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Analysis of the causes and consequences of the major concern on biodiversity change in the Curonian Lagoon and Baltic Sea Lithuanian coast

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Abstract

This study employs a bow-tie risk analysis framework to examine four critical biodiversity loss processes in Lithuanian coastal waters: blue mussel decline, commercial fishery stock reduction, dune habitat loss, and eutrophication. The framework identifies human activities, resulting pressures, preventive controls, mitigation measures, and consequences across ecological, economic, and social dimensions. The analysis reveals distinct temporal patterns of risk occurrence. The invasive round goby caused rapid blue mussel eradication, with ineffective monitoring and preventive controls leading to habitat degradation and ecosystem service losses. Commercial fishery stocks, particularly cod and pikeperch, have experienced long-term decline due to overfishing combined with climate change impacts, resulting in economic losses and trophic cascade effects. Coastal dune habitats require continuous management to maintain their UNESCO cultural landscape status, with climate change and tourism presenting significant pressures. Finally, eutrophication remains a persistent challenge, with Lithuania still needing substantial nutrient reduction to meet Baltic Sea Action Plan targets. Climate change further complicates management efforts across all four areas. The study highlights the effectiveness of the bow-tie approach in integrating diverse stakeholder perspectives and identifying critical control points for biodiversity conservation and ecosystem management in coastal environments.

Keywords: mussel decline, commercial fishery stock reduction, dune habitat loss, and eutrophication

Introduction

Lithuanian coast is part of the coastal system of the SE Baltic Sea dominated by an open exposed sandy coast with some insertions of hard stony bottoms as a relic of glacier moraine formations since 12-15 thousand years ago and Curonian Spit — sand-dune spit, separating Curonian Lagoon from the Baltic Sea coast. The Curonian Lagoon is the largest lagoon in Europe with a total area of 1,584 km^2. It is non-tidal estuary, predominately a freshwater water body, dominated by the Nemunas River discharge, average annual amount is 22–24 km^3 (Umgiesser et al., 2016). It is a transboundary waterbody divided between Russian Federation (majority 1171 km^2) in the southern part and Lithuania (413 km^2) in the northern part. Here it is connected to the Baltic Sea via the Klaipeda Strait which also serves as a Lithuanian sea gate to the port (Fig. 1).

