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~~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, 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 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).

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That is why empirical researches on the influence of abiotic conditions onto determination of current state, threats and development perspectives of valuable, coastal phytocoenoses are particularly important.

Unique in the world are the sites of 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 complex (Matuszkiewicz, 2001, 2014). The uniqueness of this phytocoenosis stems from endemic and specific character of site 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 (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 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 analysis. On the other hand, the main aim of this elaboration was the up-to-date evaluation of the reach and floristic composition of *Cr-F*, and possible growth of this exceptional phytocoenosis, in the context of climate changes and morphodynamics of cliff coast expected to take place in this century.

2 Study Area and Methods

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 (erosion or stagnation). The researched site type is rich in species characteristic for, both, forest and non-forest phytocoenoses.

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Forest species, typical for *Fagetalia* and *Querco-Fagetea* as well as meadow species with *Molinio-Arrhenatheretea* occur in large numbers (Piotrowska, 1993). Increased light supply from the coastal direction favours the occurrence of many heliophilous species, characteristic for sandy meadows and turfs. Gramineous species prevail in the ground cover, among others: *Brachypodium sylvatica*, *Poa Nemoralis*, *Dactylis glomerata*. The most valuable are orchid species, *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* order (*Acetea spicata*, *Daphne mezereum*, *Lathyrus vernus*, *Mercurialis perennis*) and *Querco-Fagetea* class (*Aegopodium podagraria*, *Campanula trachelium*, *Corylus avellana*) that feature considerable share in all other orchid beech woods, which evidences the distinction and uniqueness of the *Cr-F* complex (Matuszkiewicz, 2001). 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* sites reach chart on Wolin island was drafted (Fig. 1). An assumption was adopted that *Cr-F* site reach is determined by soil conditions, 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.

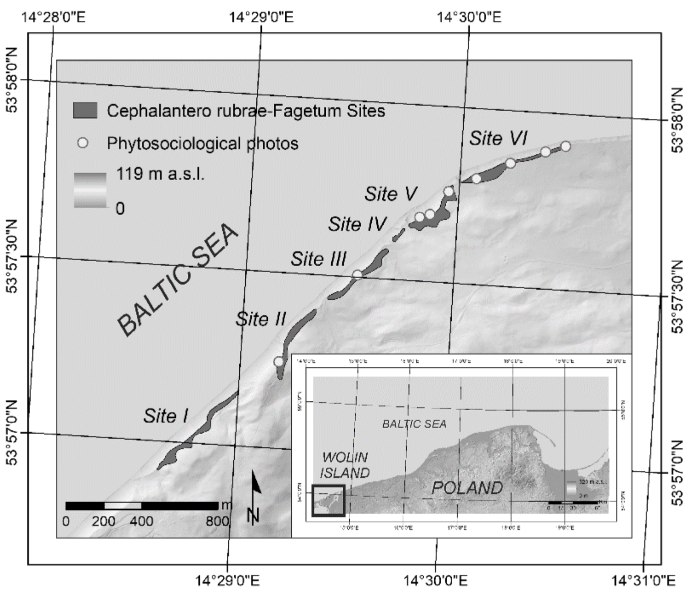

Figure 1. Sites of *Cr-F*, localisation of phytosociological mapping on Wolin Island.

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Detailed recognition of hydrometeorological conditions and the recession rate of the cliff top are vastly important for the functioning of *Cr-F* site. For the purpose of defining long-term trend, daily hydrometeorological data in the period of 1960–2019, collected in measurement station in Swinoujscie, were used. The data were provided by the Polish Institute of Meteorology and Water Management. The meteorological and mareographical station in Swinoujscie is located 15 km from the research area and provides 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* (Budeanu et al., 2016): De Martonne aridity index (AI) (De Martonne, 1926) with optimal thresholds for beech wood in the range of 35–40 (Satmari, 2010), Ellenberg Quotient (EQ) (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) with climatic conditions favouring beeches of below 4.75 (Führer et al., 2011), 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 Reach and Floristic Composition of *Cr-F*

Currently, *Cr-F* grows along the northern cliffed coast of Wolin island, between Biala Gora 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 fertile lowland beech wood, *Luzulo pilosae-Fagetum*.

