growth and expansion of stenothermal species. A regularity of a considerable heat resource rise has been confirmed, especially over the last 20 years. The dynamics of increasing the heat resources, especially in the 21st century is more noticeable than the increase in duration of the vegetative season.

Z komentarzem [JT35]: MR. KOZŁOWSKI, MRS. KIJOWSKA
R2 value, regression equation,
correlation index and p-value included in the figures

Sformatowano: Czcionka: Kursywa

Z komentarzem [JT36]: MR. WELSH: Raw data source added as suggested

Sformatowano: Czcionka: Kursywa

Sformatowano: Czcionka: Kursywa

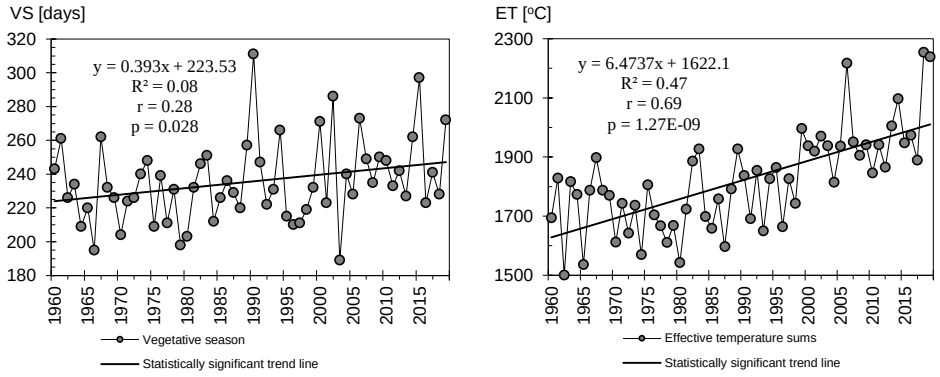
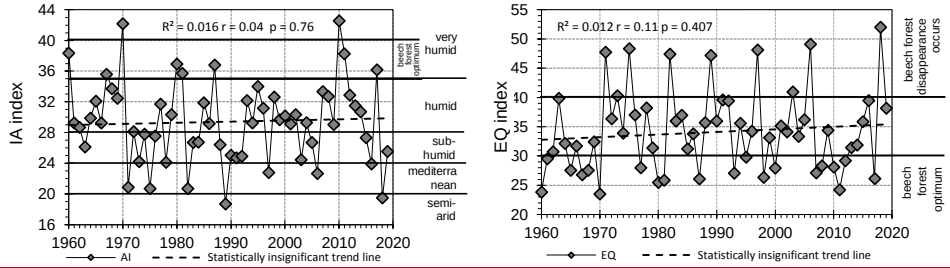


Figure 4. Long-term trends in the length of vegetative season (VS) and effective temperature sums (ET), (Świnoujście, 1960–2019). *(Own study based on raw data from the Institute of Meteorology and Water Management in Warsaw).*

In the last 60 years, the AI, EQ and MT indicators confirm long-term trend of worsening climatic conditions for *Cr-F* (Fig. 5). The AI and FAI indicators point to statistically insignificant (p>0.05) dropping trend, and the EQ indicator - insignificant rising trend. The proven long-term regularities of these indicators suggest worsening thermal and precipitation conditions for the researched forest phytocoenosis in subsequent years of the 21st century. Climatic indicators will probably head towards the threshold values for sub-humid conditions (AI index), which will spur the decay of beech forest (EQ index). Unfavourable thermal conditions will grow especially rapidly in the vegetative season (MT index), for which a statistically significant rising trend (p>0.05) has been established with the value of 0.33°C per 10 years (Fig. 5). Taking into account this trend's continuance in the future, it should be expected that within approximately 50 years, the thermal conditions for occurrence of *Cr-F* will be too excessive, and as a result, its degeneration will advance. Analysis of agro-climatic indicators (Fig. 5) pictured that during phytosociological mappings of *Cr-F* in 2018 and 2019, highly unfavourable climatic conditions occurred for its functioning.



Sformatowano: Czcionka: Kursywa

Z komentarzem [JT37]: MR. WELSH: Raw data source added as suggested

Z komentarzem [JT38]: MR. KOZŁOWSKI, MRS. KIJOWSKA
R2 value, regression equation,
correlation index and p-value included in the figures

Sformatowano: Czcionka: Kursywa

Sformatowano: Czcionka: Kursywa

Z komentarzem [JT39]: ANONYMOUS REFEREE (line 189): exchange word from ground cover to herb layer

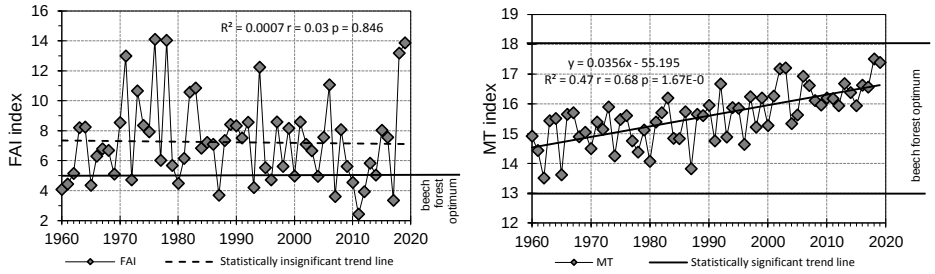


Figure 5. Long-term trends in climatic indicators: De Martonne Aridity Index (AI), Ellenberg Quotient (EQ), Forestry Aridity Index (FAI), Mayr Tetratherm Index (MT), (Świnoujście, 1960–2019). *(Own study based on raw data from the Institute of Meteorology and Water Management in Warsaw).*

3.2 Cliff Coast Morphodynamics Hazard

The mean annual rate of cliff top recession in 1984–2019 at *Cr-F* habitats II, III and V amounted to 0.24 m yr^{-1}. The lowest mean annual value of cliff recession was measured for site V (0.12 m yr^{-1}), where the cliff is built mainly of clayey sediments. The clayey sediments are characterised by relatively high resistance to degradation processes and the reaction time of cliff top to abrasion undercuttings is extended. A large number of storms is needed for the damages to reach the cliff top. On the other hand, the highest rate of cliff erosion has been established for site III (0.31 m yr^{-1}), where the cliff is built mainly of sandy material that is non-resistant to erosion. Sandy sediments are characterised by very low cohesion and are subject of rapid degradation. During stormy swellings, the sandy cliffs are undercut in a short time, which favours initiation of aeolian processes (deflation) and mass movements (sheddings, slidings). The processes cause the sediments to move across the entire slope profile, and thus the reaction of cliff top to abrasion undercutting is relatively short. An increased erosion dynamics has been observed also in site II (0.27 m yr^{-1}), on the cliff built of, both, clayey and sandy sediments. Its characteristic feature is the occurrence of underground water effluences, and high humidity of clayey sediments increases the susceptibility to landslide processes. The efficiency of the cliff springs is rather small <1 dm^3 min^{-1}. Landslide processes generate the highest cliff's transformations, contributing to movements of its top and cause reduction of *Cr-F* site area. In total, over the last 35 years, the researched cliffs recessed by an average of 7.32 m. The rate of recession of cliff top was spatially varied. The largest local and pinpoint movements were measured in the western part of site II (28.44 m) (Fig. 6). In this location, owing to high activity of landslide processes, the cliff top recessed with a high rate of 0.81 m yr^{-1}. In turn, the smallest local movements of cliff top were noted for eastern and western part of site V (0.30–0.42 m). In these locations, a very small rate of cliff top recession was connected with high resistance of clayey sediments to erosion processes and amounted to merely 0.01 m yr^{-1}.

Sformatowano: Czcionka: Kursywa

Z komentarzem [JT40]: MR. WELSH: Raw data source added as suggested

Z komentarzem [JT41]: MR. KOZŁOWSKI, MRS. KIJOWSKA
R2 value, regression equation,
correlation index and p-value included in the figures

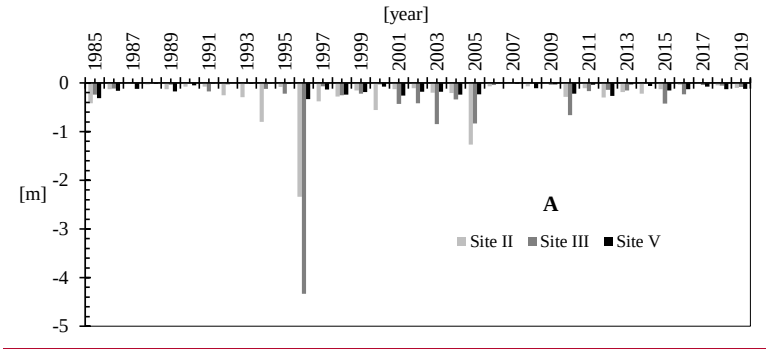
Sformatowano: Czcionka: Kursywa

Sformatowano: Czcionka: Kursywa

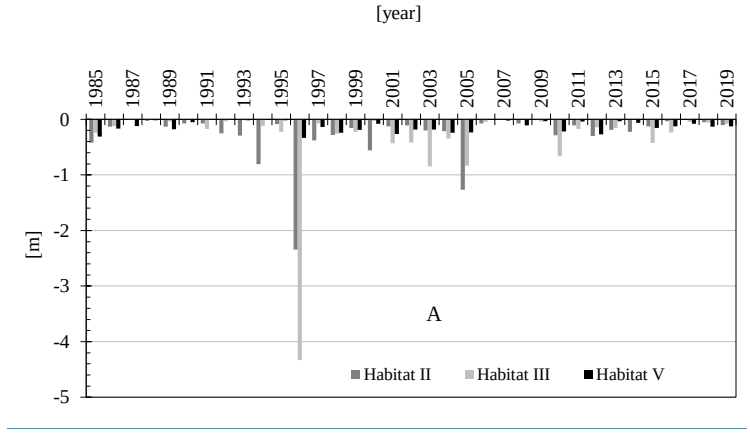
Z komentarzem [JT42]: ANONYMOUS REFEREE (line 207): the text has been completed as suggested

Sformatowano: Indeks górny

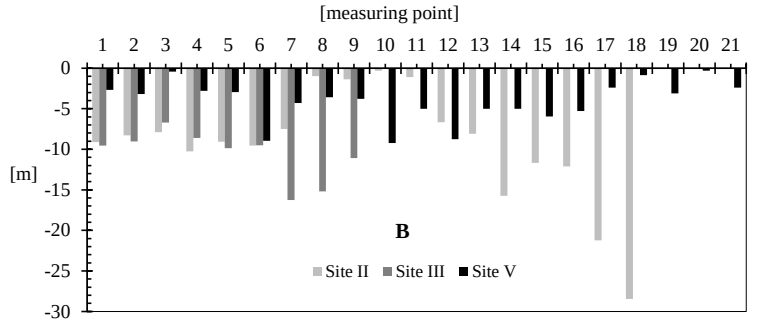
Sformatowano: Indeks górny


[year]
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
0
-1
-2
-3
-4
-5
[m]
A
Site II
Site III
Site V

207


[year]
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
0
-1
-2
-3
-4
-5
[m]
A
Habitat II
Habitat III
Habitat V