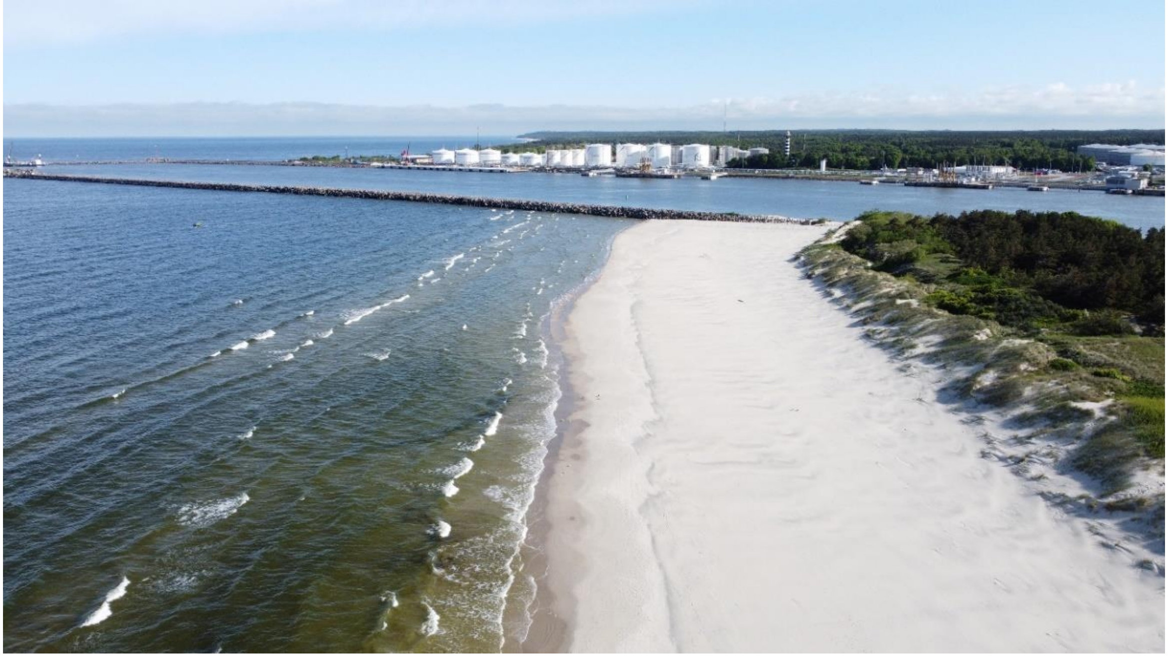

Fig. 1. Curonian Lagoon outlet to the Baltic Sea, serving as Klaipėda port sea gate. Photo by Edvinas Tiškus.

There is a long-term history of management actions aiming to protect the coastal environment of the Curonian Lagoon and Lithuanian Baltic Sea coast, starting with dune planting and fishery regulations, since the 19th century. The Curonian Spit sand dunes are protected by national and international low. It is designated as UNESCO World Heritage Site. Eight types of terrestrial natural habitats of European Community importance have been identified in the Curonian Spit. Directly related to marine environment is the foredune — formed by both human activity and aeolian processes — to protect the land from wind and wave erosion, both of which are intensifying due to climate change, and increased high sea level duration (Wolski & Wiśniewski, 2021). The foredune is also a habitat for many specialist species, adapted to live in an open sand and tolerating salt spray, such as *Salsola kali* L., *Glaux maritima* L., *Eryngium maritimum* L., some endemic species for the SE Baltic Sea — *Linaria loeselii* Schweigg., *Tragopogon heterospermus* Schweigg. Most populations of these plants show decreasing trends and therefore have national protection status (Avizienė et al., 2008, Rašomavičius, (ed.). 2021). Conservation efforts to protect habitats of Embryonic shifting dunes 2110 and Shifting dunes with *Ammophila arenaria* (white dunes) 2120 are Europe wide (e.g. Angelini et al., 2024).

The entire Lithuanian territorial sea and exclusive economic zone belongs to the smallest sea areas in Europe, therefore different sectors (shipping, military guard, fisheries, wind farms and associated infrastructure, damping sites, sand extraction for beach nourishment) is increasingly competing for the limited sea space, especially because most of the coastline has environmental protection status. In terms of biodiversity the Baltic Sea coastal waters hold NATURA 2000 protected habitat type reefs (1170) that are of Baltic-wide importance and are in many cases hot spots for the biodiversity (HELCOM, 2013, 2024). A key species, the blue mussel (*Mytilus edulis trossulus* L.), not only hosts associated macrobenthic fauna (Šiaulys & Bučas, 2015), but also serves as a preferred foraging ground for wintering sea ducks — Long-tailed duck (*Clangula hyemalis* L.) and Steller's eider (*Polysticta stelleri* Pallas), the latter of which has been rarely seen in Lithuanian waters since 2010 (Dagys, 2021). A deteriorating effect of the invasive round goby (*Neogobius melanostomus* Pallas) on blue mussel and related consequences will be presented here in more detail.

The whole Lithuanian part of the Curonian Lagoon has been designated as NATURA 2000 area, both habitat and bird directives protected territories. In terms of biodiversity the area specifically holds the NATURA 2000 habitats (Habitat types 1130 Estuaries and 1150 Lagoons), vulnerable charophyte beds, unionid habitats, areas important for spawning and migration of protected fish species such as *Alosa falax*, *Salmo salar*, *Coregonus lavaretus, Pelecus cultratus, Aspius aspius* as well as valuable commercial and recreational fishery stocks of bream, pikeperch, perch, vimba, smelt. The River Nemunas Delta is a vital component of this ecosystem. Besides its role as a migration route and spawning area for many fish, it is also a designated Ramsar wetland, hosting a stopover for migrating birds of international importance and serving as a nesting area for the globally vulnerable species Aquatic Warbler (*Acrocephalus paludicola* Vieillot) and Great Snipe (*Gallinago media* Latham). Eutrophication and loss of fishery stocks are main risks linked to the Curonian Lagoon ecosystem (Sinkevičienė et al., 2017, Andrašūnas et al., 2022).