The floral richness of *Cr-F* complex consists in 113 species of vascular plants. They represent 2 divisions — *Pterydiophyta* and *Spermatophyta*. In *Pterydiophyta* divisions 4 species have been confirmed: *Dryopteris filix-mas, Pteridium aquilinum, Dryopteris carthusiana* and *Polypodium vulgare*. And, in *Spermathophyta* division 3 classes have been confirmed: *Pinopsida* (2 species: *Juniperus communis* and *Pinus Sylverstris*), *Magnoliopsida* (23 orders, 29 families and 82 species) and *Liliopsida* (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 rubra, 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 psammophilic meadows and turfs (*Brachypodium*

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

~~Site 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'. Aeolian deposition on the cliff top is ~~very limited~~ and the *Cr-F* site ~~decays~~. In surface sediments, the presence of calcium carbonate has been confirmed, 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, which may be relics of a once well-developed site. There are no other orchid species found, though. The ground cover ~~was poor~~, and the confirmed species of ~~*Luzula pilosa*, *Trientalis europaea* are more typical for acidic beech wood than for orchid beech wood.~~

~~Site II (1.3 ha).~~ In terms of phytosociology, this is a ~~typical patch of orchid beech wood.~~ The cliff wall is exposed, active and predisposed to aeolian processes. The ground cover is rich in species. There is a high concentration of orchids, and 4 species have been found: *Cephalanthera rubra*, *Epipactis hellaborine*, *Epipactis atrorubens*, *Cephalanthera damasonium*. There are also numerous species of *Poaceae* family (among others, *Brachypodium sylvaticum*, *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, rich in species. A large portion of the site is covered by beech brushwood, which evidences an intensive renewal of forest.

~~Sites III (1.1 ha) and IV (0.1 ha).~~ The sites are moderately formed. At site III, there are intensive erosion processes taking place. Despite the aeolian deposition ~~on the cliff top is high (40 m a.s.l.),~~ then due to a relatively high rate of cliff's recession, 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 strip along the cliff top.

~~Site V (1.7 ha).~~ The patch of ~~a typical orchid beech wood~~, developed the best. The cliff's wall is exposed, and high (35-50 m a.s.l.) aeolian deposition on cliff top is visible. The ground cover is well developed, rich in species, although in some areas their number drops due to poorer light conditions (high coverage of forest canopy). There is a high concentration of *Cephalanthera rubra*, as well as other orchid species. This site is a strongly, upon inland, encroaching part of the site. Species ~~typical for orchid beech wood~~ have been found even up to 100 metres from the cliff's edge. In total, 6 species of *Orchidaceae* have been identified: *Cephalanthera rubra*, *Epipactis atrorubens*, *Epipactis* ~~*hellaborine*~~, *Neottia nidus-avis*, *Cephalanthera damasonium*, *Platanthera bifolia*.

~~Site VI (1.5 ha).~~ This ~~site~~ may also be considered a ~~typical orchid beech wood~~, but a smaller concentration of orchids 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. The cliff tableland is flat. And the ground cover covers up to 90 % of the ~~area~~ and is rich in species typical for orchid beech wood. There have been 3 species of ~~orchids~~ confirmed: *Cephalanthera rubra*, *Epipactis atrorubens*, *Epipactis* ~~*hellaborine*~~.

The most valuable orchid beech woods sites are II, V and VI. Site V is the best developed patch of ~~orchid beech wood~~, with optimal habitat conditions: favourable morpholitodynamic conditions (high abrasive cliff, 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,