208



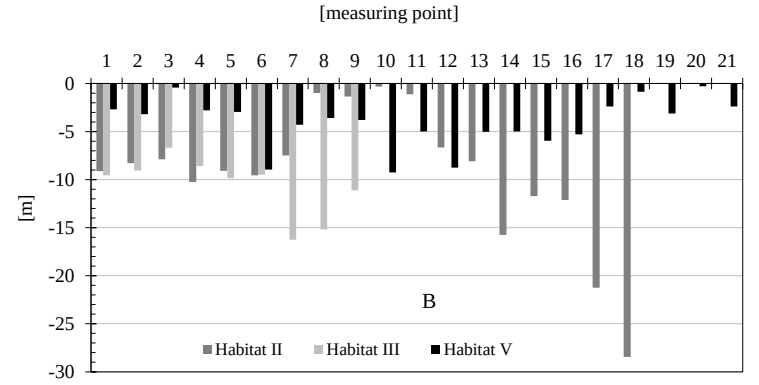


Figure 6. Location changes of cliff top at sites II, III and V of *Cr-F* in the period of 1985–2019: A – annual mean at sites, B – total multiannual in measurement points at sites. *(Own study based on own measurements and raw data from Kostrzewski et al. 2015, Winowski et al. 2019).*

A relatively lower sections of cliff coast (<30 m a.s.l.), which are primarily built of non-resistant to erosion sandy formations, do not favour the occurrence of the *Cr-F* phytocoenoses. In these sections of cliff coast, the deposition of sediments containing the calcium carbonate required by the orchid beech wood is relatively small (sandy sediments contain 4-5 times less calcium carbonate 2% than clay sediments) and an increased erosion (sandy sediments are much less resistant to erosion than clay sediments) of the coast results additionally in the reduction of habitat's area. A different situation is with the high cliff, with considerable share of clayey sediments. When aeolian processes occur, the dusty material, originating mainly in the clayey slope, rich in calcium carbonate, is accumulated on the cliff top and in cliff's hinterland, causing soil

Sformatowano: Czcionka: Kursywa

Z komentarzem [JT43]: MR. WELSH: Raw data source added as suggested

Sformatowano: Czcionka: Kursywa

Sformatowano: Czcionka: Kursywa

Z komentarzem [JT44]: ANONYMOUS REFEREE (line 219): the text has been supplemented as suggested

Z komentarzem [JT45]: ANONYMOUS REFEREE (line 220): exchange words from orchid beech wood to Cr-F phytocoenoses

Sformatowano: Czcionka: Kursywa

Z komentarzem [JT46]: ANONYMOUS REFEREE (line 221): clarification added

deacidification. This is the condition that particularly favours the development of *Cr-F* habitats (e.g., habitat V). Limited occurrence of the orchid beech wood or its lack stems also from development cycles of the cliff coast. For the sandy and dusty material — that is the components of the cliff naspa — to be supplied, a morphogenetic activity at the cliff's slope is required. Only then material deflation from the cliff's slope and its subsequent aeolian deposition in the cliff's hinterland is possible. Thus, the aeolian deposition is indispensable for the formation and development of the cliff naspa for inland. When the cliff coast, over an extended period of time, is not subject to processes of maritime abrasion and slope erosion, then its slope is covered with vegetation under of biocenotic succession. The vegetation considerably hinders, and even renders impossible the supply of aeolian matter, and, in consequence, the formation of cliff naspa, which in a longer perspective spurs the decay of the *Cr-F* phytocoenoses (e.g., habitat I). That is the occurrence of the active morphogenetic processes of small intensity is desirable (e.g., at habitat V, mean annual rate of cliff top recession in the last 35 years amounted to 'as little as' 0.12 m yr^{-1}). The dynamics of coast recession may not, however, be too intensive, and exceed the natural expansion of the cliff naspa and *Cephalanthero rubrae-Fagetum* habitat for inland direction. Then, the decrease in habitat area is spurred (e.g., on habitat III, mean annual rate of cliff top recession in the last 35 years has been considerable and amounted to 0.32 m yr^{-1}). Therefore, the optimal morpholitodynamic conditions for the growth of *Cr-F* are found mainly on habitat V. Similar conditions are on habitats II and IV. On the remaining habitats of the *Cr-F* phytocoenoses, the morpholitodynamic conditions are rather unfavourable - too much (habitat III) or too little (habitat I) cliff erosion.

Z komentarzem [JT47]: ANONYMOUS REFEREE (line 229): exchange words from movement to development

Z komentarzem [JT48]: ANONYMOUS REFEREE (line 230): exchange words as suggested

Sformatowano: Czcionka: Kursywa

Sformatowano: Czcionka: Kursywa

Z komentarzem [JT49]: ANONYMOUS REFEREE (line 239): the text has been supplemented as suggested

3.~~1~~ 3 Reach and Floristic Composition of *Cr-F*

Currently, *Cr-F* grows along the northern cliffed coast of Wolin island, between ~~Biała~~ Biała ~~Góra~~ Góra and Grodno, in 6 isolated sites with total area of merely 7.3 ha. The researched phytocoenosis occurs over a short, 3 km section of the coast, in the form of narrow belt of approximately 100 m for inland, between cliff's edge and a complex of ~~acidic~~ lowland acidophilous beech forest~~fertile lowland beech wood~~, *Luzulo pilosae-Fagetum*.

The floral richness of *Cr-F*, association ~~complex~~ consists in 113 species of vascular plants. They represent 2 divisions — ~~*Pterydiophyta*~~ *Pteridophyta* and *Spermatophyta*. In ~~*Pterydiophyta*~~ *Pteridophyta* ~~divisions~~ 4 species have been recorded~~confirmed~~: *Dryopteris carthusiana*, *Dryopteris filix-mas*, *Polypodium vulgare*~~*Pteridium aquilinum*, *Dryopteris carthusiana*~~ and *Pteridium aquilinum* ~~*Polypodium vulgare*~~. And, in *Sperma~~t~~ophyta* ~~division~~ 3 classes have been confirmed: *Pinopsida* (2 species: *Juniperus communis* and *Pinus s~~S~~ylve~~r~~stris*), *Magnoliopsida* (23 orders, 29 families and 82 species) and *Liliopsida* (respectively 3, 6 and 27~~3 orders, 6 families and 27 species~~). The richest in species have been the families of: *Poaceae* (14 species), *Asteraceae* (13 ~~species~~), *Fabaceae* (11 ~~species~~) and *Rosaceae* (6 ~~species~~). *Orchidaceae* ~~family~~ has been represented by 7 species: *Cephalanthera damasonium*, *Cephalanthera rubra*, *Corallorhiza trifida*, ~~*Cephalanthera damasonium,*~~ *Epipactis atrorubens*, *Epipactis hellaborine*, *Neottia nidus-avis*, ~~*Corallorhiza trifida,*~~ *Platanthera bifolia.* The researched site is an example of a coexistence between forest species of fertile and acidic beech woods, acidophilic oak woods and forests, and species of meadows and psammophilous swards. ~~psammophilic meadows and turfs (*Brachypodium*~~

Z komentarzem [JT50]: ANONYMOUS REFEREE (line 105): exchange words from acidic fertile lowland beech wood to lowland acidophilous beech forest

Z komentarzem [JT51]: ANONYMOUS REFEREE (line 107): exchange word from complex to association

Sformatowano: Czcionka: Nie Kursywa

Z komentarzem [JT52]: ANONYMOUS REFEREE (line 108): the text has been changed as suggested

~~sylvaticum, Poa nemoralis, Dactylis glomerata~~). There have observed species from syntaxa~~There have also been species registered from syntaxa~~: *Artemisietea vulgaris, Festuco-Brometea, Molinio-Arrhenatheretea,* *Querco-Fagetea*~~, –~~ and *Vaccinio-Piceetea*~~, *Festuco-Brometea, Molinio-Arrhenatheretea* and *Artemisiatea vulgaris*~~.

Table 1. Localisation and plant indicators of *Cr-F* habitats in 2019.

Number of habitat	Habitat area [ha]	Habitat localisation Project Coordinate Reference System (CRS): WGS-84 EPSG code: 4326			Plant indicators			
		Western border	Geometric center point	Eastern border	Number of *Cephalanthera rubra* individuals	Population density of *Cephalanthera rubra* per ha	Number of vascular plants species	Number of orchid species
I	1.6	E 14.4773470193 N 53.9486589253	E 14.4806801645 N 53.9506233460	E 14.4834568531 N 53.9525988261	6	4	59	1
II	1.3	E 14.4867629684 N 53.9532540446	E 14.4874208216 N 53.9553690329	E 14.4893115966 N 53.9566819942	57	44	97	4
III	1.1	E 14.4901694844 N 53.9572079802	E 14.4928896207 N 53.9585486797	E 14.4946745712 N 53.9597487270	34	31	91	4
IV	0.1	E 14.4951038446 N 53.9601527431	E 14.4955996444 N 53.9604923130	E 14.4959653287 N 53.9607642732	5	50	47	4
V	1.7	E 14.4963451055 N 53.9608660790	E 14.4985988815 N 53.9614999353	E 14.4996322142 N 53.9629403030	51	30	73	6
VI	1.5	E 14.5002867011 N 53.9631609678	E 14.5046702332 N 53.9643211393	E 14.5085083424 N 53.9651740858	22	15	78	5

~~Site~~ Habitat I ~~(1.6 ha)~~. The cliff slope is not subject to erosion processes, and for over 35 years it has been the so-called 'dead cliff'. Therefore, a~~A~~eolian deposition on the cliff top is very limited and the *Cr-F* ~~site~~ habitat decays. Soil profile and ~~In surface sediments,~~ the presence of calcium carbonate in surface sediments ~~has been confirmed~~confirm~~, which may evidence~~ the presence of cliff naspa and morphodynamic activity of this cliff section in the past. On cliff top, there is a little number of *Cephalanthera rubra* specimens (Table 1), which ~~may be~~are relics of a once well-developed ~~site~~habitat. There are no other orchid species found, though. The ground cover was poor (<5% coverage in the herb layer), and the confirmed species of *Luzula pilosa* and *Trientalis europaea* are the distinguishing species of the *Luzulo-Fagenion* beech forests.~~*Luzula pilosa, Trientalis europaea* are more typical for acidic beech wood than for orchid beech wood.~~

~~Site~~ Habitat II ~~(1.3 ha)~~. In terms of phytosociology, this is a phytocoenosis of *Cr-F* typicum~~typical patch of orchid beech wood~~. The cliff wall is predisposed to aeolian processes as it is exposed and morphogenetically active~~The cliff wall is exposed, active and predisposed to aeolian processes~~. The ground cover is rich in species. The highest number (97) of vascular plants species was found in this habitat (Table 1). There is ~~a~~ high~~high~~ concentration of *Cephalanthera rubra* (44 individuals per ha)~~orchids,~~ and 4 orchid species have been found: *Cephalanthera damasonium,* *Cephalanthera rubra*, *Epipactis hellaborine*, *Epipactis atrorubens*~~, *Cephalanthera damasonium*~~. There are also numerous species of *Poaceae* family (among others, *Brachypodium sylvaticum*, *Calamagrostis arundinacea*, *Deschampsia flexuosa*, *Poa nemoralis*~~, *Calamagrostis arundinacea, Deschampsia flexuosa*~~). Density of beech heads at this site is little (approximately 50–%) and light conditions are favourable for the development of the ground cover (94% coverage in the herb layer), rich in species. A large portion (20%) of the site is covered by beech brushwood, which evidences an intensive renewal of forest.