The overall significant advancement in standardization of assessment of protected habitats and vulnerable species warning criteria and thresholds has been developed via the implementation of EC directives (EU birds and habitats directives, WFD, MSFD, MSP, Common Fisheries Policy) and international efforts coordinated by HELCOM, European Environment Agency, ICES, UNESCO and others. Two ministries are mostly involved in the decision-making process relevant to the environmental management of the coastal area. The Ministry of Environment and its agencies is the main player in protecting and managing biodiversity and environment, whereas a Ministry of Agriculture plays a key role in eutrophication management through the different incentives in the agricultural policy, also being responsible of commercial fish stock management. However, rapidly changing environment, climate, socio-economic trends bring a new challenge and creates unique local management context. The bow-tie analyses could help to analyse and communicate risks and visualise the cause-effect relationship of biodiversity loss issues, potentially helping in setting priorities for the environmental challenges, addressing multiple biodiversity loss processes.

Methodology

In our study, four central events referring to significant changes in ecological state and biodiversity are considered in the bow-tie risk analyses framework: 1) loss/reduction in blue mussel abundance; 2) reduction of commercial fishery stock (cod, pikeperch); 3) loss/reduction of habitats (dunes); 4) eutrophication of the lagoon and coastal waters. On the left-hand side, the bow-tie analyses list ACTIVITIES affecting the marine environment and anthropogenic PRESSURES through which human activities affect the marine ecosystems as well as preventive CONTROLS, aiming to reduce pressures. While on the right-hand side of the bow-tie scheme the analyses presents the MITIGATION measures (indicated as CONTROLS), and the CONSEQUENCES of ecological and biodiversity status change. To operationalise the tool across European seas, the standardised vocabulary and classification of each element is applied following the Elliot et al., manuscript in preparation. Letters and numbers in the text and Figure 2 are decoded as following: Ctrl1.3 Activities regulation (spatial, temporal and/or intensity); Ctrl2.2 Technology improvements or adoption of alternative practices towards reduction/mitigation of the impact; Ctrl2.2.1 Building with nature-based solutions; Ctrl2.2.2 Organic farming; Ctrl2.2.3 Sustainable meat production; Ctrl2.2.4 Arable land for crops; Ctrl2.2.5 Crop rotation; Ctrl2.2.6 Regionalised agriculture; Ctrl2.2.8 Controlled drainage; Ctrl2.2.9 Erosion control on fields; Ctrl2.2.10 Environmentally friendly energy generation; Ctrl2.2.11 Technical improvements of waste water treatment plants related to aspects other than nutrients; Ctrl2.2.12 Riparian zones; Ctrl2.2.13 Flood defence - hard engineering methods; Ctrl2.2.14 Coastal erosion defence (sand dunes, wetlands); Ctrl3.1 Monitoring (of the environment, activities, impacts on the ecosystem and/or society); Ctrl3.2 Developing/using better assessment methodology / indicators to provide more robust management measures; Ctrl4.1 EU/international legislation (enforcement, new adoption); Ctrl4.2 National/local legislation (enforcement, new adoption); Ctrl4.3.6 Developing/implementing high-level/broad-scale strategies/plans; Ctrl5.1 Funding/incentives/investments; Ctrl6.2 Foster societal participation in management (e.g. stakeholder engagement, citizen participation in monitoring) Ctrl6.3 Changing societal perception of values.

Results of bow-tie analysis

The primary topics related to biodiversity loss in Lithuanian coastal waters have been identified through consultations with key stakeholders, including the Ministry of Environment, managers of protected areas, municipal representatives, fisheries associations, researchers, and subject-matter experts and NGOs). All four central events in our bow-tie analysis (Fig. 2) exhibit different temporal patterns of risk occurrence. Eutrophication status changes in the Curonian Lagoon and entire Baltic Sea, as well as reduction of fishery stocks show a long-term trend observed since the mid — 20th century, largely influenced by human activity, such as nutrient runoff and overfishing. The loss or reduction of the foredune ridge during a storm event could be analysed either as a single event causing considerable damage to a protected habitat or as analyses of a continuous habitat loss/recovery process over time. Finally, the rapid expansion of the invasive round goby has led to near-complete eradication of blue mussel in coastal reefs within just a few years. This event serves as an example of rapid unmanaged loss of substantial portion of the mussel bed, with the unpredictable recovery rate. We will present the analysis using bow-tie framework in more detail below.