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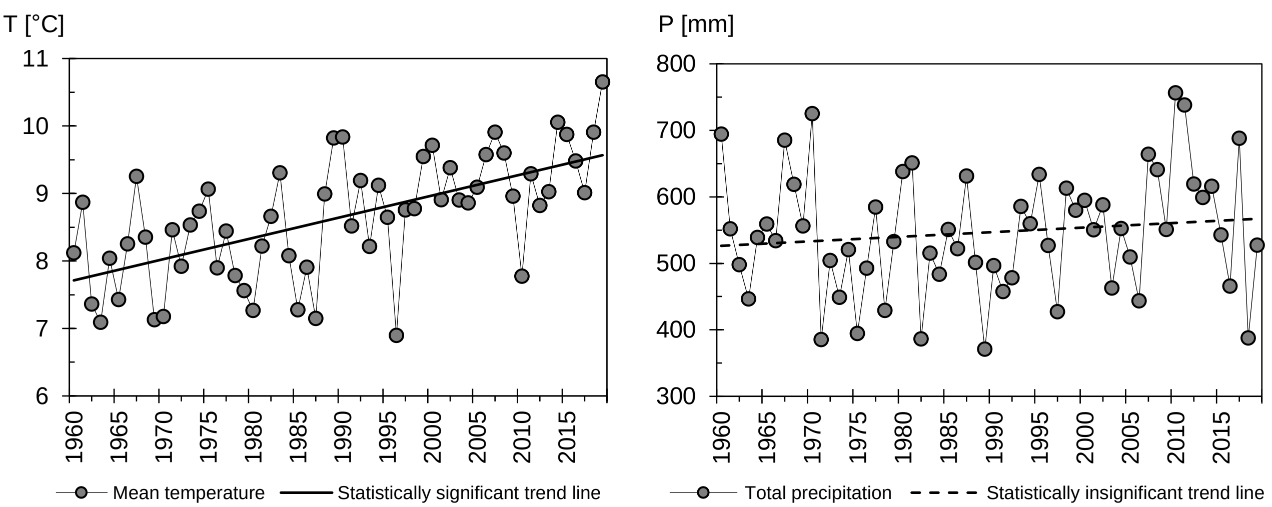
low rate of cliff's recession); favourable light conditions; ~~beech forest without the share of pine — no pinetisation~~; ground cover of orchid beech wood, moving for inland for a dozen or so meters in some points). The relatively poorest condition was confirmed for site I, which due to unfavourable morpholitodynamic conditions of sea coast is decaying (dead cliff, stabilised with compact pine wood, no possibility of forming naspa).

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.



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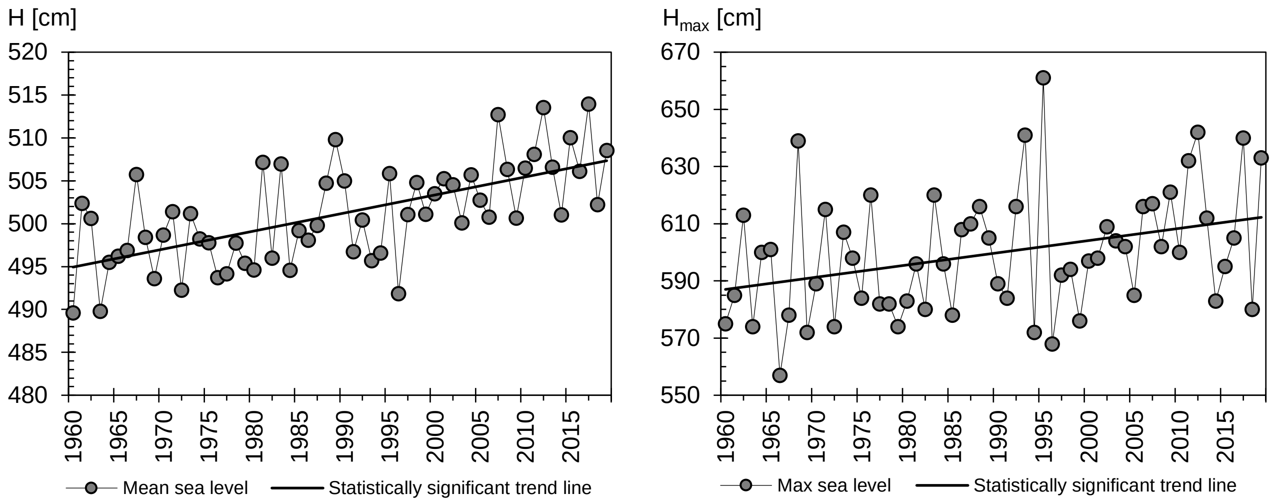

Figure 2. Long-term trends in hydrometeorological conditions: annual mean air temperature (T), annual total precipitation (P), annual mean sea level (H), annual maximum sea level (H_{max}), (Swinoujscie, 1960–2019).

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.