Sformatowano
Z komentarzem [JT53]: ANONYMOUS REFEREE (line 10
Sformatowano
Z komentarzem [JT54]: ANONYMOUS REFEREE (line 11
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowana tabela
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano
Sformatowano

~~Sites~~ Habitats III ~~(1.1 ha)~~ and IV ~~(0.1 ha)~~. The plant indicators in Table 1 show that the habitats are moderately ~~The sites are moderately~~ formed. At ~~site~~ habitat III, there are intensive erosion processes taking place. Despite the aeolian deposition on the cliff top (40 m a.s.l.) is high~~on the cliff top is high (40 m a.s.l.)~~, then due to a relatively high rate of cliff's recession (0.31 m yr^{-1}), the site's reach in this location decreases. The ground cover is well developed, and there are 4 species of *Orchidaceae* ~~family~~: *Cephalanthera rubra*, *Epipactis atrorubens*, *Epipactis hellaborine*, *Neottia nidus-avis*. They are, however, quite diffused and occur in a relatively narrow (*Cephalanthera rubra* density 31 individuals per ha) strip along the cliff top (max 40 m). However, the habitat IV is a very small (0.1 ha), isolated area, where 5 individuals of *Cephalanthera rubra* have been found.

~~Site~~ Habitat V ~~(1.7 ha)~~. The biggest patch of *Cr-F* typicum~~a typical orchid beech wood~~, developed the very good (Table 1)~~best~~. The cliff's wall is exposed, and high (35-50 m a.s.l.) aeolian deposition on cliff top is visible. Aeolian material is visible on plants and the ground surface. The increment of aeolian cover in the soil profile is about 4 mm y^{-1} in 2000-2019. The ground cover is well developed (57% coverage in the herb layer), rich in species (73), although in some areas their number drops due to poorer light conditions (high coverage of forest canopy). There is a high abundance~~concentration~~ of *Cephalanthera rubra* (51), as well as other orchid species. This site is a strongly, upon inland, encroaching part of the site. Species regionally characteristic for *Cr-F* ~~typical for orchid beech wood~~ have been found even up to 100 metres from the cliff's edge. Even in this zone there were orchids, but their numbers were smaller than at the cliff. In total, 6 species of *Orchidaceae* have been identified: *Cephalanthera damasonium*, *Cephalanthera rubra*, *Epipactis atrorubens*, *Epipactis hellaborine*, *Neottia nidus-avis*, ~~*Cephalanthera damasonium*~~, *Platanthera bifolia*.

~~Site~~ Habitat VI ~~(1.5 ha)~~. This ~~site~~ habitat may also be considered a patch of *Cr-F* typicum (Table 1)~~typical orchid beech wood~~, but a smaller concentration of *Cephalanthera rubra* (15 ~~orchids~~ individuals per ha) has been confirmed there. The cliff is mostly clayey and low (25-30 m a.s.l.), thus the intensity of aeolian deposition is relatively smaller (2 mm y^{-1} in 2000-2019). The cliff tableland is flat. And the ground cover covers up to 90 % of the phytocoenose area~~area~~ and is rich in species typical for orchid beech wood. There have been ~~3~~ 5 species of ~~o~~orchid species from *Cephalanthero- Fagenion* ~~rchids~~ confirmed: *Cephalanthera damasonium*, *Cephalanthera rubra*, *Corallorhiza trifida*, *Epipactis atrorubens*, *Epipactis hellaborine*.

The most valuable orchid beech woods ~~sites~~ habitats are II, V and VI. ~~Site~~ Habitat V is the best developed patch of *Cr-F*~~orchid beech wood~~, with optimal habitat conditions: favourable morpholitodynamic conditions (~~high~~ abrasive coast ~~cliff~~but low rate of cliff's recession 0.12 m yr^{-1}, higher share of clay sediments, rich in calcium carbonate 8-10%~~with balanced share of clayey and sandy sediments and considerable supply of dusty and sandy formations, rich in calcium carbonate, to the cliff's hinterland, low rate of cliff's recession~~); favourable light conditions (relatively greater insolation of the forest floor);~~; beech forest without the share of pine — no pinetisation;~~ ground cover of orchid beech wood, developing~~moving~~ for inland for a dozen or so meters in some points). The relatively poorest condition was confirmed for ~~site~~ habitat I, which does not develop due to unfavorable morpholithodynamic conditions~~which due to unfavourable~~

Sformatowano: Indeks górny

Sformatowano: Czcionka: Kursywa

Sformatowano: Nie Wyróżnienie

Sformatowano: Czcionka: Kursywa

Z komentarzem [JT68]: ANONYMOUS REFEREE (line 131-135):
added quantitative description

Sformatowano: Czcionka: Kursywa

Sformatowano: Nie Wyróżnienie

Sformatowano: Indeks górny

Z komentarzem [JT69]: ANONYMOUS REFEREE (line 128-129):
more information have been added

Sformatowano: Nie Wyróżnienie

Sformatowano: Czcionka: Kursywa

Z komentarzem [JT70]: ANONYMOUS REFEREE (line 136-142):
more information have been added

Sformatowano: Czcionka: Kursywa

Sformatowano: Nie Wyróżnienie

Sformatowano: Czcionka: Kursywa

Sformatowano: Czcionka: Kursywa

Z komentarzem [JT71]: ANONYMOUS REFEREE (line 143-144):
more information have been added

Sformatowano: Czcionka: Kursywa

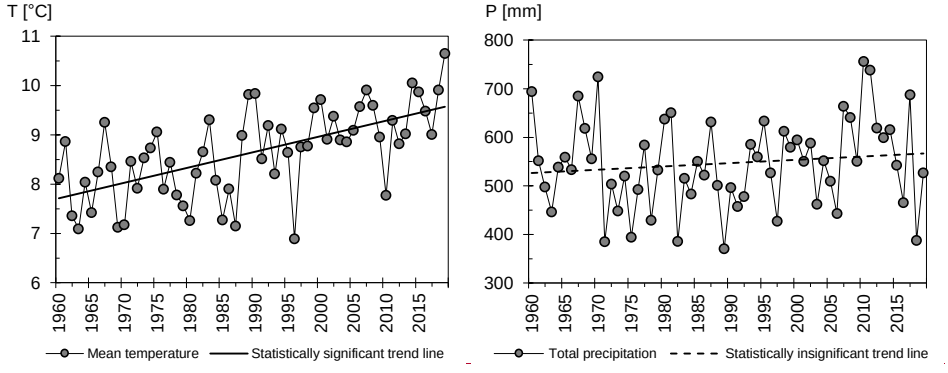
Sformatowano: Indeks górny

~~morpholitodynamic conditions of sea coast is decaying~~ (dead non-erosive cliff, stabilised with compact pine wood, no possibility of forming naspa).

Z komentarzem [JT72]: ANONYMOUS REFEREE (line 148-152):
sentence was corrected as suggested

~~3.2 Hydrometeorological Conditions and Hazards~~

~~In the researched 60-year period, the mean annual air temperature reached 8.7°C, with statistically significant rising trend of 0.3°C per 10 years (Fig. 2). A cooler period lasted until the end of 1980s. Since 1990s, a considerable warming up may be observed, and especially warm period has been the decade of 2010s. The mean annual precipitation reached 546.7 mm. Annual sum of precipitation has not shown statistically significant long-term trend (Fig. 2). However, for the mean and maximum annual sea level, statistically significant rising trends in their values have been observed. The mean sea level has been rising by 2 cm per 10 years, which correlates with the results of Church et al. (2013). On the other hand, the dynamics in the maximum level rise is twice as high and amounts to 4 cm per 10 years (Fig. 2). Such positive long-term trends evidence a rising threat of cliff coast abrasion in the future. The mean annual sea level in the period of 1960–2019 amounted to 501 cm, but in the last 10 years it reached 508 cm.~~



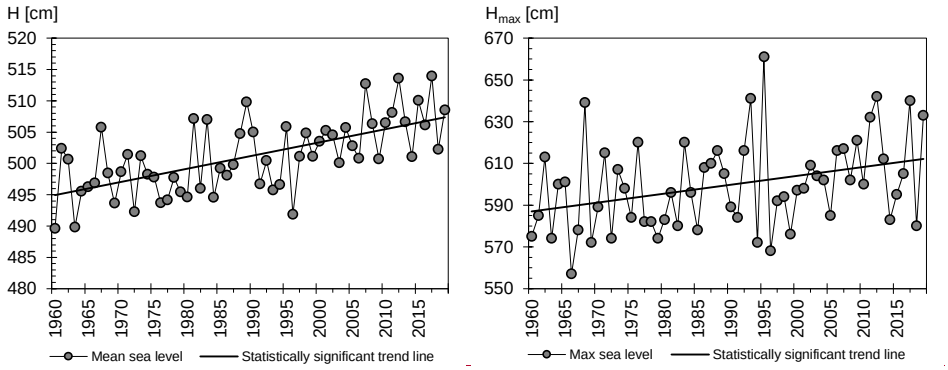


Figure 2. Long-term trends in hydrometeorological conditions: annual mean air temperature (T), annual total precipitation (P), annual mean sea level (H), annual maximum sea level (H_{max}), (Swinoujscie, 1960–2019).

For recognition of thermal conditions of floral growth, a detailed analysis of thermal conditions trend may be presented with the data on vegetative season and heat resources. In Poland, the vegetative season starts, when the man daily air temperature exceeds 5°C. Heat resources in the vegetative season may be presented with the sum of effective temperatures, which are the sum of surpluses of the mean daily temperature exceeding 5°C (Tylkowski, 2015). The vegetative season in the research area lasts, on average, 228 days; it usually starts on March 30 and ends November 12. A statistically significant trend of extending the vegetative season by +3 days per 10 years has been proved (Fig. 3). The mean annual (1960–2019) sum of effective temperatures reached 1817°C, and annual range of variability amounted to 1,500°C in 1967, and up to 2,254°C in 2018. The indicator of effective temperature sums featured for the researched area a positive trend of heat resource rise by 60°C per 10 years (Fig. 3), which is a favourable condition for the growth and expansion of stenothermal species. A regularity of a considerable heat resource rise has been confirmed, especially over the last 20 years. The dynamics of increasing the heat resources, especially in the 21st century is more noticeable than the increase in duration of the vegetative season.

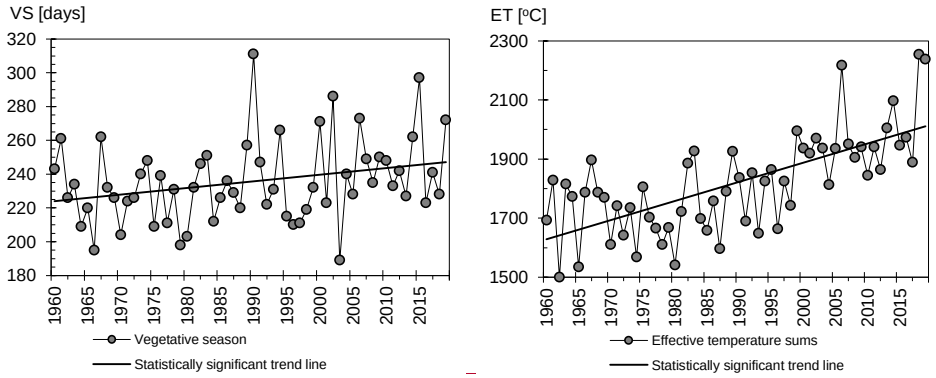
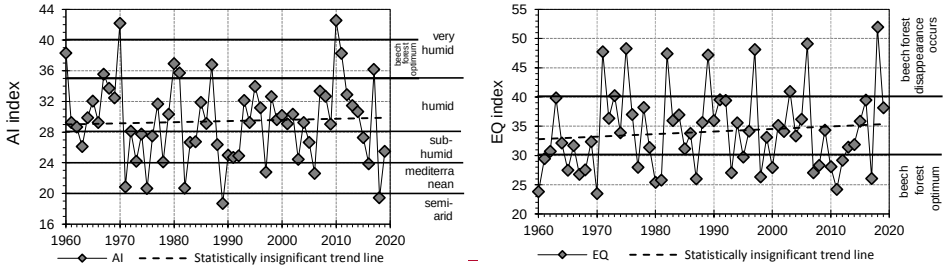


Figure 3. Long-term trends in the length of vegetative season (VS) and effective temperature sums (ET), (Swinoujscie, 1960–2019).

