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ORIGINAL PAPER
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DEFINING SAFE INVESTMENT BOUNDARIES IN COASTAL AREAS: A PLANNING TOOL FOR SUSTAINABLE SHORELINE MANAGEMENT

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ABSTRACT

Motives: Due to human activities, shoreline transformation processes are accelerating. The existing policy to protect them often results in costly and inefficient public investments that protect private investments. Such a policy is not only questionable in terms of the rationality of public spending but also fuels a vicious circle—further investments accelerate erosion.
Aim: The objective of the study is to formulate guidelines for determining safe investment boundaries, grounded in the analysis of scientific research, legal frameworks, and case studies.
Results: The study has made it possible to formulate criteria for defining the safe investment boundaries in coastal areas, develop a set of recommendations for effectively implementing this tool, and contribute to rationalising investment processes in coastal areas.

Keywords: coastal areas, shoreline, shore, spatial planning, integrated coastal management

INTRODUCTION

Coastal areas are characterised by a valuable and sensitive natural environment, which offers high scenic and recreational values. In addition, they serve as a space for numerous maritime economy processes, in which, alongside logistics, the importance of energy is increasing (Rusu, 2020).

Most sections of the Polish coast are subject to erosion (Frankowski et al., 2009; Łabuz, 2015; Michałowska & Głowienka, 2022). Although shoreline transformation processes have always occurred (Deng et al., 2017; Schwarzer et al., 2003), contemporary anthropopressure contributing to both changes in relief and vegetation cover of dunes and changes in coastal dynamics has an accelerating effect on destruction processes (Łabuz, 2005). Long-term observations of the Polish shore indicate an expansion of the area and an acceleration of the phenomenon. The shoreline retreat for the years 1875–1979 was 0.12 m/year. In the mid-1990s, it was already 0.5 m/year and at the end of the last century, as much as 0.9 m/year (Zawadzka, 1999).

Anthropogenic factors affecting shoreline processes can be divided into those occurring from the waterside and from the land side. The former can include the location of negatively impacting artificial formations (e., Hsu et al., 2007; Łabuz, 2013b), while

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the main threats from the land side are the disturbance of the stability of dunes by changing the relief of the terrain and tourist pressure disturbing the vegetation stabilising the shore (Łabuz, 2005). The physical destruction of natural habitats and human heritage is the most serious consequence of shoreline erosion, but it is worth bearing in mind the broader context of the phenomenon. Caused by tourist pressure – in the conditions of the Polish coast compounded by the relatively short tourist season (Soldatke et al., 2023) – negative processes threatening dunes are the basis of many conflicts and violate the landscape values of seaside towns (Bal, 2018; Baum & Kistowski, 2004; Kistowski & Korwel-Lejkowska, 2005).

The vulnerability of the seashore and the need to take integrated action for its protection have been raised by researchers for years (Cieślak, 1995; Post & Lundin, 1996; Forst, 2009; Zuercher et al., 2022). Against this background, one of the key themes has been the introduction of marine spatial planning principles (Zaucha & Ścibor, 2009; Zaucha & Kreiner, 2021). Scientific demands were also reflected in European Union policy (Commission of the European Communities, 2000; Commission of the European Communities, 2002). Meanwhile, for many years, coastal protection policy was limited to implementing the Strategy for the Protection of the Sea Shores (2003). This strategy and the draft of the next one (2024) are primarily directed towards protecting existing development on land without considering preventing threats from land. The policy of focusing on protecting existing investments with public money reflects a broader problem. As a report by the Supreme Audit Office has shown, the area of management of the coastal technical strip has been used by maritime administration bodies over the years primarily to satisfy the interests of local governments and private investors (Olczyk, 2020).

Years of conceptual work and pilot activities (Turski et al., 2018; Zaucha & Ścibor, 2009) later led to the creation of a legal framework (2013) and the drafting of the Spatial Management Plan for Polish Maritime Areas (2021). These have contributed to a document that has filled a particular gap concerning the planning of the seashore from a water perspective, but does not fill the formal gap concerning the safe limit of investment from the land side.

Both literature sources and case studies confirm that the legal criterion of storm resistance is not an exhaustive list of factors influencing the limit of safe development. When conducting a responsible spatial policy in this respect, the following should be considered, among others: changes in water levels, geological and hydrological conditions on land and buildings at the back of the shoreline.

The objective of this study is to provide evidence-based recommendations for integrating these boundaries into national and local planning tools, as well as to support sustainable coastal development that prevents further erosion and reduces public costs related to infrastructure damage.

THEORETICAL AND LEGAL FRAMEWORK

Coastal protection in Poland

Shore protection must be carried out at many levels. It involves the interaction between natural forces and human activity. The most significant priority under current conditions is preserving the shoreline and preventing loss of the shoreline. For this to be possible, legal provisions must specifically define the forms of shore protection. To achieve this, the factors shaping the shore – such as the sea, wind, plants, sediments, geology, and human activities – must be considered (Pruszak, 2003).

Legal basis

In order to consider shore protection from the land side, it is crucial to understand the concept of the coastal strip and its components. The coastal strip is the land area adjacent to the seashore; it consists of the technical strip and the protective strip. The former is the zone of mutual, direct interaction between sea and land. It is an area designed to maintain the shore in a condition consistent with safety and environmental protection requirements.

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The protective strip covers the area where human activity directly affects the technical strip. The boundaries of the technical and protective strips are defined by the director of the competent Maritime Office after prior agreements with relevant entities (Act on maritime areas, 1991; Article 36).

Coastal protection is understood as the prevention of coastal retreat through several protective measures. In Poland, two Maritime Offices, based in Gdynia and Szczecin, are responsible for coastal protection. The primary legal basis for protecting the Polish coast is the Act of 28 March 2003 on establishing a multi-annual programme, "Programme of Coastal Protection" (2003), which encompasses all kinds of undertakings aimed at protecting the coast against erosion. The programme envisages implementing measures concerning the construction, extension and maintenance of a flood protection system in coastal areas. The act provides for implementing the intended objectives between 2004 and 2023. An important element of the act is the provision of a shoreline – according to the state in 2000 – and preventing further beach loss. For most stretches of shoreline, artificial shore recharge (reefing) is recommended. In some cases, upgrading or building new shoreline fortifications, cliff dewatering, or a harbour debris transfer system is advisable.

The above law is supplemented by the Decree of the Council of Ministers of 29 April 2021 on the minimum and maximum width of the technical and protective strip and the manner of delimiting their boundaries.

The Ordinance of the Minister of Maritime Affairs and Inland Navigation of 17 November 2017 on the minimum level of safety of the seashore and the course of the sea shore protection boundary line contained kilometre designations of the shore. The required levels of safety, understood as the probability of a storm per N years, are assigned to them. However, this act was repealed in 2019, assigning the competence to establish the boundary line of coastal protection to the competent director of the maritime office for the area by way of a decision. This is the line beyond which the intersection of the water table and land cannot be retracted at the average sea level over the last 10 years. The legislator left the provision that the minimum level of safety of the seashore in the technical strip is determined by the probability of a storm event in this area (Act on maritime areas, 1991).

The Regulation of the Minister of Transport and Maritime Economy concerning the technical conditions to be met by maritime hydraulic structures and their location (2025) is a document which contains definitions and parameters for maritime structures located within the territorial limits of seaports and marinas. This information is particularly relevant for the design of safe development lines in the port zone. The Act of 21 March 1991 on the Maritime Areas of the Republic of Poland and the Maritime Administration (1991) introduced spatial development plans for internal marine waters. The plans, adopted in 2021, define the intended use of maritime areas and allow for their protection—albeit only up to the shoreline. However, the Act lacks instruments that would enable planning interventions or restrictions on land use aimed at shoreline protection. Consequently, it does not provide legal mechanisms to influence land-based spatial planning in order to safeguard the coast. A further piece of legislation is constituted by the Comprehensive Act of 16 April 2004 on Nature Conservation. Given that the majority of the shoreline is subject to various forms of nature conservation, the provisions of this legislation should largely condition the possibilities for its protection, both from the water and from the land. Familiarity with this Act is fundamental in the context of moving into the coastal zone and possible interference with the existing environment, as in some cases, this determines shore protection measures.

Despite the implementation of comprehensive protection measures and the existence of planning documents at national and regional levels, local authorities continue to play a pivotal role in shaping spatial policy for the coastal strip from a terrestrial perspective. The amendment to the Act on Spatial Planning (2023) introduces a new local planning act in the form of a general plan covering the entire municipal area. This supersedes the previously

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established Study of Conditions and Directions of Spatial Development, which was formally weaker. This new document enables zones to be designated where development is prohibited and where planning permission cannot be granted. However, this new instrument does not guarantee that urbanisation towards the sea will be halted. Notably, the establishment of these areas is not mandatory and the established configuration criteria do not consider maritime threats. The current situation, in which all municipalities are obliged to implement their general plans and give due consideration to their existing spatial policies, provides an opportunity to introduce measures to reduce investment pressure in coastal areas. Consequently, there is a valuable opportunity to effectively incorporate the concept of the limit of safe investment into the municipality's spatial policy.