Loss/reduction in blue mussel abundance. Input or spread of non-indigenous species (P1.1) is the main pressure causing loss of blue mussel population depicted on the left-hand side of the bow-tie diagram (Fig. 2.). The round goby was first recorded in the Gulf of Gdańsk in 1990 and has since spread throughout the entire coastal area of the Baltic Sea either naturally or via ship ballast water (Kotta et al., 2016). The control mechanism of a ballast water regulation i.e. Ballast Water Management Convention (Ctrl. 4.1) was adopted later in 2004, however the associated actions could not prevent the further spread of this species. During its expansion phase in 2011-2012 round goby caused near complete eradication of blue mussel in Lithuanian coastal waters at < 20 m depth (Skabeikis et al., 2019). After blue mussel biomass decline, the round goby population has stabilised, however it is high enough to prevent recruitment of new mussel generations and recovery of the epibenthic community. The reef scientific monitoring (Ctrl3.1) helped to detect and document the event, however the frequency was too low to observe the first notable change and produce a warning signal. However, these activities were not part of the state-sponsored monitoring programme, but rather the initiative of individual scientists. The regular reef monitoring (Ctrl3.1) as part of NATURA 2000 network management has been established only in 2021 (Šiaulys et al., 2023), whereas criteria for good conservation status and conservation objectives were established for reef habitats only in 2025 (Daunys et al, 2025). There were no prior control actions implemented to stop blue mussel decline. Among the direct consequences of the blue mussel loss is the deteriorated quality of wintering bird habitat and reduced numbers of wintering birds, associated with the failure to achieve the MSFD good environmental status goals and considerable challenge to achieve newly established conservation goals associated to the reef habitat loss and MPA management (C1.5.). It is difficult to estimate or document other direct consequences of blue mussel decline. There could be some unknown losses in the provision of fish (C.2.1.1), because of loss of the foraging ground and competitive exclusion due to the territorial behaviour of this invasive species and reduction of refuge availability (flounder, viviparous eelpout). Loss of water filtration function of blue mussel reduced the capacity of nutrient and resuspended sediment removal leading to the decrease of water clarity and light conditions for macroalgae (Šiaulys et al., 2023). It further leads to increased eutrophication of coastal waters and associated economic consequences (C2.1., C2.2.). It also contributes to loss of feeling of sense of place (e.g. no more shells on the beach, sounds of diving ducks), enjoyment of healthy ecosystem and its value, recognized by scientists and environmental managers (C3.3., C3.4). Governmental response to the increase in round goby abundance was motivated mostly by the significant effects on the fisheries sector: decreased value of fish catches, costs related to the transportation and sale of the massive catch of this invasive fish (C2.1., C2.2., C2.3.), deteriorated state of commercial fish populations, competition with native fish species (flounder, viviparous eelpout) for food and habitats (C1.2.1). Increased round goby biomass contributed to the establishment of a new cormorant colony in the Seaside Regional Park MPA, which escalates the conflict between the fisheries and bird conservation priorities (C1.5.). To support round goby fishery, state initiated set of actions, which could be classified as indirect mitigation control measures to reduce the pressure. The mitigation actions included: (i) support for research on food safety, concluding that round goby is safe resource to consume (Ctrl5.1); (ii) support of research of new fishery practices using fishing traps (Ctrl2.2); (iii) investment into fish processing projects (acquisition of necessary equipment and cars for transportation) Ctrl5.1; (iv) local cultural festivities of goby angling (Ctrl6.3); (v) support for research on new cormorant colony effect on round goby which enhances the acceptance of this management type by society (Ctrl6.3). Despite the state incentives aimed to mitigate this invasion, now it is understood that once established it can't be eradicated. There are no direct measures to control the population of this species, except for: (i) unlimited fishery (Ctrl1.3.9), and (ii) allowing of an unregulated cormorant colony to persist in the Seaside Regional Park (Ctrl1.2).

Blue mussels and reefs are vulnerable across the entire Baltic Sea to other major pressures such as pollution, climate change (including microliter), and salinity shifts (P3.1, P3.4, P4.1, P4.2, P4.3), seabed constructions (P2.1) (HELCOM Red List, 2013). Therefore, restoration of degraded habitats (e.g., from bottom excavation) would improve conservation status (Ctrl. 1.2.1 and Ctrl. 1.2.2), while adaptation of the ban on bottom trawling is crucial to protect the habitat (Ctrl1.3.9).