In the last 60 years, the AI, EQ and MT indicators confirm long-term trend of worsening climatic conditions for *Cr-F* (Fig. 4). The AI and FAI indicators point to statistically insignificant (p>0.05) dropping trend, and the EQ indicator – insignificant rising trend. The proven long-term regularities of these indicators suggest worsening thermal and precipitation conditions for the researched forest phytocoenosis in subsequent years of the 21st century. Climatic indicators will probably head towards the threshold values for sub-humid conditions (AI index), which will spur the decay of beech forest (EQ index). Unfavourable thermal conditions will grow especially rapidly in the vegetative season (MT index), for which a statistically significant rising trend (p>0.05) has been established with the value of 0.33°C per 10 years (Fig. 4). Taking into account this trend's continuance in the future, it should be expected that within approximately 50 years, the thermal conditions for occurrence of *Cr-F* will be too excessive, and as a result, its degradation will advance. Analysis of agro-climatic indicators (Fig. 4) pictured that during phytosociological mappings of *Cr-F* in 2018 and 2019, highly unfavourable climatic conditions occurred for its functioning.



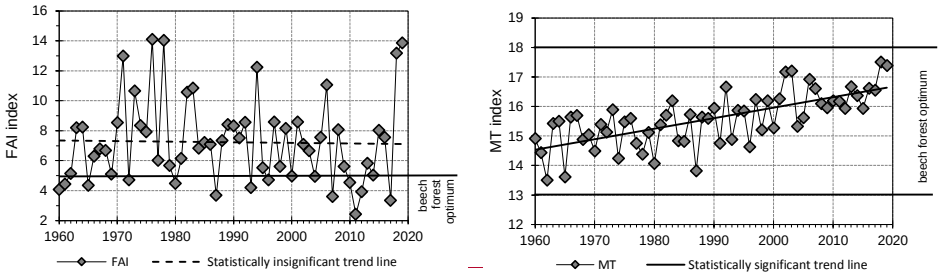
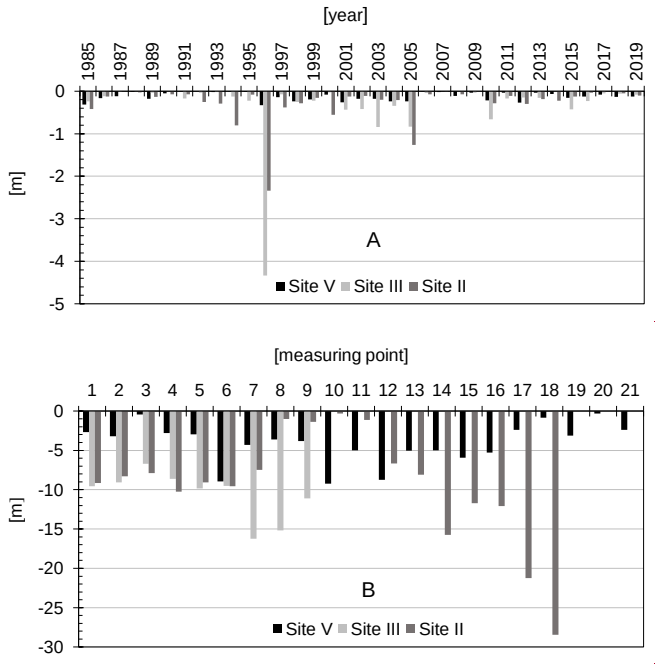


Figure 4. Long-term trends in climatic indicators: De Martonne Aridity Index (AI), Ellenberg Quotient (EQ), Forestry Aridity Index (FAI), Mayr Tetratherm Index (MT), (Swinoujscie, 1960–2019).

3.3 Cliff Coast Morphodynamics Hazard

The mean annual rate of cliff top recession in 1984–2019 at *Cr-F* sites II, III and V amounted to 0.24 m yr^{-1}. The lowest mean annual value of cliff recession was measured for site V (0.12 m yr^{-1}), where the cliff is built mainly of clayey sediments. The clayey sediments are characterised by relatively high resistance to degradation processes and the reaction time of cliff top to abrasion undercuttings is extended. A large number of storms is needed for the damages to reach the cliff top. On the other hand, the highest rate of cliff erosion has been established for site III (0.31 m yr^{-1}), where the cliff is built mainly of sandy material that is non-resistant to erosion. Sandy sediments are characterised by very low cohesion and are subject of rapid degradation. During stormy swellings, the sandy cliffs are undercut in a short time, which favours initiation of aeolian processes (deflation) and mass movements (sheddings, slidings). The processes cause the sediments to move across the entire slope profile, and thus the reaction of cliff top to abrasion undercutting is relatively short. An increased erosion dynamics has been observed also in site II (0.27 m yr^{-1}), on the cliff built of, both, clayey and sandy sediments. Its characteristic feature is the occurrence of underground water effluences, and high humidity of clayey sediments increases the susceptibility to landslide processes. Landslide processes generate the highest cliff's transformations, contributing to movements of its top and cause reduction of *Cr-F* site area. In total, over the last 35 years, the researched cliffs recessed by an average of 7.32 m. The rate of recession of cliff top was spatially varied. The largest local and pinpoint movements were measured in the western part of site II (28.44 m) (Fig. 5). In this location, owing to high activity of landslide processes, the cliff top recessed with a high rate of 0.81 m yr^{-1}. In turn, the smallest local movements of cliff top were noted for eastern and western part of site V (0.30–0.42 m). In these locations, a very small rate of cliff top recession was connected with high resistance of clayey sediments to erosion processes and amounted to merely 0.01 m yr^{-1}.



~~Figure~~ 5. ~~Location changes of cliff top at sites II, III and V of *Cr-F* in the period of 1985–2019: A – annual mean at sites, B – total multiannual in measurement points at sites.~~

~~A relatively lower sections of cliff coast, which are primarily built of non-resistant to erosion sandy formations, do not favour the occurrence of the orchid beech wood. In these sections of cliff coast, the deposition of sediments containing the calcium carbonate required by the orchid beech wood is relatively small and an increased erosion of the coast results additionally in the reduction of habitat's area. A different situation is with the high cliff, with considerable share of clayey sediments. When aeolian processes occur, the dusty material, originating mainly in the clayey slope, rich in calcium carbonate, is accumulated on the cliff top and in cliff's hinterland, causing soil deacidification. This is the condition that particularly favours the development of *Cr-F* site (e.g., site V). Limited occurrence of the orchid beech wood or its lack stems also from development cycles of the cliff coast. For the sandy and dusty material – that is the components of the cliff naspa – to be supplied, a morphogenetic activity at the cliff's slope is required. Only then material deflation from the cliff's slope and its subsequent aeolian deposition in the cliff's hinterland is possible. Thus, the aeolian deposition is indispensable for the formation and movement of the cliff naspa for inland. When the cliff coast, over an extended period of time, is not~~

~~subject to processes of maritime abrasion and slope erosion, then its slope is covered with permanent crust vegetation. The vegetation considerably hinders, and even renders impossible the supply of aeolian matter, and, in consequence, the formation of cliff naspa, which in a longer perspective spurs the decay of orchid beech wood (e.g., site I). That is the occurrence of the active morphogenetic processes of small intensity is desirable (e.g., at site V, mean annual rate of cliff top recession in the last 35 years amounted to 'as little as' 0.12 m yr^{-1}). The dynamics of coast recession may not, however, be too intensive, and exceed the natural expansion of the cliff naspa and *Cephalantero rubrae-Fagetum* site for inland direction. Then, the decrease in site area is spurred (e.g., on site III, mean annual rate of cliff top recession in the last 35 years has been considerable and amounted to 0.32 m yr^{-1}). Therefore, the optimal morpholitodynamic conditions for the growth of *Cr-F* are found mainly on site V. Similar conditions are on sites II and IV. On the remaining sites of the orchid beech wood, the morpholitodynamic conditions are rather unfavourable.~~

4 Discussion

Current condition and future development of coastal phytocoenoses depends, primarily, on changes in climatic conditions and morphodynamics of sea coasts. In the 21st century, in the Polish coastal zone of the Baltic Sea, the mean annual air temperature may rise by 2–3°C, with concurrent rise in total precipitation by 0–10% during summer and 10–20% during winter (Collins et al., 2013). Many research works indicate that in the last half-century, as a result of global warming (Sillmann et al., 2013) the increase in activity of cyclones occurred, as well as the frequency of western winds in northern Europe (Pinto et al., 2007) and over the Baltic Sea region (Sepp, 2009) increased. Another of the observed changes is the northward displacement of trajectories of lows, which may cause advections of warm and humid air to northern Europe and decrease in precipitation in central Europe (Bengtsson et al., 2006). The changes are connected with a varied location of the Icelandic Low and the North Atlantic oscillation (NAO), (Omstedt et al., 2004). In the Baltic Sea catchment area, the warming will probably be higher than the mean global value, and the air temperature rise will, probably, be accompanied by higher precipitation, especially in winters. Also, the rise in frequency and duration of droughts (Orlowsky and Seneviratne, 2012) and heat-waves (Nikulin et al., 2011) is also expected. In the 21st century, the forecast climate changes will be accompanied by the rise in sea levels up to 1 m, and absolute rise of the Baltic Sea level is estimated to reach 80% of the mean rise of the world ocean level. For the south-west coasts of the Baltic Sea, the estimated rise in water level would be high, reaching approximately 60 cm (Grinsted, 2015). The executed hydrodynamic modelling iterations assume also the rise in frequency of stormy swellings for the entire Baltic Sea, in all seasons (Vousdoukas et al., 2016). Changes of the climate and hydrodynamic characteristics of seas will favour high frequency of extreme hydrometeorological events. In Poland, for the Baltic coasts, over the recent half-century, a rise in the frequency of extreme hydrometeorological events has been confirmed (Paprotny and Terefenko, 2017; Tylkowski and Hojan, 2018). Extremely high stormy swellings and precipitation intensify hydrological and geomorphological process, e.g., stormy floods or mass movements at cliff coasts. For the Polish coastal zone of the

Baltic Sea, the occurrence of such unfavourable geomorphological results of extreme and above-average hydrometeorological events has been confirmed for, both, cliff and dune coasts (Florek et al., 2009; Furmańczyk et al., 2012; Hojan et al., 2018; Kostrzewski and Zwoliński, 1995; Tylkowski, 2017, 2018).