Another new type of document that may indirectly affect coastal zone protection is the landscape audit, which is developed at the regional level. A landscape audit plays a pivotal role in this regard, substantially influencing the spatial development plan. A specific methodology is employed to identify priority landscapes and make recommendations for their protection. Audits of coastal regions have identified the majority of coastal areas as priority landscapes (Regional Planning Office of the Zachodniopomorskie Voivodeship, 2023; Pomorskie Regional Planning Office, 2025). The tool has been designed to be effective in the face of local investment pressure. It could be argued that preserving landscapes and encouraging investment in coastal regions are mutually reinforcing. However, at the time of writing this article, these documents had not yet been incorporated into local planning regulations, which hinders the assessment of their effectiveness.

Following a thorough analysis of Polish legal acts, several conclusions can be drawn. Firstly, the prevailing legislation on shore protection is predominantly oriented towards the land zone and the protection of existing buildings, with no consideration given to the economic or environmental rationality of the process. A further limitation of the policy is the absence of reference to long-term forecasts of the effects of climate change.

In addition to the scope of planning competences and responsibilities of municipalities and regions, the inadequacy of Polish law is also evident in the scope of tasks assigned to the Maritime Authorities. These authorities are responsible for maintenance of the coastline and protection of the shore. With regard to investments situated within the protective strip, i.e. the zone directly affecting the technical strip, it should be noted that they are only eligible to offer an opinion without binding force. Technical strip conversion is one of the key challenges, particularly in regions experiencing high levels of tourism. In such locales, the expansion of accommodation facilities frequently necessitates the intensive development of zones in close proximity to beaches. While a single development will not significantly impact the shoreline, multiple developments of this kind over a slight stretch may disturb the hydrological conditions or the bearing capacity of the soil. In order to obtain permission for an investment in the technical strip, it is necessary to obtain the approval of the Maritime Authority. The decision can be regarded as positive if the investment does not pose a threat to the stability of the coastal zone. However, even prior to the establishment of the technical and protective strip, construction of buildings in the immediate vicinity of the shores was underway.

Supplementary terminology

The legal terminology described above needs to be supplemented with several terms relating to the seashore taken from scientific publications. For the purpose of this research, a shoreline is defined as "the land or area adjacent to a body of water, not flooded by the sea. On the dune and beach coast, it is formed by the ridges of coastal dunes and the interdune gutters separating them, as well as depressions covered with aeolian sand, while on the moraine coast, it is formed by plateaus, edges and cliff slopes" (Łabuz, 2018a, p. 436). In the case of dunes, coastal vegetation acts as a buffer between the impact of the sea on human habitats; for cliffs, it is a form of stabilisation on land and one of the factors preventing erosion. The coastal zone is a transition zone between the

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shore and the sea (Furmańczyk & Musielak, 2005). The shore is usually a beach that can be periodically flooded by water due to sea-level changes. The point where the sea meets the land is the "waterline", while the long-term resultant sea level at the point where the land meets the sea is called the "coastline". The foreshore is the underwater part of the coast, seabed in the shallow water zone, where the waves influence the sediment structure. The foreshore includes the zone of the tidal flats (underwater shoals), whose primary function is to initiate the refraction of the wave, i.e. to contribute to the gradual dissipation of the energy of the water mass movement transmitted towards the shore. These formations can be considered important natural morphological structures protecting shores and beaches from the excessive impact of waves and currents, especially during storms (Frankowski et al., 2009; Pruszak, 2005). In addition, the positive role of the foreshore is to act as a natural storage area for sediments eroded from the shore, which, under calmer hydrodynamic conditions, are used by nature to rebuild the shore damaged during storms (McCarroll et al., 2020). In understanding the coastal zone, it is important to consider its unstable location and the constant change of the forms that make it up. Such changes can be periodic and result from changes in sea level and storms (Łabuz, 2013b). There can also be permanent changes to the coastal zone due to accumulative or erosive sea activity. In the case of the Baltic Sea, which is considered free of currents, periodic sea-level fluctuations are related primarily to pressure systems and developing wind waves (Bartnik & Jokiel, 2012).

Safe development

The Regulation of the Minister of Maritime Affairs and Inland of 17 November 2017 on minimum levels of coastal safety of the sea and the course of the coastal protection line, minimum levels of coastal safety are defined. This level is determined based on the probability of a storm event once in N years (N is assumed to be 100 years). This probability is defined as a storm caused by wind with an average speed of 18 m/s, blowing in the Baltic Sea area at its most unfavourable angle to the shore for 5 hours. The appendix to the regulation contains distances given in metres and assigned to a specific section of shore, which contains specific safety levels. Dubrawski and Zawadzka-Kahlau (2006) define safe management limits as an "area reserve for shore retreat". The width of this area depends on the type of shore, the type of erosion, flood and storm hazards, the sediment stock and the expected rate of shore erosion. The authors point out that the proposed conditions for safe management should follow local spatial development plans and consider hydrological relations, protection of natural assets and topography of the area.

The present authors adopt this perspective. The exception to this is the rejection of local spatial development plans as determinants. The authors consider the existing buildings and their degree of occupancy. Despite being conscious of the difficulties involved in challenging acquired rights, they treat the current planning policy as an area that may be subject to review.

General characteristics of the Polish shores

There are three basic types of shorelines on the Polish Baltic coast: dune, cliff and alluvial (Angiel & Gerstmannowa, 1992); however, dune spit shorelines of accumulation origin significantly dominate (approx. 75% of the shore length). These are coasts shaped by marine processes: accumulation and erosion (Gerstmannowa, 2004).

Taking the morphodynamic and lithogenetic characteristics of the seashore as the characteristic parameters determining its state and the way it interacts with the surrounding environment, three basic forms can be distinguished: low-lying shores, dune shores and cliff shores (Tomczak, 1995).

Low-lying shores

This type of shore occurs in lagoons, river deltas and low-lying areas. On the Polish shore, a few sections of open sea occur near low-lying areas. Much larger sections of this type are found in bays or lagoons.

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In the case of Poland, this is the area of Zatoka Pucka, Zalew Wiślany and Zalew Szczeciński. This type of shore, due to its partial closure and shielding from the direct action of sea forces and due to the dense vegetation covering the shore, usually does not require protection against erosion.

The shores extending pointwise from Rewa to Jurata on the Bay of Puck are separated from the sea by the undersea Szpryk shoal and the short spit of Ryf Mew. Both forms, being in their initial stage, limit the influence of sea waves on the shore, making it relatively stable. The main threat to the flat shore is flooding, both of the shore itself and the low-lying areas that form its hinterland (Łabuz, 2013b).

Cliff shores

Cliff sections are scattered throughout the Polish coast and cover approximately 65 km. They extend along the shore in sections ranging from 0.5 km to 10 km in length (Łabuz, 2012a). They are represented by sections of shorelines varying in height, geological structure, dynamics and vegetation cover. The cliff shores of the southern Baltic coast are built mainly of glacial till, fluvioglacial sands and gravels and stagnant silts. The cliffs were formed on a coast built of moraine uplands, which were subject to the process of destruction by the sea during the lithorhinal transgression. Even cliffs located close to each other can vary in structure due to the impact of the sea (Subotowicz, 1982). In the structure of a cliff, it is necessary to distinguish between the edge, the slope and the foot. Due to specific processes, landslide niches, kernels, runoff, and abrasion niches can form on the slope (Regulation, 2017). The rupture of sediment moved by gravity from the top of the cliff (edge) downwards can also occur. This situation can lead to a change in the structure of the cliff, involving the formation of several steps staggered on the slope. Among the meso and microforms, aeolian ripples and wind wrinkles on the sands or rainwater runoff troughs are formed.

Intense abrasion of landslides and the movement of sediments lead to structural changes in the cliffs (Subotowicz, 1995; Uścinowicz et al., 2024).

Dune shores

A great variety of forms and types characterises dune shores. They may be formed by low-medium or high dunes, which may be vegetated to varying degrees. Therefore, these shores may be subject to erosion, erosion-accumulation and accumulation processes. Depending on the dune's height or the dune system's size, they protect the back of the shore to varying degrees. The relief of dunes depends on the speed and direction of winds and the width of the substrate caused by the terrain and the vegetation present (Łabuz, 2013b). The diameter of the material present on the beach is also an important factor. The dune shore is made up of different shore forms.