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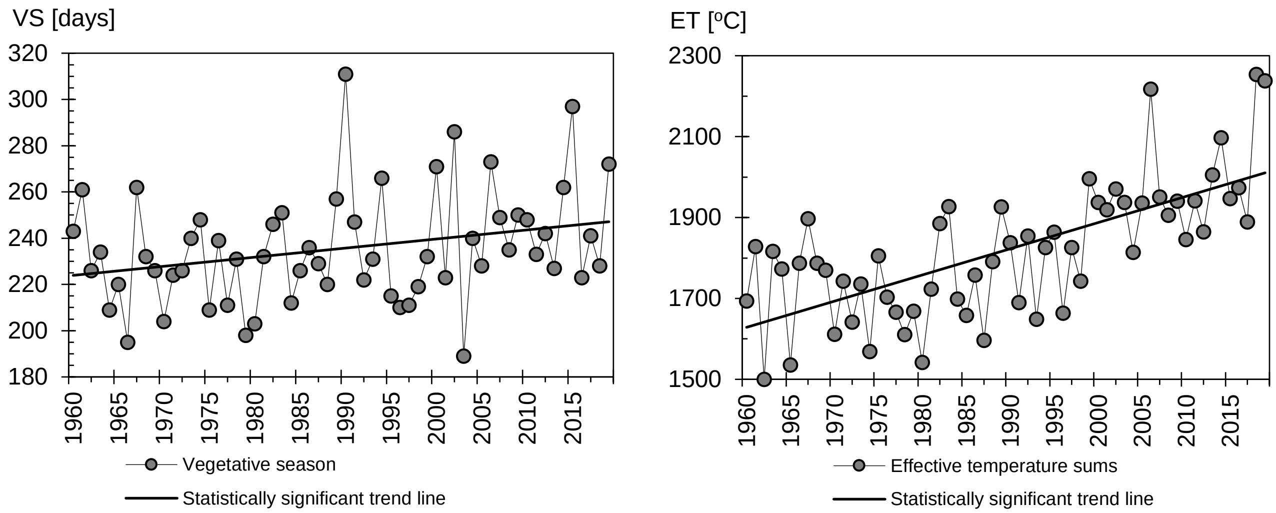
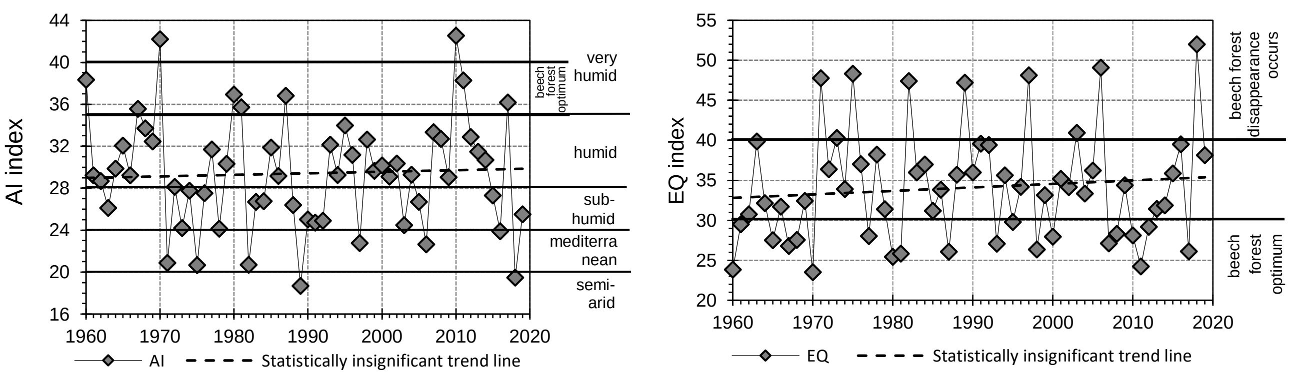


Figure 3. Long-term trends in the length of vegetative season (VS) and effective temperature sums (ET), (Swinoujscie, 1960–2019).

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.