Climate changes in the 21st century will cause dynamic changes in the reach of forest phytocoenoses, including *Fagus ~~Silvatica~~sylvatica*. The forecast warming and gradual deterioration of water conditions in the coming 50 years will not influence considerably the changes in beech forest sites, yet. But from 2070 onwards, climatic conditions will be too warm and too dry for the growth of *Fagus ~~Silvatica~~ sylvatica* and this species will start to withdraw from the area of researches (Falk and Winckelmann, 2013). The above forecast corresponds to the long-term trend of the agro-climatic indicators presented in the elaboration, especially with Mayr Tethraterm Index. According to the forecast variability of this indicator, in 50 years, climatic conditions will not be suitable for the development of the *Cr-F* habitat.

In the analysed period (1985-2019), the average annual rate of the cliff crown retraction on the examined sections amounted to 12 up to 31 cm and it was much lower than the values estimated (80-100 cm) by the mid-twentieth century by Subotowicz (1982) and Kostrzewski (1984). Whereas, the maximum annual point retraction of the cliff crown was almost 10 m. The average annual retraction rate of the Wolin cliffs is approximately 2-4 times lower than other monitored cliff coasts, e.g. in the vicinity of Ustka, Jastrzębia Góra or Gdynia (e.g., Florek et al. 2009; Łęczynski 1999). Although the Wolin cliffs are much higher and are not subjected to any protective measures, the relatively lowest rate of their retraction results primarily from specific hydrogeological conditions. For example, contrary to the cliff coast in Jastrzębia Góra (Uścinowicz et al. 2017) on the island of Wolin, underground waters practically do not play any role in erosion processes and shore degradation.

Species composition of association's phytocoenoses has not changed extensively over the last half-century, which confirms its relative stability; however, some *Orchidaceae* habitats of do not keep up with the rate of the cliff's recession or they do not develop due to many years of cliff erosive stagnation. No specimens of *Malaxis monophyllos* were confirmed, which was occurring at the cliff's edge tens of years ago (Piotrowska, 1993; Prusinkiewicz, 1971). A vast loss for the site is also the lack of current confirmation for the occurrence of *Listera ovata*. Also, it has been confirmed that the number of *Lonicera xylosteum* decreased — a species important for the orchid beech wood. In past elaborations, the indicatory species of *Cephalantero rubra* featured a larger reach in the area of Wolin National Park, e.g., in forest divisions of Miedzyzdroje 16 and Wiselka 2. Currently, no specimens of *Cephalantero rubra* have been found on those sites, which is the confirmation for the decreasing reach of this species in Wolin National Park. ~~will be too demanding for the growth of *Cr-F*.~~

5 Conclusions

The analysis of *Cr-F* ~~site~~ habitats indicated its small total area of merely 7.3 ha. This valuable site consists of 6 isolated, single sites with an area of 1.7 ha to just 0.1 ha. ~~This valuable site is de-fragmented into 6 individual sites with the area from 1.7 ha to as little as 0.1 ha.~~ Discontinuity ~~and de-fragmentation~~ of the site stems from many natural factors —

Z komentarzem [JT73]: ANONYMOUS REFEREE (line 270): sentence was corrected as suggested

Sformatowano: Czcionka: Kursywa

Z komentarzem [X74]: MR. KOZŁOWSKI: sentence was addeded as suggested

Sformatowano: Angielski (Stany Zjednoczone)

Z komentarzem [JT75]: ANONYMOUS REFEREE (line 276-282): sentence moved to discussion

Z komentarzem [JT76]: ANONYMOUS REFEREE (line 276-282) MRS. KIJOWSKA: sentence moved from conclusions

Z komentarzem [JT77]: ANONYMOUS REFEREE (line 272-273): sentence was corrected as suggested

mainly due to the spatial variability of the cliff's morpholitodynamics. Phytosociological ~~mappings~~ studies evidenced relatively good condition of *Cr-F* in majority of sites. ~~Species composition has not changed extensively over the last half-century, which confirms its relative stability; however, some *Orchidacea* species do not keep up with the rate of the cliff's recession. No specimens of *Malaxis monophyllos* were confirmed, which was occurring at the cliff's edge tens of years ago. A vast loss for the site is also the lack of current confirmation for the occurrence of *Listera ovata*. Also, it has been confirmed that the number of *Lonicera xylosteum* decreased — a species important for the orchid beech wood. In past elaborations, the indicatory species of *Cephalantero rubra* featured a larger reach in the area of Wolin National Park, e.g., in forest divisions of Miedzyzdroje 16 and Wiselka 2. Currently, no specimens of *Cephalantero rubra* have been found on those sites, which is the confirmation for the decreasing reach of this species in Wolin National Park.~~

The analysis of temporal variability of hydrometeorological conditions, duration of the vegetative season and heat resources (1960–2019), as well as cliff coast morphodynamics (1985–2019) has indicated, up to now, rather favourable conditions for the growth of *Cr-F* site. A statistically significant trends of the increase in mean annual air temperature, sea level, duration of the vegetative season and heat resources have been verified. Analysis of climatic indicators AI, EQ and FAI in the last 60 years have not evidenced a trend of unfavourable climatic conditions clustering, and the occurrence of unfavourable thermal and precipitation conditions was of random character. Only the analysis of MT indicator pointed to an alarming and statistically significant rise in its value. It must be stressed that as of now, the regularities in long-term changes of AI, EQ indicators are unfavourable. Climatic conditions at the end of the 21st century may be too warm for *Fagetum* type forests, which — concurrently with uncertainty of precipitation efficiency and their time distribution ~~with high uncertainty of precipitation~~ — will intensify evapotranspiration and draught. It seems that climatic conditions of the southern Baltic Sea are heading for change in the 21st century from humid to subhumid, and in an even longer perspective — to mediterranean (IA index). Therefore, it is possible that access to water will be limited, and may influence a drastic change in the conditions of *Cr-F* ~~*F site*~~.

As a result of global warming, the sea level rises, and in the future, this may be the cause of an intensified coastal erosion. Current cliff erosion rate is 0.3 m yr^{-1}. Thus, in the coming decade, the morphodynamic processes should not cause sudden degradation in the reach of *Cr-F* site. In a longer perspective, the dynamics definition of these processes is very difficult without precise recognition of submarine slope configuration and functioning of the circulatory cell system. Erosion process of the cliff coast are taking place over various time and spatial scales, and the highest erosion intensity is featured during extreme events that cannot be predicted. But, taking into account the increasing frequency of the maximum level of the Baltic Sea and stormy swellings, the erosion intensification of the sea coast may be expected. The development of *Cr-F* site is highly conditioned by the presence of cliff naspa and its formation due to aeolian processes. The cliff's erosive activity is a favourable condition for the development of the analysed site only to a certain degree. High activity of morphodynamic processes influences the high rate of cliff top recession, and this, in turn, contributes to the decay of *Cr-F* site area. On the other hand, the limited influence of morphogenetic process favours the cliff's stabilization and sprouting of vegetation, and thus the *Cr-F* site does not develop. Therefore, the optimal condition for the development of *Cr-F* is the balanced cliff's

Z komentarzem [JT78]: ANONYMOUS REFEREE (line 291): more information have been added

Sformatowano: Czcionka: Kursywa

dynamics. This notion is, however, difficult to be defined quantitatively due to high morpholitological diversity of cliffs. The simplest assumption is that the optimal condition for the growth of the orchid beech wood is the case, in which the cliff top recesses with a small, but stable rate of up to, approximately, 0.15 m yr^{-1}.

Future existence of *Cr-F* ~~site~~ depends, primarily, on climatic conditions, and, to a lesser extent, on erosive process on cliff coast. Taking into account that *Cr-F* sites are found in the strict nature reserve of Wolin National Park, there is no need to introduce special protection measures. A favourable condition is the lack of cliff coast protection against erosive processes. Full limitation of cliff's erosion would result in lack of cliff naspa formation. As evidenced by multiannual field researches that have been conducted until now, more favourable conditions for the development of *Cr-F* are found in the cliff coast zone in erosion phase, and not stagnation, as the benefits stemming from aeolian accumulation and formation of cliff's naspa outweigh the losses in coastline due to cliff top recession.

Data availability. Data in this paper can be made available for scientific use upon request to the authors.

Author contributions. JT designed the research with participation of all the authors. JT and MW compiled data and conducted hydrometeorological and sea coast morphodynamics analyses. PC compile data and conducted phytosociological analysis. All other authors contributed with data or conducted a small part of data compilation or analysis. JT drafted the paper with participation from MH and comments from all authors.

Competing interests. The authors declare no competing interests.

Acknowledgements. The authors would like to thank the Polish Institute of Meteorology and Water Management in Warsaw for the provided hydrometeorological data. We would also like to thank the management of Wolin National Park, Marek Dylawerski and Stanislaw Felisiak, for their consent and assistance in scientific research. We also thank Natura company, especially Wojciech Zyska, for his help in drafting this elaboration.

Financial support. The research was supported mainly by the Forest Fund, within the scope of funding admitted by the Directorate General of State Forests National Forest Holding for Wolin National Park (agreement No. EZ.0290.1.21.2019 of 22 July 2019).

References

Bengtsson, L., Hodges, K., Roeckner, E.: Storm tracks and climate change, Journal Climate 19 (15), 3518-3543, https://doi.org/10.1175/JCLI3815.1, 2006.

Budeanu, M., Petritan, A. M., Popescu, F., Vasile, D., Tudose, N. C.: The resistance of european beech (Fagus Sylvatica) from the eastern natural limit of species to climate change, Not Bot Horti Agrobo 44 (2), 625-633, DOI:10.15835/nbha44210262, 2016.

Collins, M., Knutti, R., Arblaster, J., Dufresne, J. L., Fichefet, T., Friedlingstein, P., Wehner, M.: Long-term climate change: Projections, commitments and irreversibility, IPCC, Climate Change: The Physical Science Basis. Contribution of Working

Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change; Cambridge University Press, Cambridge, UK, and New York, USA, 1029-1136, 2013.

Church, J. A., Clark, P. U., Cazenave, A., Gregory, J. M., Jevrejeva, S., Levermann, A., Merrifield, M. A., Milne, G. A., Nerem, R. S., Nunn, P. D., Payne, A.J ., Pfeffer, W. T., Stammer, D., Unnikrishnan, A. S.: Sea Level Change, Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, (eds.): Stocker, T. F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. M. Midgley, Cambridge University Press, Cambridge, UK and New York, USA, 1137-1216, 2013.

Czubiński, Z., Urbański, J.: Park Narodowy na wyspie Wolin. Chrońmy Przyrodę Ojczystą 7 (7-8), 1-64, 1951.

De Martonne, E.: Une nouvelle fonction climatologique: L'indice d'aridité, La Meteorologie, 449-458, 1926.

Ellenberg, H.: Vegetation Ecology of Central Europe. Fourth ed. Cambridge University Press, Cambridge-New York-New Rochelle-Melbourne-Sydney, 731, 1988.

Falk, W., Hempelmann, N.: Species Favourability Shift in Europe due to Climate Change: A Case Study for *Fagus sylvatica L.* and *Picea abies (L.)* Karst. Based on an Ensemble of Climate Models, Journal of Climatology, Volume 2013, Article ID 787250, 18, doi.org/10.1155/2013/787250, 2013.

Feagin, R. A., Sherman, D. J., Grant, W. E.: Coastal erosion, global sea- level rise, and the loss of sand dune plant habitats, Frontiers in Ecology and the Environment 3 (7), 359-364, doi.org/10.1890/1540-9295(2005)003[0359:CEGSRA]2.0.CO;2, 2005.

Florek, W., Kaczmarzyk, J., Majewski, M.: Intensity and character of cliff evolution near Ustka, Quaestiones Geographicae 28 A/2, 27-38, 2009.