The foreground of the dune is the beach, and the width and slope are reflections of the dynamics of a given stretch of shore. The width of the beach is also influenced by the shoreline and how many revetments it is composed of. In the case of a well-developed system of revetments, additionally covered with vegetation, sediment runoff is much less than in the absence of such a system and a steep shoreline. Behind the beach is the initial field of the front dune, where sand is accumulated, retained by vegetation and transported by the wind. Behind this space, the frontal dune is formed, which is the mobile base of the shore and is usually made up of a white dune. Behind this shore formation is already the stable shore of the dune field. In a few cases, this zone comprises moving dunes, but in most of the Polish coast, these forms are inactive and covered with vegetation. Such a great diversity of dune shores requires forecasting the resistance of specific shore sections through diagnosed morphology and the current and estimated speed of dune erosion (Łabuz, 2013a).

Such studies make it possible to adapt hinterland defences to forecast changes and sea level rise over time. According to T.A. Łabuz on the Polish coast, three types of dune shores can be distinguished. The shores of coastal plains retreat due to abrasion. Spit-dune shores occur as sand barriers formed during accumulation. The last type is the dune shores of moraine sections, formed when dunes from coastal plains and spits overlap post-glacial moraine

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formations. Nowadays, moraine cliffs are formed due to shore retreat, with the dune forming the crown of the cliff (Łabuz, 2005). In this study, the division into dunes undergoing accumulation and abrasion was applied, and the dune-marine shore was also specified.

MATERIALS AND METHODS

The study aimed to define criteria for establishing safe investment boundaries in coastal areas, ensuring sustainable development and reducing public expenditure on erosion and infrastructure damage.

To this end, the research evaluated the natural dynamics of various Polish coastlines, such as cliffs, dunes, and accumulation zones, as well as the effectiveness of current spatial planning instruments. The study also examined the intersection of investment pressure and coastal vulnerability.

A multi-method approach was adopted to address the research problem.

First, a detailed examination of scientific literature and national and EU legal frameworks was conducted to understand the geomorphological, hydrological, and legal conditions that shape coastal protection in Poland.

Based on this, six localities representing different coastal typologies were selected for case studies. These sites provided a varied testing ground in which to explore the interaction between natural and anthropogenic factors and spatial planning.

The case studies cover the following factors:

– locality development profile: information on the specific nature of spatial policy based on local planning documents, and statistical data on coverage by local spatial development plans (LSDP) (2023), issued building condition decisions (BCD) (2009–2023), and the Topographic Objects Database (2020); in addition to the descriptive part, a map of the general land use pattern was prepared based on Topographic Objects Database data (2020) and used to develop a boundary proposal;
– characteristics of the coast: information on scale and structure (literature), and areas of exceptional natural value (Central Register of Nature Conservation Forms, 2019);
– characteristics of coastal processes, based on literature;
– characteristics and assessment of the effectiveness of coastal protection processes: based on literature and field research.

Based on the above, safe development limits for coastal areas were proposed for each analysed case. Due to the lack of literature on cliff coast protection, an interview was conducted with Dr Andrzej Cieślak, a long-standing expert at the Maritime Office in Gdynia. The proposed methodology is anchored in a comprehensive analysis of the theoretical framework and case studies, supplemented by expert opinion. It aims to establish a framework for determining the safe investment boundaries. The method under discussion takes a different approach to cliff and dune waterfronts. The study's authors assume the rationalisation of the social costs of coastal protection, which assumes that investment in areas whose safety would require investment from the seaward side should be limited. The sole constraint on this approach relates to circumstances in which its implementation would require the abandonment of the protection of culturally or socially significant structures.

To illustrate more effectively how the safe investment boundary can complement existing models that support decision-making in spatial planning, analyses were conducted. These analyses allowed the mapping of the elements described in the chapter "Legal and Theoretical Framework: Coastal Protection Methods", which includes:

– shoreline safety level (the authors' elaboration of the line based on the 2017 Regulation on minimum safety levels for the seashore and the protection line);
– technical strip and protective strip, based on the Maritime Administration Spatial Information System (SIPAM, 2020);
– flood risks from the sea, based on data from the Internet System of Land Protection (ISOK, 2020);
– mass movement hazards – Landslide Protection System (SOPO, 2020).

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These recommendations are grounded in spatial planning studies, which reveal a significant gap in current practices. This, in turn, entails certain limitations. Further refinement of the designation of safe investment boundaries may require in-depth geological and hydrological studies tailored to specific coastal areas.

CASE STUDIES

Based on previous research, localities representing six different coastal types – ranging from cliff coasts with varying degrees of activity, abrasive dune coasts, accumulation dune coasts and dune-surface accumulation dune coasts to low-activity (neutral) dune coasts – were selected for case study analysis.

Active cliff coast – Jastrzębia Góra

Jastrzębia Góra is a locality with a dominant tourist function (Łojek, 2003) (Fig. 1) in the municipality of Władysławowo. The spatial policy is also dominated by extensive development with residential, recreational and spa functions (Studium, 2024), with many residential buildings having a seasonal tourist function (Golędzinowska, 2015). Despite the fact that the plan coverage of the entire commune in 2023 was 48.5%, whereas in the period 2009–2023, 349 DDC were issued (LDB, 2024), there are several LSDP in the village, but in the area of the technical strip, investments have been issued based on DBC.

The cliff lies in one of the most beautiful parts of the Polish coast. The terrain's surface is uplifted over one kilometre to 30 metres above sea level. It breaks off abruptly about 40–80 metres from the coastline, falling towards the sea with an almost vertical scarp (Szawłowski & Wawrzyński, 2015). The cliffs built of boulder clays, sand, and clays are prone to landslides (Subotowicz, 1982). The hydrological system with suspended water layers further destabilises the ground (Kamiński at al., 2012). The area is distinguished by its high natural values, protected within the Seaside Landscape Park and reserves, including Lisi Jar and Rosettowe Buki (Central Register of Nature Protection Forms, 2019).

On average, the shoreline is receding by 0.9 m/year, threatening buildings in the near-cliff zone, including nearby towns. Between Władysławowo and Jastrzębia Góra, 18 landslides have been identified. In Karwieńkie Błota, frequent flooding is due to high groundwater levels, exacerbating illegal and intensive development in the floodplain (Lidzbarski & Tarnawska, 2015).

The destruction of the cliff was first mentioned in the 19th century, and a comprehensive survey began in the 1970s. Between 1992 and 2010, protective measures were taken, including the construction of gabion bunds and reinforced soil slopes, which served not only to protect the cliff but also the endangered hotel buildings. Design errors, e.g. inadequate groundwater drainage, caused damage to the defences, such as the displacement of the structure in 2010 (Uścinowicz et al., 2014). A protection system including gabion ties, drainage and reinforced slopes is now in place, but additional measures may be required, considering sea level rise and climate change (Boniecka et al., 2013; IMGW, 2014).

Although the currently presented investments do not threaten the protection of the cliff in Jastrzębia Góra, an increase in the number of incidents of encroachment of buildings into the technical strip may cause its destabilisation. Currently, the only barrier in this respect is the existing protective forest, which would be irretrievably lost if degraded under the influence of anthropopressure. As a result of the situation, the Maritime Authorities will not have the possibility to block further investments that could disturb the stability of the above-mentioned stretch of coastline.

Cliff coast with little activity – Puck Cliffs

In 2023 only 28.1% of the town was covered by LSDP, whereas in the period 2009–2023, only one DBC was issued (LDB, 2024) Puck has a diverse programme of functions. However, tourism and recreational services dominate near the cliff (Fig. 2). In the bay near the historic part of the town are the remains of a medieval harbour (Janta, 1997), which has been destroyed due to erosion (Uścinowicz at al.,

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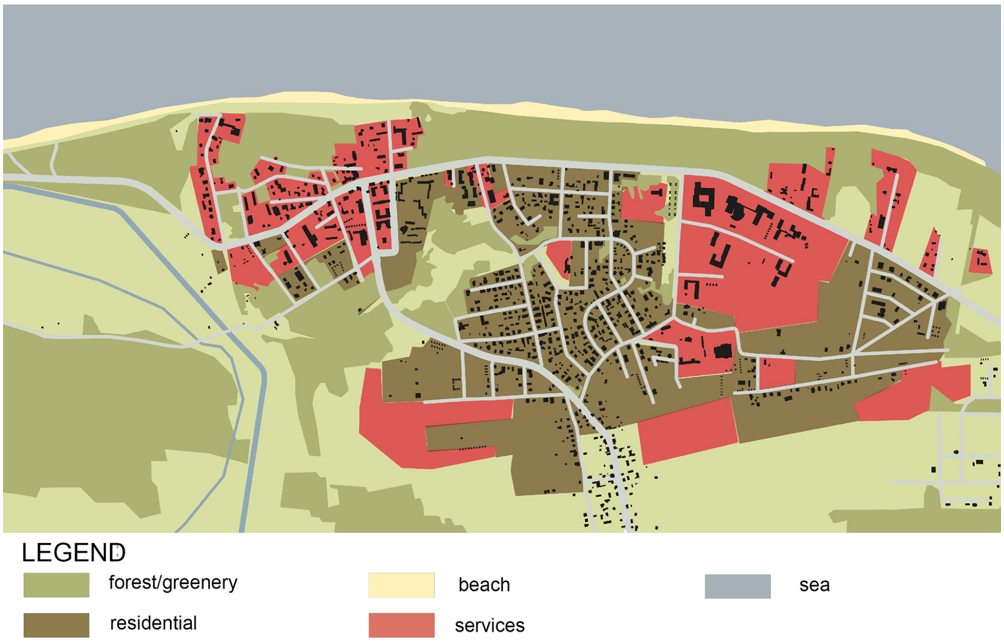

Fig. 1. General land use pattern in the structure of Jastrzębia Góra
Source: own elaboration based on BDOT.