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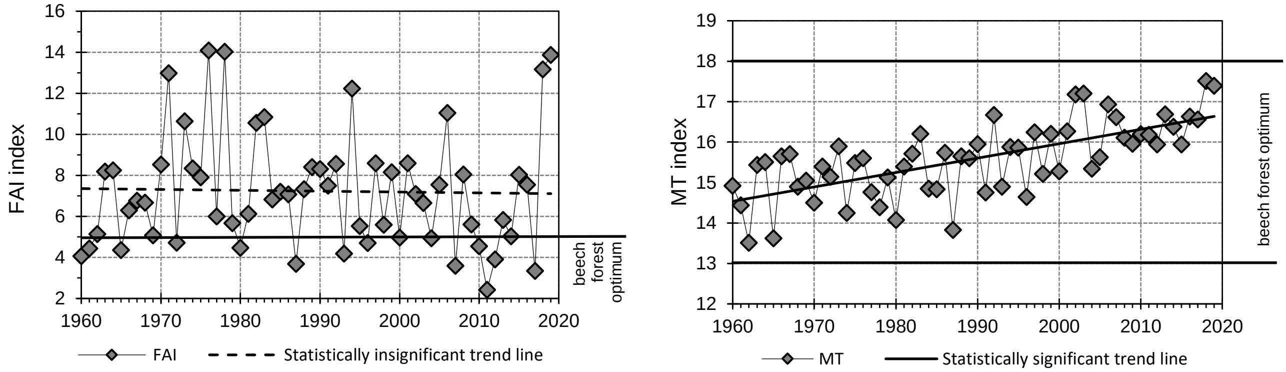

Figure 4. Long-term trends in climatic indicators: De Martonne Aridity Index (AI), Ellenberg Quotient (EQ), Forestry Aridity Index (FAI), Mayr Tetratherm Index (MT), (Swinoujscie, 1960–2019).

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}.

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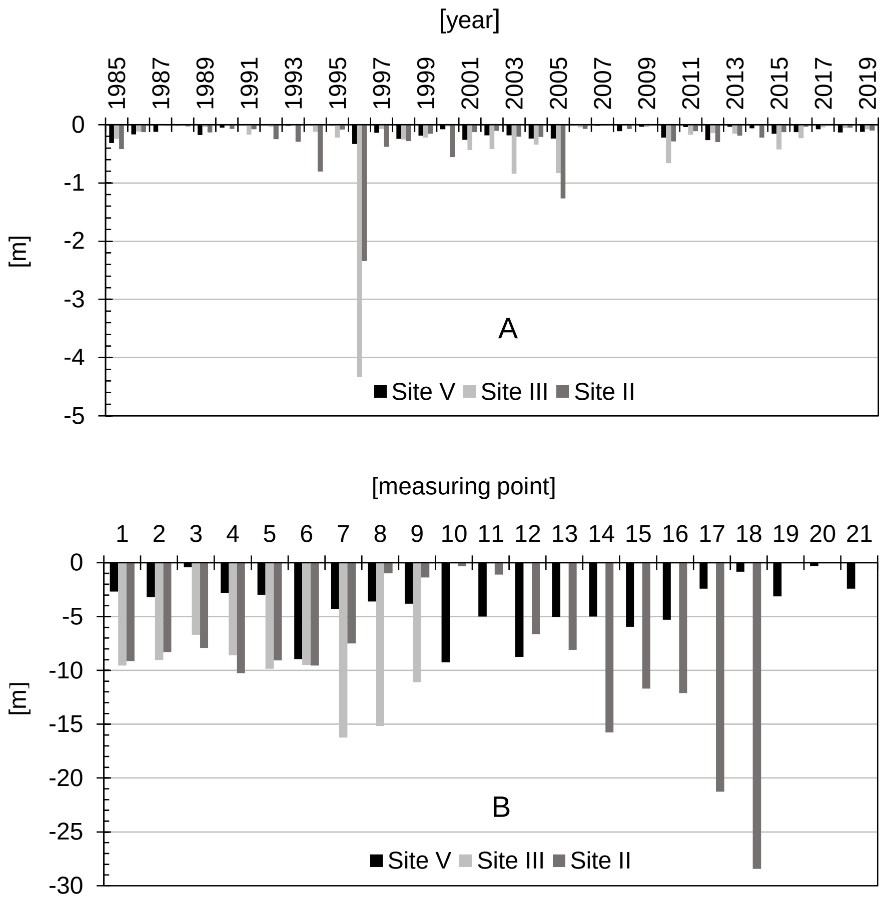

Figure 5. Location changes of cliff top at sites II, III and V of *Cr-F* in the period of 1985–2019: A – annual mean at sites, B – total multiannual in measurement points at sites.

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

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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

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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*. 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* 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 be too demanding for the growth of *Cr-F*.

5 Conclusions

The analysis of *Cr-F* site indicated its small total area of merely 7.3 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 — mainly due to the spatial variability of the cliff's morpholitodynamics. Phytosociological mappings 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 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 meditterranean (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* ~~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 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.

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.

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