Furmańczyk, K. K., Dudzińska-Nowak, J., Furmańczyk, K. A., Paplińska-Swerpel, B., Brzezowska, N.: Critical storm thresholds for the generation of significant dune erosion at Dziwnow Spit, Poland, Geomorphology 143-144, 62-68, https://doi.org/10.1016/j.geomorph.2011.09.007, 2012.

Führer, E., Horváth, L., Jagodics, A., Machon, A., Szabados, I.: Application of a new aridity index in Hungarian forestry practice, Időjárás 115 (3), 205-216, 2011.

Grinsted, A.: Projected Change-Sea Level, Second Assessment of Climate Change for the Baltic Sea Basin, BACC II Author Team, Ed., Springer, London, UK, 253-263, 10.1007/978-3-319-16006-1, 2015.

Hojan, M., Tylkowski, J., Rurek, M.: Hydrometeorological conditions for the occurrence of aeolian processes on the Southern Baltic coast in Poland, Water 10 (12), 1745, doi:10.3390/w10121745, 2018.

Jackowiak, J., Celka, Z., Chmiel, J., Latowski, K., Żukowski, W.: Red list of vascular flora of Wielkopolska (Poland). Biodiversity Research and Conservation 5-8, 95-127, 2007.

Kostrzewski, A.: Rozwój wybrzeży klifowych wyspy Wolin w oparciu o materiały archiwalne, Sprawozdania PTPN 100, 129-132, 1984.

Sformatowano: Polski

Sformatowano: Polski

Sformatowano: Polski

Sformatowano: Polski

Kostrzewski, A., Zwoliński, Z.: Present-day morphodynamics of the cliff coasts of Wolin Island, Journal of Coastal Research 22, 293-303, 1995.

Kostrzewski, A., Zwoliński, Z., Winowski, M., Tylkowski, J., Samołyk, M.: Cliff top recession rate and cliff hazards for the sea coast of Wolin Island (Southern Baltic), Baltica 28 (2), 109-120, doi:10.5200/baltica.2015.28.10, 2015.

Łęczyński, L.: Morpholitodynamics of the shoreface on the cliff coast at Jastrzębia Góra, Peribalticum VII, 9-20, 1999.

Mayr, H.: Waldbau auf naturgesetzlicher Grundlage, Verlag Paul Perey, Berlin, 568, 1909.

Matuszkiewicz, W.: The systematic position of termophilous beechwoods (*Cephalanthero-Fagenion*) in Poland, Fragmenta Floristica et Geobotanica 45, 1–2, 2001.

Matuszkiewicz, W.: Przewodnik do oznaczania zbiorowisk leśnych Polski, PWN, Warszawa, 537540, 20142020.

Nikulin, G., Kjellström, E., Hansson, U., Jones, C., Strandberg, G., Ullerstig, A.: Evaluation and future projections of temperature, precipitation and wind extremes over Europe in an ensemble of regional climate simulations, Tellus 63A, 41-55, DOI: 10.1111/j.1600-0870.2010.00466.x, 2011.

Omstedt, A., Pettersen, C., Rohde, J., Winsor, P.: Baltic Sea climate: 200 yr of data on air temperature, sea level variation, ice cover and atmospheric circulation, Clim. Res. 25, 205-216, 2004.

Orlowsky, B., Seneviratne, S. I.: Global changes in extreme events: Regional and seasonal dimension, Climate Change 116, 669-696, DOI 10.1007/s10584-011-0122-9, 2012.

Paprotny, D., Terefenko, P.: New estimates of potential impacts of sea level rise and coastal floods in Poland. Natural Hazards 85, 1249-1277, https://doi.org/10.1007/s11069-016-2619-z, 2017.

Pinto, J. G., Ulbrich, U., Leckebusch, G. C, Spangehl, T., Reyers, M., Zacharias, S.: Changes in storm track and cyclone activity in three SRES ensemble experiments with the ECHAM5/MPI-OM1 GCM, Climate Dynamics 29 (2), 195-210, DOI: 10.1007/s00382-007-0230-4, 2007.

Piotrowska, H.: Zespoły leśne wyspy Wolin, Prace Komisji Biologii PTPN 16 (5), 3-169, 1955.

Piotrowska, H.: Buczyna storczykowa wzdłuż nadmorskiego klifu na wyspie Wolin (północno-zachodnia Polska), Zeszyty Naukowe UG, Biologia 10, 5–29, 1993.

Prusinkiewicz, Z.: Naspy przyklifowe – nowy typ gleb morskiego pobrzeża, Zeszyty Naukowe UMK w Toruniu, Geografia 26 (8), 133-157, 1971.

Satmari, A.: Lucrari practice de biogeografie (Practical applications of biogeography). Available on: http://www.academia.edu/9909429/05_indici_ecometrici, 2010.

Sepp, M.: Changes in frequency of Baltic Sea cyclones and their relationships with NAO and climate in Estonia, Boreal Environmental Research 14 (1), 143-151, 2009.

Sillmann, J., Kharin, V. V., Zhang, X., Zwiers, F. W., Bronaugh, D.: Climate extremes indices in the CMIP5 multimodel ensemble: Part 2. Future climate projections, Journal of Geophysical Research, Atmospheres 118, 2473-2493, https://doi.org/10.1002/jgrd.50188, 2013.

~~Stojanovic~~Stojanović, D., Kržiče, A., ~~Matovic~~Matović, B., ~~Orlovic~~Orlović, S., Duputie, A., ~~Djurdjevic~~Djurdjević, V., ~~Galic~~Galić, Z., ~~Stojnic~~Stojnić, S.: Prediction of the European beech (*Fagus sylvatica L.*) xeric limit using a regional climate model: An example from southeast Europe, Agricultural and Forest Meteorology 176, 94-103, http://dx.doi.org/10.1016/j.agrformet.2013.03.009, 2013.

Strandmark, A., Bring, A., Cousins, S. A. O., Destouni, G., Kautsky, H., Kolb, G., de la Torre-Castro, M., Hambäck, P. A.: Climate change effects on the Baltic Sea borderland between land and sea, AMBIO 44, 28-38, https://doi.org/10.1007/s13280-014-0586-8, 2015.

Subotowicz, W.: Litodynamika brzegów klifowych wybrzeża Polski, Gdańskie Towarzystwo Naukowe, Ossolineum, Wrocław, 150, 1982.

Tabari, H., Talaee, H., Nadoushani, M., Wilems, P., Marchetto, A.: A survey of temperature and precipitation based aridity indices in Iran, Quaternary International 345, 158-166, https://doi.org/10.1016/j.quaint.2014.03.061, 2014.

Tylkowski, J.: The variability of climatic vegetative seasons and thermal resources at the Polish Baltic Sea coastline in the context of potential composition of coastal forest communities, Baltic Forestry 21 (1), 73-82, 2015.

Tylkowski, J.: The temporal and spatial variability of coastal dune erosion in the Polish Baltic coastal zone, Baltica 30 (2), 97-106, DOI 10.5200/baltica.2017.30.11, 2017.

Tylkowski, J., 2018: Hydrometeorologiczne uwarunkowania erozji wybrzeża klifowego wyspy Wolin, Przegląd Geograficzny 90, 111-135, https://doi.org/10.7163/PrzG.2018.1.6, 2018.

Tylkowski, J., Hojan, M.: Threshold values of extreme hydrometeorological events on the Polish Baltic coast, Water 10 (10), 1337, doi:10.3390/w10101337, 2018.

Uścinowicz, G., Jurys, L., Szarafin, T.: The development of unconsolidated sedimentary coastal cliffs (Pobrzeże Kaszubskie, Northern Poland), Geological Quarterly 61 (2), 491-501, 2017.

Vousdoukas, M. I., Voukouvalas, E., Annunziato, A., Giardino, A., Feyen, L.: Projections of extreme storm surge levels along Europe, Climate Dynamics 47, 3171-3190, DOI 10.1007/s00382-016-3019-5, 2016.

Winowski, M., Kostrzewski, A., Tylkowski, J., Zwoliński, Z.: The importance of extreme processes in the development of the Wolin Island cliffs coast (Pomeranian Bay-Southern Baltic), Proceedings, International Scientific Symposium New Trends In Geography, Macedonian Geographical Society, Ohrid, Republic of North Macedonia, October 3-4, 99-108, 2019.

Sformatowano: Polski

Sformatowano: Polski

Sformatowano: Polski

Sformatowano: Polski

Sformatowano: Domyślna czcionka akapitu, Angielski (Zjednoczone Królestwo)

RESPONSES TO REVIEWS AND COMMENTS

All comments of the reviewer will be included in the article:

(line 1)
ANONYMOUS REFEREE (line 1): I propose to shorten the title: Influence of Hydrometeorological Hazards and Sea Coast Morphodynamics onto Development of the Cephalanthero rubrae-Fagetum (Wolin Island, the Southern Baltic Sea)
ANSWER JT (line 1): "The title was shortened: Influence of Hydrometeorological Hazards and Sea Coast Morphodynamics onto Development of the *Cephalanthero rubrae-Fagetum* (Wolin Island, the Southern Baltic Sea)"

(line 12, 13, 18)
ANONYMOUS REFEREE (line 13, 14, 19): remove the space
ANSWER JT (line 12, 13, 18): spaces have been removed

(line 18-20)
MR. WOLSKI (3) (lines 19-21): Please add a few words in bracket in the sentence in Abstract: (lines 19-21): "It has been established that in the 21st century, a relatively larger hazard to the functioning of the researched site are climate changes (ie mostly changes in thermal conditions and precipitation conditions) not the sea coast erosion" This will be clear to the reader.
ANSWER JT (line 18-20): the sentence was completed as suggested: "It has been established that in the 21st century, a relatively larger hazard to the functioning of the researched site are climate changes (i.e. mostly changes in thermal and precipitation conditions) not the sea coast erosion."

(line 31)
ANONYMOUS REFEREE (line 32): all, not only valuable
ANSWER JT (line 31): exchange word from valuable to "all"

(line 32)
ANONYMOUS REFEREE (line 33): coastal thermophilous
ANSWER JT (line 32): exchange word from stenotermal coastal to "coastal thermophilous"

(line 34)
ANONYMOUS REFEREE (line 35): association
ANSWER JT (line 34): exchange word from complex to "association"

(line 35)
ANONYMOUS REFEREE (line 36): plant community
ANSWER JT (line 35): exchange word from phytocoenosis to "plant community"

(line 35)
ANONYMOUS REFEREE (line 36): habitat

ANSWER JT (line 35): exchange word from site to “habitat”

(line 37-43)

ANONYMOUS REFEREE (line 76-80): the cliff naspa determines the occurrence of Cephalanthera rubra and Epipactis artorubens, which are species regionally characteristic of Cephalanthero rubrae-Fagetum. transfer and combine with information onto lines 35-39. Give there the full description of the naspa according to Prusinkiewicz 1971; change Silvatica into sylvatica

ANSWER JT (line 37-43): sentence was moved as recommended. Soil genetic levels added. “Naspa's accumulation level consists in interbeddings of fine-grain sand and dust drifted by wind from eroded cliff slopes, and rich in humus, dark-grey organic accumulation laminas (mainly leaves of *Fagus sylvatica*). The cliff naspa is a soil with reaction close to neutral, rich in calcium carbonate and characterised by high porosity and efficient humification of organic remains. That is why naspa is a fertile soil. Naspa is deposited on the fossil podzolic soil. Naspa has the following sequence of soil levels: A0 litter level; A1I accumulation level of sand and organic matter layers; A1 (fos) accumulation level of fossil podzolic soil; A2 (fos) eluvial level of fossil podsolic soil; B (fos) iluvial level of fossil podzolic soil; C (fos) parent rock of fossil podzolic soil (Prusinkiewicz, 1971).” Exchange word from silvatica to “sylvatica”

(line 45-47)

MR. KOZŁOWSKI: The Authors wrote: “In these sections of cliff coast, the deposition of sediments containing the calcium carbonate required by the orchid beech wood is relatively small. . .”. Did the Authors examine the amount of the deposition size?