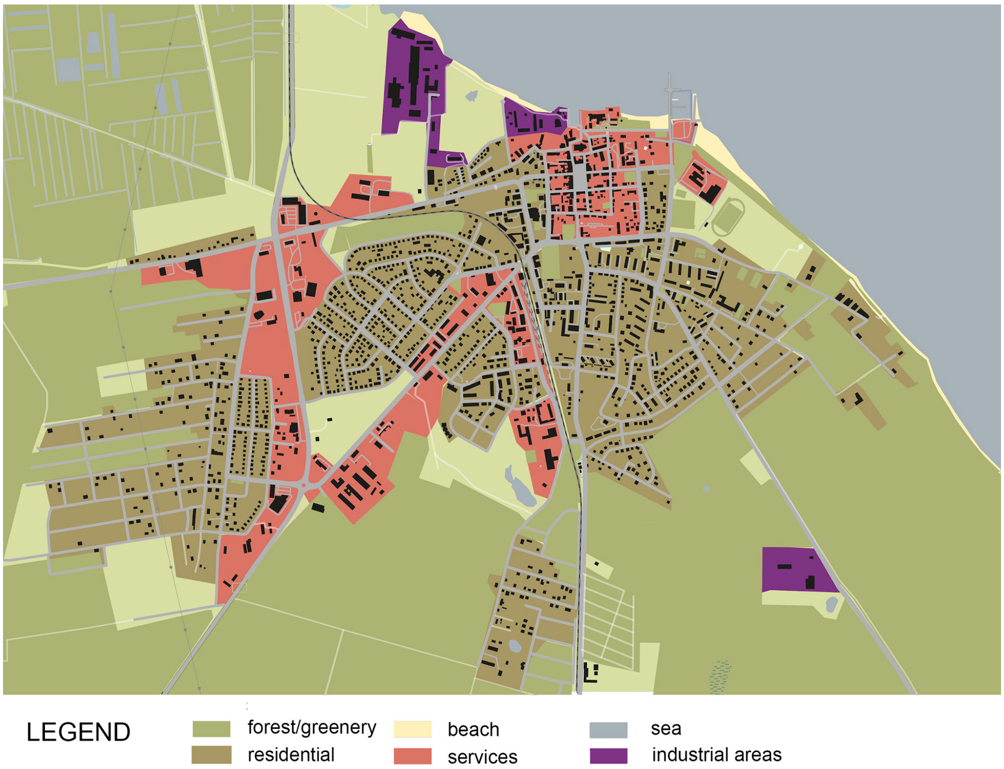

Fig. 2. General land use pattern in the structure of Puck
Source: own elaboration based on BDOT.

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2013). Beech trees grow on the cliff top, and private properties are within 100 m of the edge. In recent years, tourist development has been allowed in this area. Areas favourable for development are those located on the upland and composed of glacial till, clayey sands and locally occurring sand and gravel formations. In the case of these areas, special attention should be paid to the slopes of the terrain reaching up to 12%, in the case of the Puck Cliff, and to the clay fractions that may deteriorate due to water seepage (Kruk-Dowgiałło, 2013).

The area's geomorphology is complex, and the unstable alluvial, peat, and sandy substrate means that areas suitable for development are concentrated on the upland, where glacial till and sand dominate. The cliff zone is affected by winter glaciations and winds, which affect sediment transport in the Bay of Puck in different ways (Łabuz, 2013b). Erosion processes are limited by the shoal "Mew Riff", which acts as a natural shore protection (Klekot, 1980).

The cliff edge has receded by 160–220 m over the last 2000 years, corresponding to an erosion rate of 0.08–0.11 m/year. Due to the low dynamism of the processes, this cliff is considered "dead" and represents the uplift type (Kistowski, 1997).

As the shore retreat rate within the town of Puck is low, this gives reason to believe that the Puck Cliff does not currently pose a major threat to existing buildings, and therefore, there is no need for technical forms of shore protection. The only interference from the seaward side is from the harbour, the functioning of which is connected with the built breakwater and the band of blocks. The biggest threat currently facing the city authorities is pressure from tourism and investment. When planning shore protection works, attention should also be paid to protecting marine relics and sunken ships so that any shore protection works do not lead to the devastation of this unique resource (Łabuz, 2013b).

Abrasive dune coast – Kołobrzeg

In 2023 52.3% of Kołobrzeg was covered with LSDP, whereas in the period 2009–2023, 612 DBC were issued (LDB, 2024). With its tourist and spa functions, the city is characterised by a striped spatial layout cut by the mouth of the Parsęta River (Fig. 3). An important component of the space are maritime facilities, including a commercial and fishing harbour with a yacht marina and passenger functions. The landscape includes beaches, dune ramparts, wooded areas, and spa development areas. Development in the dune zone has reached a high level.

Kołobrzeg lies on a peaty plain with a dune belt. Within its administrative boundaries, most of the city is located on depressional wetlands prone to flooding. Extensive abrasive areas characterise the shore in the area of the Parsęta estuary due to the negative sediment balance and the presence of a sub-bank made of clay and gravel (Łabuz, 2013b).

The dunes in Kołobrzeg are prone to abrasion and destruction as a result of storms. Between 1993 and 2009, these phenomena contributed to the retreat of the beach despite the application of hydro-technical protection. Abrasive processes are exacerbated east of the Parsęta River, where the dune is partially protected by bands (wooden, steel and concrete), a system of coastal spurs and breakwaters. These areas are characterised by intensive development, which requires advanced protection measures (Łabuz, 2013b).

Between 1992 and 2012, the beach was reefed, adding 700,000 m^2 of sand (Łabuz, 2013b), which helped to stabilise the shoreline temporarily. Stone underwater thresholds and a modular spur system were also introduced. The problem of the receding shoreline in Kołobrzeg has still not been solved, and so far, there is no idea how to stop the process of intensive erosion (Cieślak, 2020; Łabuz, 2013b).

Accumulation dune coast – Świnoujscie

Świnoujście is located in the delta area of the Świna River, comprising dunes and a rich hydrological system with a backwater delta (Fig. 4). The spatial layout of the town is banded. On the seaward side are beaches, dunes, green areas and forests, the seaside district, and intensively urbanised urban areas. The dominant element of the city structure is the harbour.

Peat soils, which comprise more than 30% of the area, occur mainly on the islands of Usedom and