Reduction of commercial fishery stock (cod, pikeperch).

Commercial fisheries (A4.1) have a long tradition and still play a key role in local communities in the coastal areas of the Curonian Lagoon, while recreational angling (A8.2) is of interest for a large population of the entire country, and plays a role in overall tourism potential of the lagoon and especially delta area. Large predatory fish, such as pike-perch (*Sander lucioperca* L.) are the most wanted game for both commercial and recreational fisheries. However, in the period 2000–2020 the quota for pikeperch has never been used up (Andrašūnas et al., 2022), while the anglers complained about decreased catch success (C1.2.1). With the increasingly deteriorating status of fishery stocks in the Curonian Lagoon both interest groups experience economic losses, dissatisfaction, and mutual conflicts (C2.2, C2.3, C2.4, C.3.4). According to most recent modelling study, pikeperch stock was assessed as 'fully overfished' (Andrašūnas et al., 2022). The study advocates for model-based management approaches over tough regulations, which have proven ineffective due to their association with increased illegal fishing activities and the falsification of catch data.

State hesitates to ban commercial fishery in the lagoon, as some species stocks (e.g. bream) are still in relatively good condition, while the resistance of fisherman community remains strong. The most recent amendment of commercial fishery roles (Ctrl. 4.3.1) in the lagoon include: (i) extension of pike-perch fishing ban period from 41 day (April 20-May 31) to three months (March 1-May 31), and increase of the minimum allowed fish size to catch from L-46 cm to L-50 cm. This goes along with full ban on spawning pikeperch bycatch in migrating smelt nets and traps as before (Ministry of Environment, 2024). The angling ban period is the same as for commercial fishermen, however, according to the new angling rules, pike-perch smaller than 50 cm and larger than 65 cm must be released. In addition, 12 fishing companies and individuals who fished in the Curonian Lagoon and some lakes have submitted requests to the Fisheries Service to revoke their fishing quotas and deregister all their fishing vessels from the Inland Waters Fishing Vessel Register (Ctrl5.1). They will receive nearly 3 million euros in compensation for exiting the fishing business in the year 2025-2026 (as reported by Fisheries Service under the Ministry of Agriculture of the Republic of Lithuania).

Cod decline in 1988-1993 followed by numerous unsuccessful attempts in fisheries regulation, finally ended up in targeted fishery ban by European Commission in 2019, which now is in force. It is acknowledged, though, that overfishing (P1.6) was not the single factor threatening Baltic cod, but also climate change (CC) and eutrophication related factors: lower salinity, high water temperatures (P4.1), low oxygen, as well as parasite infestation (P1.2) have all contributed to the lack of population recovery. The cod ban resulted already in immediate closing of few recreational fishery businesses in Lithuania (C2.2.). While it is a challenge to sustain a viable small commercial fishing boat sector, already reduced to 6 companies in Lithuania, relying on herring and sprat quotas. State-funded compensation is provided to mitigate the economic impact of lost fishing quotas (C2.1) and the cod bycatch is still permitted (Ctrl. 4.3.1.).

Loss of large fish has important consequences for the functioning of the food webs, as large predators keep low abundance of lower trophic level fish, and intermediate predators, reducing their density dependent competition, as well as pressure on juvenile fish and zooplankton, in turn supporting zooplankton capacity to regulate phytoplankton growth (Estes et al., 2011). This trophic cascade is well studied in the Baltic Sea: after collapse of cod, the previously suppressed sprat population peaked, and zooplankton abundance declined (Bossier et al., 2020 and references therein). The abundance of large fish is selected as an indicator of Good Environmental Status (GES) under MSFD Descriptor 4: Food Webs (Ctrl1.1), yet in all assessed areas—both the Curonian Lagoon and coastal waters—the large fish index remains below the GES threshold (C1.5).