ANSWER JT (line 37-43): added values for aeolian deposition “The average rate of aeolian deposition in the *Cr-F* habitat was 3-5 mm y^{-1}, and the maximum point value was 8-10 mm y^{-1} (2000-2019).”

(line 48-50)

ANONYMOUS REFEREE (line 41). The authors should include the phytosociological characteristics of Cephalanthero rubrae-Fagetum association here (according to the syntaxonomy of Matuszkiewicz 2012), because the text repeatedly refers to typical Cr-F patches or typical species (lines: 124, 136, 140, 143, 145). Plant species regionally characteristic for Cr-F and characteristic for Cephalanthero-Fagenion should be given. Only Cephalanthera rubra and Epipactis atrorubens testify to the presence of well-developed patches of the association. If only Cephalanthera damasonium and Epipactis helleborine are present, phytocoenosis can only be included in the Cephalanthero-Fagenion compound and it is not a typical Cr-F

ANSWER JT (line 48-50): The text was supplemented in accordance with the comments of the reviewer “*Cephalanthera rubra* and *Epipactis atrorubens* are indicator species for *Cr-F* (Matuszkiewicz, 2020). Both species found in the 6 studied *Cr-F* habitats, but *Cephalanthera rubra* was the dominant one. Non-indicator species, e.g. *Cephalanthera damasonium* and *Epipactis helleborine*, have been found in *Cr-F* habitats too.”

(line 48)

ANONYMOUS REFEREE (line 42): phytosociological

ANSWER JT (line 48): exchange word from phytocoenotic to “phytosociological”

(line 53)
ANONYMOUS REFEREE (line 43): plant richness
ANSWER JT (line 53): exchange word from reach to “plant richness”

(line 54)
ANONYMOUS REFEREE (line 44): association
ANSWER JT (line 54): exchange word from phytocoenosis to “association”

(line 56)
ANONYMOUS REFEREE (line 46-56): Since the entire habitat occupied by the pine monoculture does not exist today, as it has been eroded (line 55 and 56), this description is absolutely unnecessary. It should be removed. The described story does not concern the places where the phytocoenoses studied by the authors occur today. Therefore, we cannot talk about the return of the habitat, but about the development of new habitats - the way of transforming those that found themselves at the edge of the cliff.
ANSWER JT (line 56): Historical aspects of Cr-F were removed as suggested

(line 60)
ANONYMOUS REFEREE (line 61): The concept of morphodynamic functions is not used in the world geomorphological literature. Replace with another, e.g. morphodynamic states or morphodynamic processes
ANSWER JT (line 60): exchange word from functions to “states”

(line 62)
ANONYMOUS REFEREE (line 63): characteristic
ANSWER JT (line 62): exchange word from typical to “characteristic”

(line 63-64)
ANONYMOUS REFEREE (line 64-65): If increased, relative to what?: Light characteristic for meadows and psammophilous short-grass swards.
ANSWER JT (line 63-64): sentence changed as suggested). “The high flow of light to the ground from the sea direction favours the occurrence on the top cliff of many heliophilous species, characteristic for meadows and psammophilous short-grass swards.”

(line 65)
ANONYMOUS REFEREE (line 65): herb layer
ANSWER JT (line 65): exchange word from ground cover to “herb layer”

(line 65-66)
ANONYMOUS REFEREE (line 66): why not in alphabetical order, Dactylis glomerata and Poa nemoralis.

ANSWER JT (line 65-66): alphabetical order of species

(line 68)
ANONYMOUS REFEREE (line 68): sylvaticae, Actaea
ANSWER JT (line 68): typing errors were corrected

(line 70)
ANONYMOUS REFEREE (line 70): Cephalanthero-Fagenion forests
ANSWER JT (line 70): exchange word from orchid beech woods to "*Cephalanthero-Fagenion* forests"

(line 70)
ANONYMOUS REFEREE (line 71): association
ANSWER JT (line 70): exchange word from complex to "association"

(line 71-72)
ANONYMOUS REFEREE (line 71-72): It was already on lines 35-39. Remove
ANSWER JT (line 71-72): Sentence removed.

(line 71-72)
ANONYMOUS REFEREE (line 45): in this chapter to give according to whom the Latin names of plant species and phytosociological units were given
ANSWER JT (line 71-72): Text added as suggested. Source of Latin names "The source of Latin names of plant species and plant communities are the publications Jackowiak et al. (2007) and Matuszkiewicz (2020)."

(line 75)
ANONYMOUS REFEREE (line 75): habitats
ANSWER JT (line 75): exchange word from site to "habitats"

(line 76-77)
ANONYMOUS REFEREE (line 76-77): "The cliff naspa determines the occurrence of Cephalanthera rubra and Epipactis artorubens, which are species regionally characteristic of Cephalanthero rubrae-Fagetum."
ANSWER JT (line 76-77): sentence changed as suggested

(line 78)
ANONYMOUS REFEREE (line 81): "…*rubra*."
ANSWER JT (line 78): The sentence was shortened as suggested

(line 80):
JT: Figure 1. exchange word from site to "habitats"

(line 81-82)

MR. KOLANDER, MRS. KIJOWSKA: An overview photo of the habitat has been added
ANSWER JT (line 81-82): Photo of habitat added as suggested

(line 84-87)
ANONYMOUS REFEREE (line 84-86): justify why, what hydrometeorological parameter?
ANSWER JT (line 84-87): the text has been completed as suggested "Thermal and precipitation conditions determine, e.g. on water and heat resources and duration of vegetative season. On the other hand, extreme storm surges may generate intensive cliff erosion and consequently reduce the spatial extent of coastal plant communities. Therefore, unfavorable hydrometeorological conditions may limit the development of the *Cr-F* habitats."

(line 88)
ANONYMOUS REFEREE (line 87): Świnoujście
ANSWER JT (line 88): exchange word from Swinoujscie to "Świnoujście"

(line 89-91)
ANONYMOUS REFEREE (line 88): the Institute's data are always reliable, what does it mean?
ANSWER JT (line 89-91): text corrected as suggested ". The meteorological and mareographical station in Świnoujście is located 15 km from the research area and provides homogeneous and complete series of actual data."

(line 93)
ANONYMOUS REFEREE (line 89): sylvatica
ANSWER JT (line 93): exchange word from silvatica to "sylvatica"

(line 93)
ANONYMOUS REFEREE (line 90): given by Budeanu et al. (2016):
ANSWER JT (line 93): sentence corrected "In the elaboration, a number of especially useful climatic indicators were calculated and their values compared with threshold values adequate for *Fagus sylvatica* given by Budeanu et al. (2016):"

(line 94-105)
MR. WOLSKI (1): "The authors of the study identified interesting climatic indicators (AI, EQ, FAI, MT).
However, they were not well described. Please complete the formulas of these indicators. Please write how the value of a particular indicator influences the development (growth) of Fagus Silvatica"
ANSWER JT (line 94-105): formulas for climate indicators have been added

"-De Martonne Aridity Index IA=P/(T+10), where P is the amount of the annual precipitation, T is the average annual temperature (De Martonne, 1926); with optimal thresholds for beech wood in the range of 35–40 (Satmari, 2010); De Martonne Aridity Index - classification by Tabari et al., (2014): IA<5

extremely arid, 5<IA<10 arid, 10<IA<20 semi-arid, 20<IA<24 mediterranean, 24<IA<28 semi-humid, 28<IA<35 humid, 35<IA<55 very humid, 55<IA extremely humid.

-Ellenberg Quotient EQ=Tw/Px1000, where Tw is the temperature of the warmest month of the year, P is the annual precipitations (Ellenberg, 1988); with optimal threshold beneficial for beech growth of below 30 and its recession threshold of above 40 (Stojanovic et al., 2013),

-Forestry Aridity Index FAI=100x(TVII-VIII/(PV-VII+PVII-VIII), where TVII-VIII is the average temperature of the months July and August, PV-VII is the amount of precipitations during May-July and PVII-VIII is the amount of precipitations during July-August; with climatic conditions favouring beeches of below 4.75 (Führer et al., 2011),

-Mayr Tetratherm: MT=(TV+TVI+TVII+TVIII)/4, where TV-TVIII represent the mean temperature for the May-August period (Mayr, 1909); with optimal thermal conditions for beech wood of 13–18°C (Satmari, 2010).

(line 113)

ANONYMOUS REFEREE (line 102): First, the abiotic conditions for Cr-F should be characterized, and then the floristic and phytosociological characteristics of Cr-F using the given characteristics of habitat conditions. Because the range and floristic composition of Cr-F depend on them. Use the past tense throughout the chapter. It is a description of some past condition that does not exist now.

ANSWER JT (line 113, 158, 205): The order of subsections was changed as recommended: 3.1 Hydrometeorological Conditions and Hazards; 3.2 Cliff Coast Morphodynamics Hazard; 3.3 Reach and Floristic Composition of Cr-F

(line 114)

ANONYMOUS REFEREE (line 155): period (1960-2019)

ANSWER JT (line 114): the text has been completed as suggested “In the researched 60-year period (1960-2019)…”

(line 123, 124, 139, 153, 154)

MR. KOZŁOWSKI, MRS. KIJOWSKA: Please add R2 value, equation and statistical significance.

ANSWER JT (line 123, 124, 139, 153, 154): R2 value, regression equation, correlation index and p-value included in the diagrams (Figure 3, 4, 5)

(line 126-127, 140-141, 156-157)

MR. WELSH: data source should be added

ANSWER JT (line 126-127, 140-141, 156-157): Raw data source added as suggested in n the title of the figures 3, 4 and 5 "(Own study based on raw data from the Institute of Meteorology and Water Management in Warsaw)"

(line 150)
ANONYMOUS REFEREE (line 189): degeneration
ANSWER JT (line 150): exchange word from degradation to "degeneration"

(line 196)
ANONYMOUS REFEREE (line 196): In this chapter, please include only the results of your research carried out with the methods described in chapter 2. The authors describe the effects of processes they have not studied. This should be in the discussion chapter
ANSWER JT: the above remark was included in the text correction

(line 159-161)
ANONYMOUS REFEREE (line 198-199): In lines 198-199 is: the cliff is built mainly of clayey sediments.
In lines 148-149 is: with balanced share of clayey and sandy sediments. What does it mean, in the geological term: balanced share of clayey and sandy sediments.
ANSWER JT (line 259-262): sentence (line 259-262, earlier 147-151) corrected: "Habitat V is the best developed patch of Cr-F, with optimal habitat conditions: favourable morpholitodynamic conditions (abrasive coast but low rate of cliff's recession 0.12 m yr-1, higher share of clay sediments, rich in calcium carbonate 8-10%); favourable light conditions (relatively greater insolation of the forest floor); ground cover of orchid beech wood, developing for inland for a dozen or so meters in some points)."