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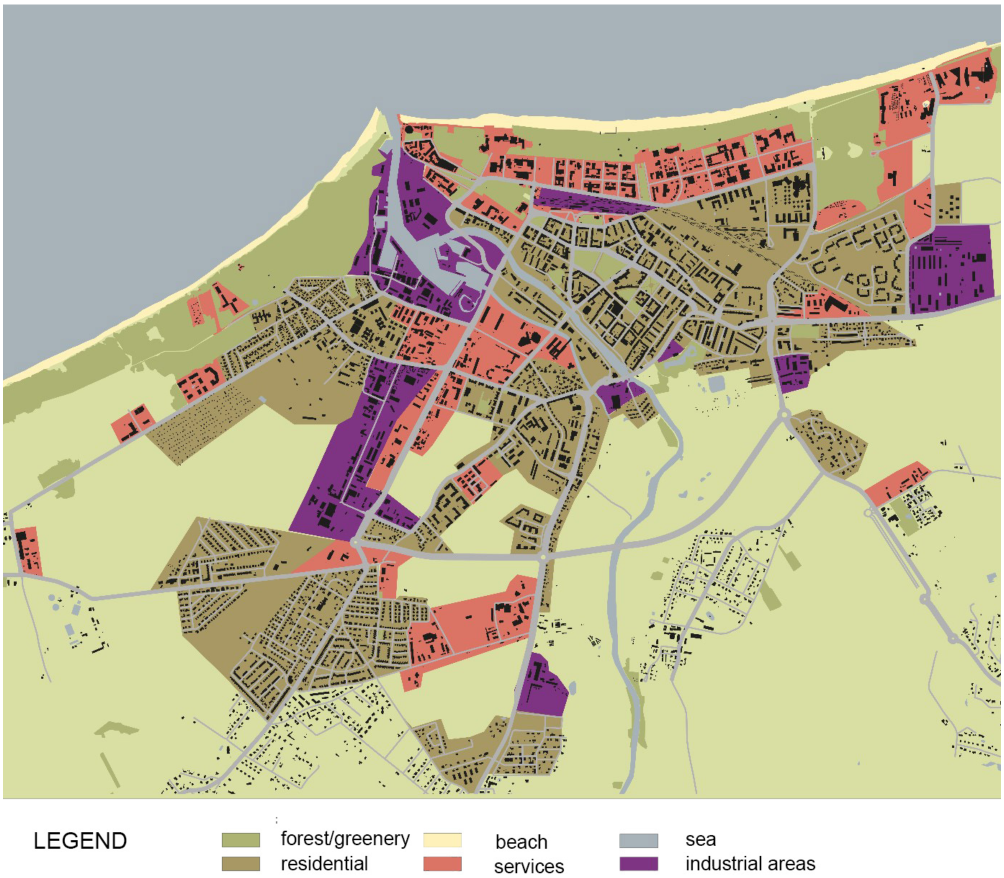

Fig. 3. General land use pattern in the structure of Kołobrzeg
Source: own elaboration based on BDOT.

Wolin, partly covered by the Wolin National Park and Natura 2000 sites (Czupryn, 2015). In 2023 48.6% of the city was covered with LSDP, whereas in the period 2009–2023, 553 DBC were issued (LDB, 2024).

Despite occasional storm processes, Świnoujście is generally characterised by a stable shoreline that is naturally recovering. The main erosion problems are due to human activities. The natural regeneration of the shore is disturbed by maritime management infrastructure and hydraulic engineering interventions. The harbour reduces sediment delivery to the shore and creates erosion bays for up to 3 km (Dudzińska-Nowak, 2015). The construction of the gas port breakwater in 2008 altered natural shoreline processes, leading to sediment accumulation on the upstream side and erosion on the downstream side (Zaucha & Matczak, 2015). This inhibited the development of dunes along a 1.2 km stretch of shoreline, leading to overgrowth and degradation (Łabuz, 2013b).

Dune-barrier accumulation coast – Hel Peninsula

The Hel Spit is one of the most attractive and, at the same time, most touristed stretches of the Polish coast. To the north, it stretches a dune overgrown with forest, which to the south, towards the Bay of Puck (Fig. 5), turns into the only stretch of beach in the country with a southern exposure. Several small villages and towns, which are administratively located within the boundaries of three communes,

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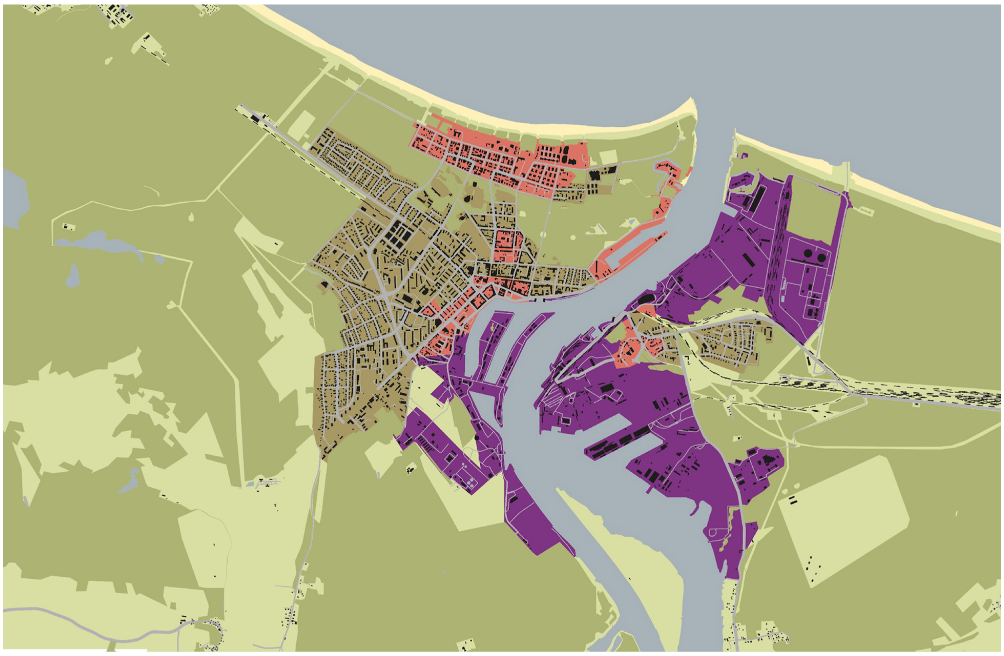

Fig. 4. General land use pattern in the structure of Świnoujście
Source: own elaboration based on BDOT.

are strung along the linear road and railway system. The pressure of tourist investment, including the development of camping and infrastructure on dunes, creates conflicts between the need for environmental protection and the development of tourist areas. The entire area is located in a Seaside Landscape Park and a Natura 2000 site. Despite this, the coverage of local spatial development plans is low here, and most building permits are based on DBC. In the municipality of Hel in 2023, the coverage of LSDP was only 0.1%, whereas in the period 2009–2023, DBC 370 were issued (LDB, 2024).

The Hel Spit is a unique geological area formed about 7,000 years ago. It was formed as a result of the accumulation of debris by sea currents, creating low terrain (up to 5 m above sea level), except for dune dikes reaching up to 22 m above sea level. The stability of the spit depends on the maintenance of afforestation and the limitation of interference with natural habitats such as dunes and reed beds (Michałek & Kruk-Dowgiałło, 2014).

Coastal processes here are complex – abrasion affects the low shores on the Bay of Puck and the bases of the dunes on the side of the open sea. The most significant problems appeared after the harbour construction in Władysławowo, which resulted in accelerated abrasion of the near-port section. Between 1908 and 1937, the spit lost an average of 0.58 m of shore annually. Fortifications (spur systems, breakwaters) were introduced, but their effectiveness was limited in the long term. Sedimentation and fortifications are concentrated in the most endangered parts, e.g., near the harbour (Dubrawski & Zawadzka-Kahlau, 2006).

Sediment accumulation occurs mainly at the tip of Hel, where sea currents overburden the shore. Storm events periodically damage the beaches and dunes, which are partially rebuilt in calmer months

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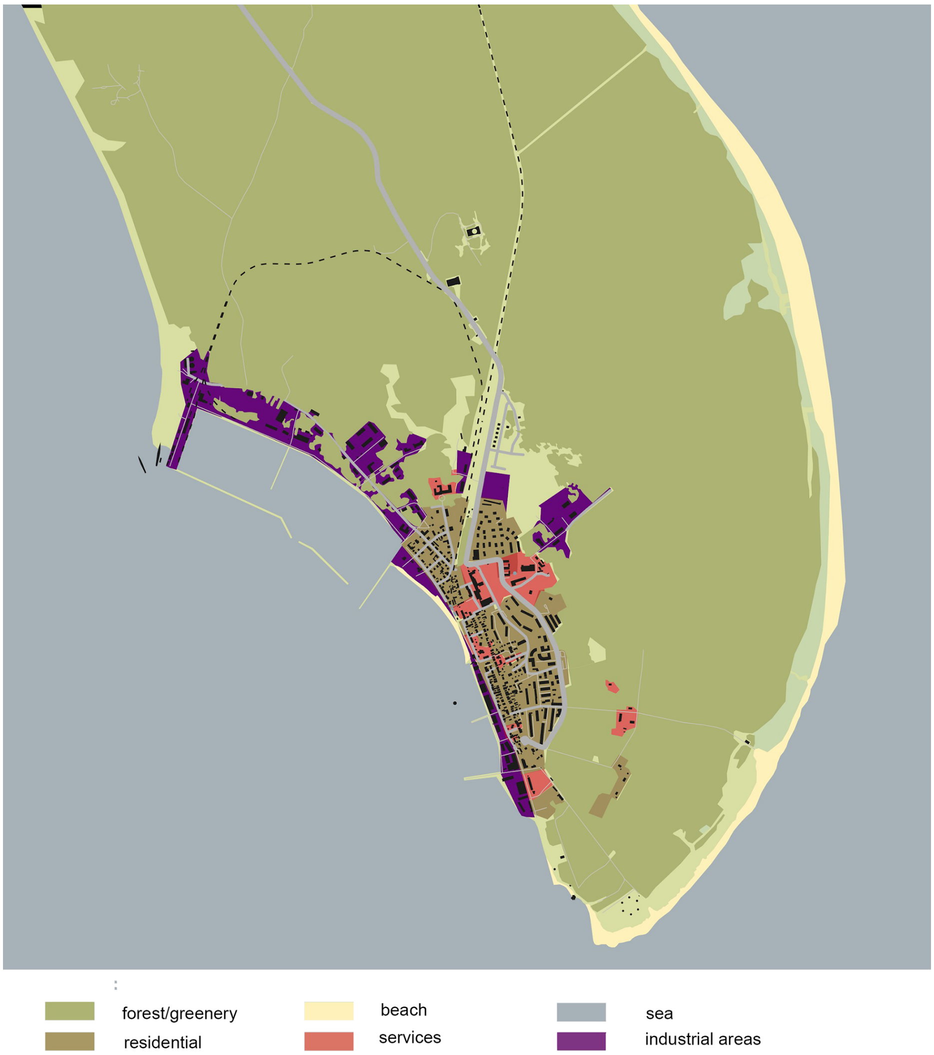

Fig. 5. General land use pattern in the structure of Hel
Source: own elaboration based on BDOT.

(Tubielewicz, 1959). However, a significant part of the Spit is subjected to artificial beach replenishment, which limits abrasion, but excessive sedimentation alters debris transport and the formation of submarine shoals (Baum & Kistowski, 2004).

Dune-neutral coast – Krynica Morska

Krynica Morska is located on the Vistula Spit, bounded north by the Baltic Sea and south by the Vistula Lagoon (Fig. 6). In 2023 LSDP covered only 4.6% of the area, whereas in the period 2009–2023, 45 DBC were issued (LDB, 2024). Illegal tourist facilities, camping sites and campsites, which negatively affect the reed beds and lead to trampling of the shores of the Vistula Lagoon, are problematic. Protection of the shore from the side of the Bay of Gdańsk is limited to planting, use of fascines and local reefing (Łomniewski, 1958; Szmytkiewicz, 2017).

The spit comprises fine-grained sands, lake sediments, and eolian sands. The area has a unique hydrological system—a freshwater lens fed exclusively by rainwater, prone to salinisation due to overexploitation during the tourist season (Makowska, 1991).

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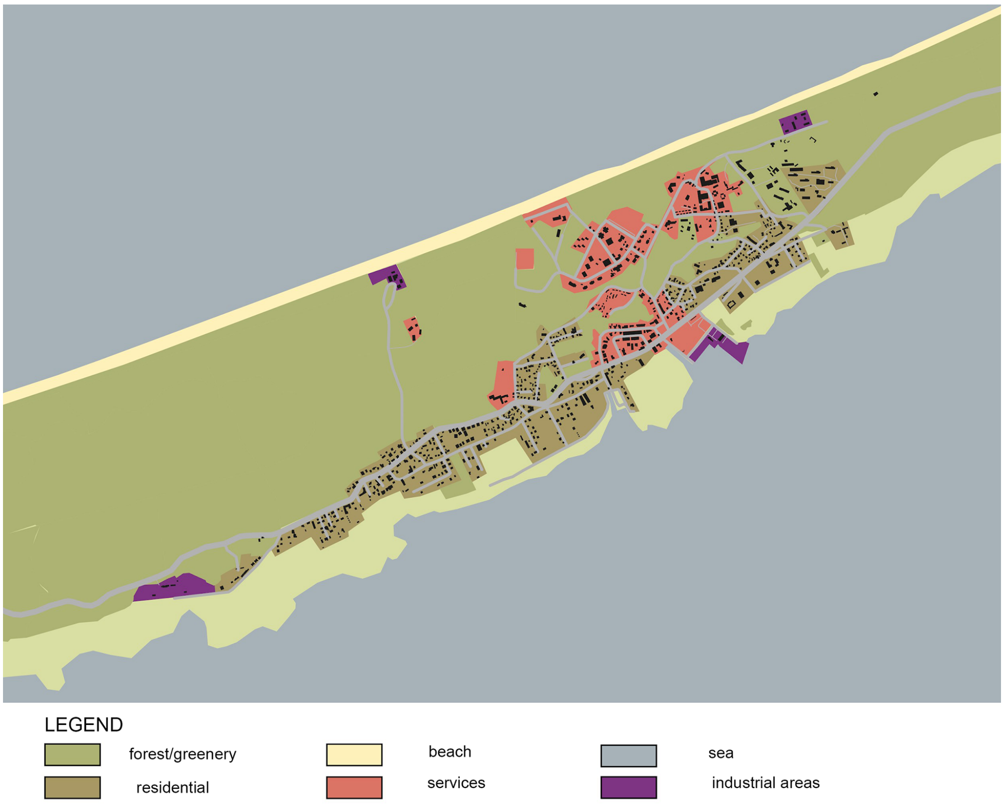

Fig. 6. General land use pattern in the structure of Krynica Morska
Source: own elaboration based on BDOT.

The shores of the Vistula Lagoon are stable due to reed beds that provide natural protection against wave action and ice flow. On the other hand, the shores from the side of the Gulf of Gdańsk are subject to limited abrasion processes, and due to the presence of dunes and moderate wave action, erosion is relatively low. Only local storm surges can cause short-term flooding (Łabuz, 2013b).

The transport of coastal debris is mainly westward, although a local shift to the east is observed in Kąty Rybackie. These processes are disturbed by human intervention, including a reduction in sediment supply after the Vistula Lagoon was cut off from the Vistula Delta (1915) and the construction of a ditch across the spit as part of the Nowy Świat project, which affects the dynamics of coastal processes. This investment has altered the coastal system, leading to sediment accumulation on the eastern side and erosion on the western side. The newly created islands, formed from material excavated during the works, are expected to act as a bird sanctuary. However, their environmental impact has not yet been thoroughly investigated (Maritime Office in Gdynia, 2015).

RESULTS

Based on the spatial management data collected, the general characteristics of the settlements and boundary processes in the area were depicted. The characteristics of the coastline, together with the specific dynamics of coastal change processes, facilitate the prediction of future developments. It was hypothesised that the coastline, characterised by cliffs and dunes, would exhibit a comparable level of vulnerability to various environmental impacts. In coastal cliff environments, the primary factors that determine safe investment boundaries are landslide risk, shore retreat rate and cliff foot stabilisation

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systems. In the case of coastal dunes, the most significant factors are dune width and height, beach width and slope, and coastal erosion rate (strongly dependent on wind frequency) (see Tab. 1).

Table 1. Basic criterion for identification of safe investment boundaries

Cliff shore	Dune shore
Basic conditions to be taken into account	
Landslide risk Shore retreat rate Cliff foot stabilisation systems used	Dune width and height Beach width and slope Coastal erosion rate

Source: own elaboration.

In view of the limited scientific literature on the safe investment of cliff coasts, an expert was asked for an opinion on this matter. With regard to the possibility of specifying specific parameters, Mr A. Cieślak, referring to the edge of the cliff, believes that the building zone should extend to a distance equal to twice the height of the cliff. This width is considered adequate when taking into account the rate of coastal retreat and sea level rise. Furthermore, the concept of the safety margin is highlighted, which is influenced by the unexplored hydrological conditions of the cliff. Therefore, the initial fundamental parameter, which is equivalent to twice the height of two cliffs, is increased by the height of the cliff.

The following essay will provide a comprehensive overview of the relevant literature on the subject.

The expert's response did not offer a definitive resolution to the issue concerning the dune shore. It was posited that the optimal distance from the coastline should be a minimum of 40 metres. However, he emphasised that this is an indicative distance, which should be adapted to local conditions and planned inland investments.

In accordance with the assumptions presented in the "Materials and methods" section, it is possible to adopt simplified parameters. Once adapted to local conditions, these parameters will allow the safe development boundary to be determined, thus ensuring the sustainable use of the coastal zone.

Active cliff coast – Jastrzębia Góra

Jastrzębia Góra, characterised by an active cliff and numerous landslides, requires special care. For this reason, the Regulation (2017) recommends moving the safety zone 200 m away from the baseline in most parts of the shore (Fig. 7). Some of the buildings in this locality are located in the technical or protective strip, and some are even on the boundary of landslides, resulting in their inclusion in the restricted development zone.

Cliff coast with little activity – Puck Cliffs

Puck represents an inactive cliff. Problems include landslides, flooding and the impact of harbour structures on the onshore stability. The boundary of the zone on the western side has been widened, but its narrowing could be possible after the construction of the dykes. On the eastern side, the boundary runs along the technical strip, and a new housing complex within its boundary indicates inadequacies in coastal protection policy (Fig. 8).