(line 170)
ANONYMOUS REFEREE (line 207): Can something more be written about the nature of these outflows? how much, where, how much water
ANSWER JT (line 170): sentence was added: " The efficiency of the cliff springs is rather small <1 dm^3 min^{-1}."

(line 180-181)
MR. WELSH: data source should be added
ANSWER JT (line 180-181): Raw data source added as suggested in n the title of the figure 6 "(Own study based on own measurements and raw data from Kostrzewski et al. 2015, Winowski et al. 2019).

(line 182)
ANONYMOUS REFEREE (line 219): enter height
ANSWER JT (line 182): the text has been supplemented as suggested "..(<30 m a.s.l.).."

(line 183)
ANONYMOUS REFEREE (line 220): Cr-F phytocoenoses.

ANSWER JT (line 183): exchange words from orchid beech wood to "*Cr-F* phytocoenoses"

(line 183-186)
ANONYMOUS REFEREE (line 221): How do you know that? how much? how much increased? in relation to what?
ANSWER JT (line 183-186): clarification added: "…. (sandy sediments contain 4-5 times less calcium carbonate 2% than clay sediments) ….. (sandy sediments are much less resistant to erosion than clay sediments) ….."

(line 193)
ANONYMOUS REFEREE (line 229): Naspa does not move. It develops in situ in a beech forest that will be about 100 meters wide along the edge of the cliff.
ANSWER JT (line 193): exchange words from movement to "development"

(line 195)
ANONYMOUS REFEREE (line 230): vegetation under of biocenotic succession.
ANSWER JT (line 230): exchange words as suggested: from permanent crust vegetation to "vegetation under of biocenotic succession"

(line 203-204)
ANONYMOUS REFEREE (line 239): why?
ANSWER JT(line 203-204): the text has been supplemented as suggested"… - too much (habitat III) or too little (habitat I) cliff erosion."

(line 206)

ANONYMOUS REFEREE (line 103): Biała Góra

ANSWER JT (line 206): exchange words from Biala Gora to "Biała Góra"

(line 208)

ANONYMOUS REFEREE (line 105): lowland acidophilous beech forest
ANSWER JT (line 208): exchange words from acidic fertile lowland beech wood to "lowland acidophilous beech forest"

(line 210)

ANONYMOUS REFEREE (line 107): association

ANSWER JT (line 210): exchange words from complex to "association"

(line 211)

ANONYMOUS REFEREE (line 108): Pteridophyta
ANSWER JT: the text has been changed as suggested

(line 211-219)

ANONYMOUS REFEREE (line 107-117): alphabetically or justify why in that order, Spermatophyta, sylvestris, respectively 3, 6 and 27, species – remove, alphabetically or justify why in that order, meadows and psammophilous swards. There have observed species from syntaxa, Artemisietea
ANSWER JT (211-219): the text has been changed as suggested, e.g. alphabetical order of species

(line 222)

ANONYMOUS REFEREE (e.g. line 118, 121, 124, 125, 131, 136, 138, 143): How was concentration tested and what is the result of these studies? Density (the number of individuals per unit of area) and size (how many individuals) population are properties of each population. Density is the number of individuals per area unit. Report the recorded density values of each of the four listed species? Cephalanthera rubra and Epipactis atrorubens are particullary important. They are regional characteristic species for Cr-F association. Enter the latitude and longitude of the center point
ANSWER JT (line 222): table with localisation and plant indicators of Cr-F habitats added as suggested. The quantitative data from the table are included in the description of habitats (line 224-260).

(line 225)

ANONYMOUS REFEREE (line 119): how much? how do you know this? please document, How do you know it goes away? Maybe it is just developing?
ANSWER JT (line 225): the added text answers the questions: "Therefore, aeolian deposition on the cliff top is very limited and the Cr-F habitat decays." The habitat is disappearing, not developing. For many years there has been no possibility of the naspa and habitat development.

(line 225-227)

ANONYMOUS REFEREE (line 119-121): The soil profile must have a morphology appropriate to the naspa - layer of aeolian sediments, etc. Only the results should be included in this chapter. All hypotheses and assumptions should be found in the discussion of results chapter.
ANSWER JT (line 225-227): The sentence needed for the specific functioning of the habitat

(line 224-260)

ANONYMOUS REFEREE
(line 121): For each site, the number of Cephalanthera rubra individuals recorded should be reported or a bioindicator such as the population density indicator of this species should be given, i.e. the number of individuals per square meter, distinguishing between vegetative and generative. Only the results should be included in this chapter. All hypotheses and assumptions should be found in the discussion of results chapter.
(line 121): For each site, the number of Cephalanthera rubra individuals recorded should be reported or a bioindicator such as the population density indicator of this species should be given, i.e. the number of individuals per square meter, distinguishing between vegetative and generative. Only the results should be included in this chapter. All hypotheses and assumptions should be found in the discussion of results chapter.

ANSWER JT (line 224-260): habitats localisation and quantitative indicators have been added (see Table 1), e.g. percentage of coverage in the herb layer, Terminology awkwardness fixed, e.g. line 229-230 "…..*Luzula pilosa* and *Trientalis europaea* are the distinguishing species of the *Luzulo-Fagenion* beech forests." Alphabetical order of species added.

(line 238)

ANONYMOUS REFEREE (line 130): A large portion of the site is covered by beech brushwood,
130 which evidences an intensive renewal of forest - move the assessment to the discussion chapter

ANSWER JT (line 238): The sentence needed for the specific functioning of the habitat. Sentence completed:"A large portion (20%) of the site is covered by beech brushwood, which evidences an intensive renewal of forest".

(line 255-256)

ANONYMOUS REFEREE (line 143-144): on what basis this an assumption?, patch of Cr-F typicum, what does a smaller concentration mean? what was the density and size population of each recorded orchid species? what does less concentration mean? what was the density and population size of each registered orchid species? especially Cephalanthera rubra and Epipactis atrorubens, which are regionally characteristic for Cr-F association, on what basis this an assumption?

ANSWER JT (line 255-256): more information have been added: "This habitat may also be considered a patch of *Cr-F* typicum (Table 1), but a smaller concentration of *Cephalanthera rubra* (15 individuals per ha) has been confirmed there. The cliff is mostly clayey and low (25-30 m a.s.l.), thus the intensity of aeolian deposition is relatively smaller (2 mm y-1 in 2000-2019)."

(line 261)

ANONYMOUS REFEREE (line 147): Cr-F

ANSWER JT (line 261): exchange words from orchid beech wood to" *Cr-F*"

(line 261-266)

ANONYMOUS REFEREE (line 148-152): In lines 198-199 is: the cliff is built mainly of clayey sediments. What does it mean, in the geological term: balanced share of clayey and sandy sediments, how much? Fractions, how rich? provide values for these parameters, What light conditions were favorable for the development of Cr-F phytocoenoses? remove, pinetisation was not discussed, the ground cover does not move for inland! The site does not decay away. The habitat conditions and floristic composition of the vegetation occurring at this site are changing.

ANSWER JT (line 261-266): sentence was corrected as suggested: "The most valuable orchid beech woods habitats are II, V and VI. Habitat V is the best developed patch of *Cr-F*, with optimal habitat conditions: favourable morpholitodynamic conditions (abrasive coast but low rate of cliff's recession 0.12 m yr^{-1}, higher share of clay sediments, rich in calcium carbonate 8-10%); favourable light conditions (relatively greater insolation of the forest floor); ground cover of orchid beech wood, developing for inland for a dozen or so meters in some points). The relatively poorest condition was confirmed for habitat I, which does not develop due to unfavorable morpholithodynamic conditions (dead non-erosive cliff, stabilised with compact pine wood, no possibility of forming naspa)."

(line 297)
ANONYMOUS REFEREE (line 270): will not be suitable for the development of the Cr-F habitat.
ANSWER JT (line 297): sentence was corrected as suggested

(line 298-305)
MR. KOZŁOWSKI: These is no reference to the observed changes in the position of the cliff in the discussion. Please add discussion with other authors
ANSWER JT (line 298-305): sentence was added as suggested "In the analysed period (1985-2019), the average annual rate of the cliff crown retraction on the examined sections amounted to 12 up to 31 cm and it was much lower than the values estimated (80-100 cm) by the mid-twentieth century by Subotowicz (1982) and Kostrzewski (1984). Whereas, the maximum annual point retraction of the cliff crown was almost 10 m. The average annual retraction rate of the Wolin cliffs is approximately 2-4 times lower than other monitored cliff coasts, e.g. in the vicinity of Ustka, Jastrzębia Góra or Gdynia (e.g., Florek et al. 2009; Łęczyński 1999). Although the Wolin cliffs are much higher and are not subjected to any protective measures, the relatively lowest rate of their retraction results primarily from specific hydrogeological conditions. For example, contrary to the cliff coast in Jastrzębia Góra (Uścinowicz et al. 2017) on the island of Wolin, underground waters practically do not play any role in erosion processes and shore degradation."

(line 306-314)
ANONYMOUS REFEREE (line 274-282), MRS. KIJOWSKA: Species composition of association's phytocoenoses, neither in the results nor in the discussion was the floristic composition of the patches 50 years ago compared to the present ones; on what basis this conclusion, Orchidaceae, Who and when found these orchids? They are not characteristic of either Cephalanthero rubrae-Fagetum, Cephalanthero-Fagenion, Fagetalia, or Querco-Fagetea. They don't have to keep up with the cliff's retreat. On what basis is this conclusion? There was no data on the current state of the population or a comparison with the state 50 years ago in the results, Why Lonicera is important for Cr-F? This species has little diagnostic value for Cr-F because it is a species characteristic of Querco-Fagetea. Transfer to discussion, cite the authors of these studies. Were these sites in Cr-F? Cephalanthera, On what basis this conclusion? The authors did not analyze the past and present geographical range of Cephalanthera rubra species in the national park.
ANSWER JT (line 306-314): sentence moved from conclusion to discussion "Species composition of association's phytocoenoses has not changed extensively over the last half-century (Piotrowska, 1993; Prusinkiewicz, 1971), which confirms its relative stability; however, some *Orchidaceae* habitats of do not keep up with the rate of the cliff's recession or they do not develop due to many years of cliff erosive stagnation. No specimens of *Malaxis monophyllos* were confirmed, which was occurring at the cliff's edge tens of years ago (Piotrowska, 1993). A vast loss for the site is also the lack of current confirmation for the occurrence of *Listera ovata*. Also, it has been confirmed that the number of *Lonicera xylosteum* decreased — a species important for the orchid beech wood. In past elaborations, the indicatory species of *Cephalantero rubra* featured a larger reach in the area of Wolin National Park, e.g., in forest divisions of Międzyzdroje 16 and Wisełka 2. Currently, no specimens of *Cephalantero*

rubra have been found on those sites, which is the confirmation for the decreasing reach of this species in Wolin National Park.

(line 314)

ANONYMOUS REFEREE (line 272-273): remove, The authors provided no evidence of habitat defragmentation. That there was a lobe that was divided into several. Cr-F habitats developed in different places, in scattered sites.

ANSWER JT (line 314): sentence was corrected as suggested "This valuable site consists of 6 isolated,….."

(line 328)

ANONYMOUS REFEREE (line 291): Write what's going on?

ANSWER JT (line 328): more information have been added: "…. uncertainty of precipitation efficiency and their time distribution…."

In addition: linguistic inaccuracies and punctuation errors have been corrected, supplementing the necessary literature