Abrasive dune coast – Kołobrzeg

Due to the dunes' abrasion, Kołobrzeg is a particularly challenging case. The stable western part of the shore allows a zone limited to the technical strip. In contrast, the eastern side of the breakwater, despite costly protection measures, requires a larger zone to protect the shore from erosion. Assuming that investments on the eastern side of the breakwater would not be continued, it would require the safe investment boundary to be moved away from the technical strip set by the Ministry (Fig. 9). In this particular case, due to the densely urbanised area and the presence of socially important spa areas, it is proposed that the safe investment boundary be supported by sea defences and thus coincide with the boundary proposed by the Ministry.

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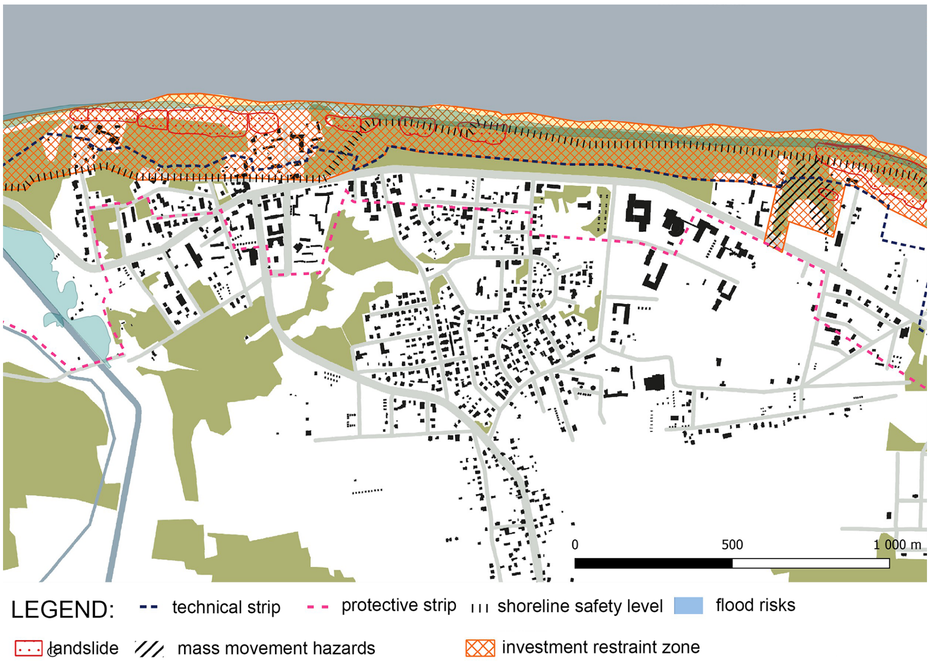

Fig. 7. Boundary for safe investment in Jastrzębia Góra
Source: own elaboration.

Fig. 8. Boundary for safe investment in Puck
Source: own elaboration.

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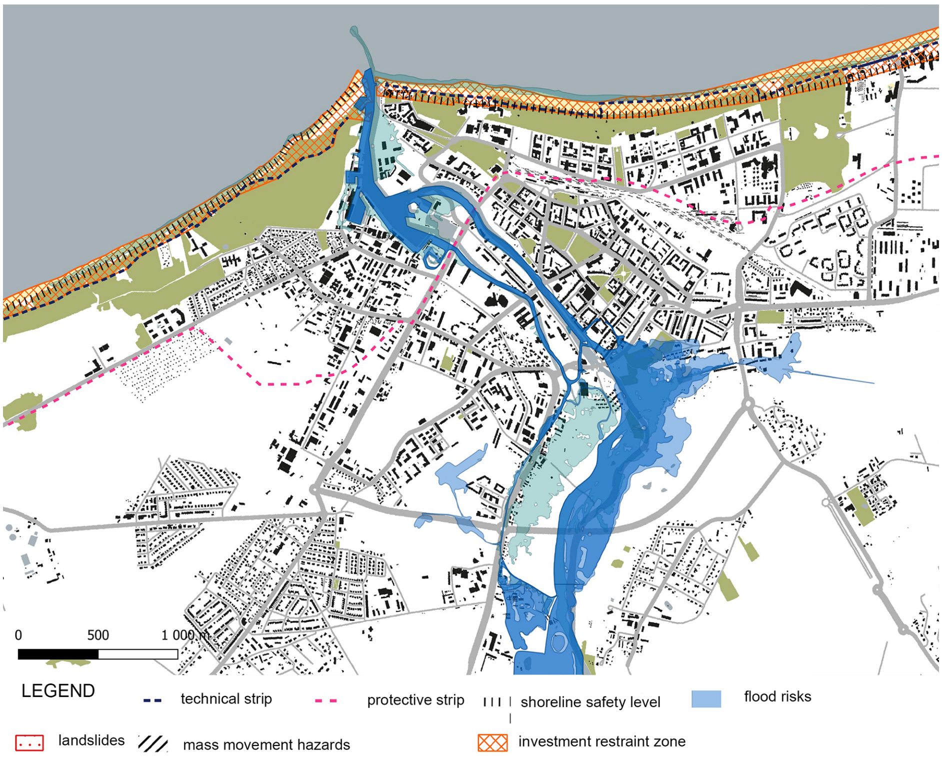

Fig. 9. Boundary for safe investment in Kołobrzeg
Source: own elaboration.

Accumulation dune coast – Świnoujscie

In the case of Świnoujście, which is characterised by coastal accumulation, the restricted zone runs along the technical strip, except on the eastern side of the Swina mouth, where it has been widened due to the erosive influence of the breakwater (Fig. 10). Due to accumulation, the zone may be further shifted in the future.

Dune-barrier accumulation coast – Hel Peninsula

Hel, as a unique area of the Hel Spit, requires consideration of both the open sea and the bays. Most of the "Kosa Helska" is included in the restricted zone, except for the harbour and development outside the flood risk zone (Fig. 11). This arrangement protects the existing forests from potential felling and shoreline destabilisation.

Dune-neutral coast – Krynica Morska

The boundary of the zone was set in Krynica Morska, located on the stable shores of the Vistula Spit, taking into account rising sea levels and more frequent extreme events. On the side of the Vistula Lagoon, the zone includes areas at risk of flooding, protecting reed beds as a natural buffer. The zone was delimited 20 m from the waterline on the seaward side (Fig. 12).

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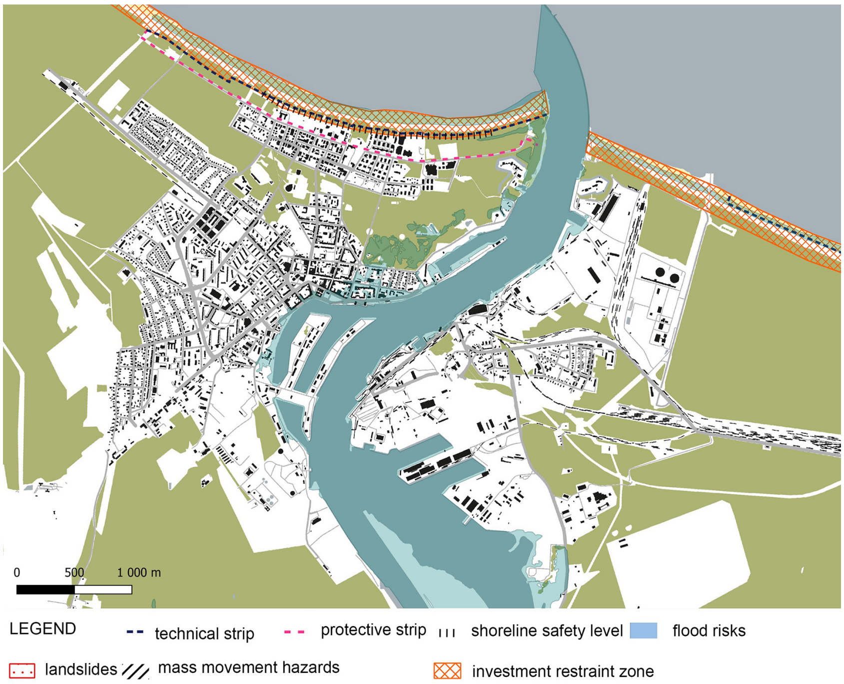

Fig. 10. Boundary for safe investment in Świnoujście
Source: own elaboration.

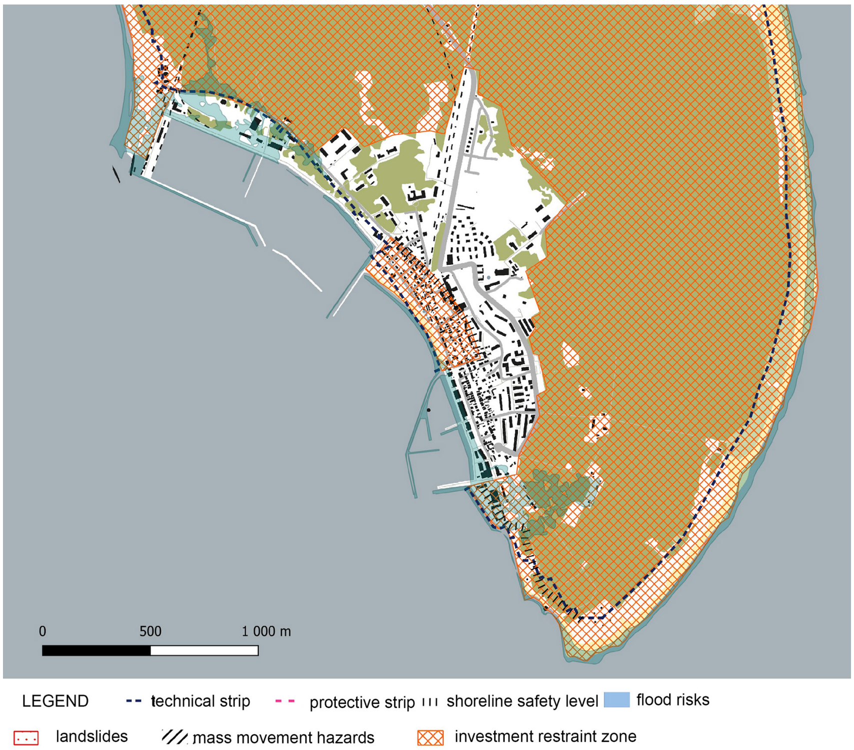

Fig. 11. Boundary for safe investment in Hel
Source: own elaboration.

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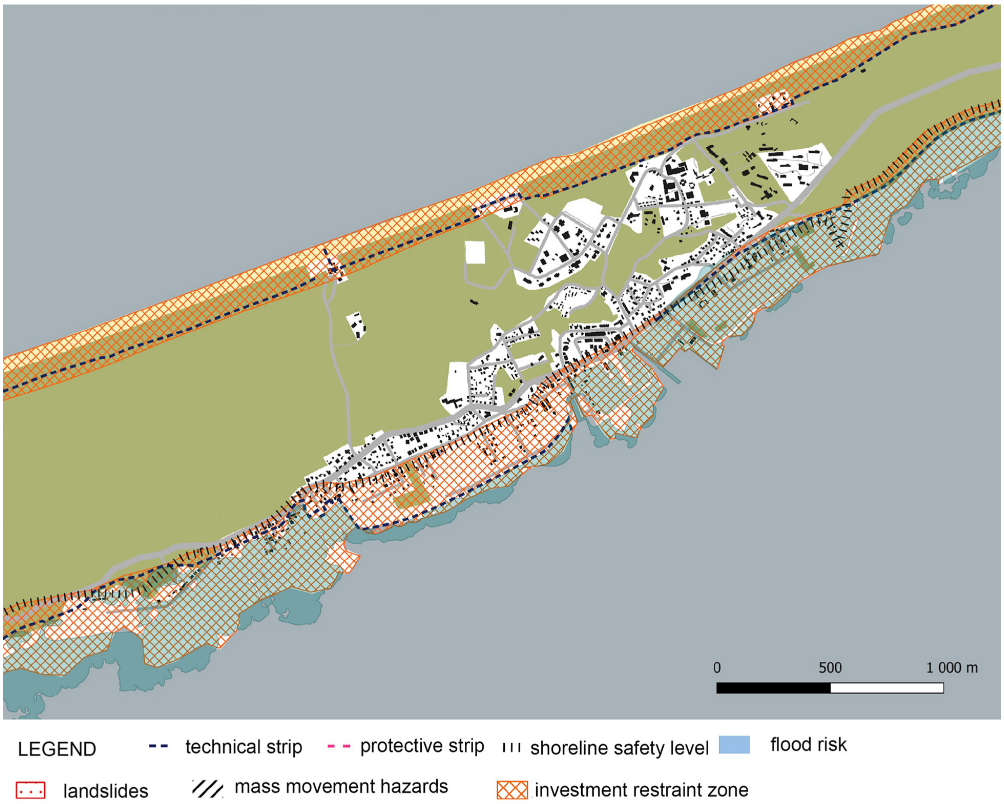

Fig. 12. Boundary for safe investment in Krynica Morska
Source: own elaboration.

CONCLUSIONS AND RECOMMENDATIONS

Natural conditions have caused changes to the coastline over the centuries, but the process is accelerating due to the effects of climate change and human investment activities. The studies carried out indicate that the safe management of Polish coastal areas – including the correct and effective delimitation of the safe investment boundary – requires several activities of a different nature.

Case studies have confirmed that investments are already circumventing existing coastal protection recommendations. Development is taking place in the technical zone (Puck, Jastrzębia Góra, Krynica Morska), protection zone (Świnoujście, Kołobrzeg, Puck, Jastrzębia Góra, Hel, Krynica Morska) and shoreline safety level (Kołobrzeg, Puck, Jastrzębia Góra, Krynica Morska, Hel).

The authors propose introducing a definition of the boundary of safe development into Polish law and designate zones of limited investment in the coastal zone, which could be applied primarily in local planning, and also be reflected in national and regional planning documents.

Taking into account the factors listed in Table 1 and expert opinion, safe investment limits have been proposed for coastal sections with varying conditions (Tab. 2).

Knowledge from the field of spatial management was the basis for determining the proposed boundaries of safe development. Administrative decisions on the development of the area should be based on the results of systematic monitoring of the state of the shore and hydrological conditions. Investors should be obliged to carry out specialised geological and hydrological surveys in coastal areas, which will allow accurate

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Table 2. Parameters for safe development zones depending on the type of coastline

Coastal type	Example	Characteristics	Recommended zone width	Justification / source
Active Cliff	Jastrzębia Góra	Intense erosion, landslides, unstable geology	2x cliff height + safety margin (1x cliff height) = 3x cliff height	Expert opinion (A. Cieślak)
Inactive Cliff (Dead Cliff)	Puck Cliffs	Low erosion dynamics, stable landforms	Along technical zone; local widening in hazard-prone zones	Low erosion rate (0.08–0.11 m/year)
Abrasive Dune Coast	Kołobrzeg	Erosion, storm vulnerability, urbanised	Minimum 40 m from shoreline (adapted to local conditions)	Stable western side/ urbanised eastern side (authors' recomendation)
Accumulative Dune Coast	Świnoujście	Naturally recovering, some erosion due to human activity	Along technical zone; widened near erosion hotspots	Coastal accretion
Dune-Barrier (Spit) Coast	Hel Peninsula	Accumulative, but sensitive to tourism and construction	Most of the area within the restricted investment zone	affected by harbour-induced erosion
Neutral Dune Coast	Krynica Morska	Low dynamics, natural vegetation buffers	20 m from shoreline (seaside); lagoon side includes flood-prone areas	based on the local coastal profile

Source: own elaboration.

delimitation of the boundary of safe investment to specific plots.

The authors propose introducing a definition of safe development limits into Polish law and designating restricted investment zones in coastal areas. Furthermore, the law should allocate the costs of coastal protection according to the source of the problem, thereby protecting the public sector from covering losses caused by private investments. This method can be applied using any spatial analysis method, but due to the recently introduced procedures for creating, agreeing and consulting planning documents, it is recommended to use software operating in a GIS environment.

Regardless of the proposed new tool to supplement the planning system in coastal areas, existing regulations should be clarified. Maritime authorities responsible for managing maritime areas in Poland should be given greater powers to control and approve investments in the protection zone. Furthermore, given the sensitivity of this area and the simultaneous high investment pressure, municipal authorities should make efforts to ensure that permits for further investments in the coastal strip are issued on the basis of the LSDP, which takes into account the broader context, rather than on the basis of the DBC administrative procedure.

It is also necessary to further strengthen integrated coastal zone management – dialogue between public and private actors for sustainable coastal development, taking into account multiple objectives such as tourism development, nature conservation and the development of new energy sources. Adequate protection and development of the coastal zone at the planning and implementation stages requires cooperation at international, national, regional and local levels. Key planning documents, such as national development strategies, Natura 2000 conservation plans, regional spatial plans, maritime spatial plans and newly emerging municipal master plans, should not only be consistent with each other in this respect, but also take into account climate change projections.

Education should support the proposed organisational, legal and methodological changes. It is extremely important to raise awareness among residents, investors and tourists about the risks associated with coastal activities, both for coastal stability and for the activities themselves. Despite the concentration of coastal communities around tourism, education can shape critical attitudes and thus contribute to reducing investment pressure on sensitive areas.

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Note: The article is based on a master's thesis (2020). The study has been expanded and key conditions have been updated.

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