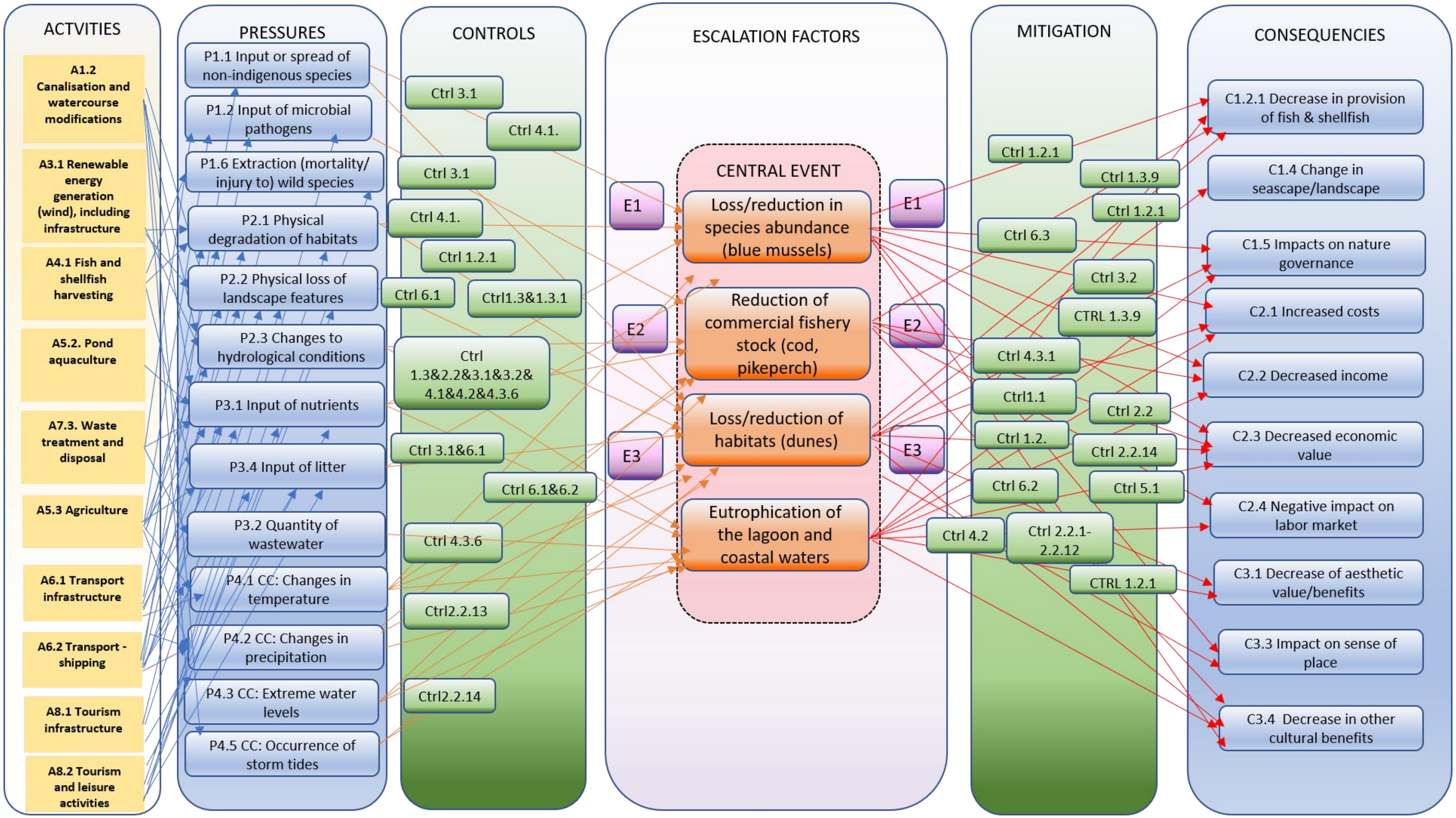

Fig. 2. Bow-tie diagram of four largest biodiversity loss processes. Ctrl referes to preventive or mitigation control measures (see text in Methodology for coding). Escalation factors: E1. Finance available to enhance control measures, E2 Shifts in public perception, E3 legislation by member states.

Loss reduction of dune habitats. Coastal foredune ridge, as semi-artificial habitat, results from both constant human management and natural processes for hundreds of years. David Gottlieb Kuwert (1748–1827) was initiator of dune planting in the Nida area of the Curonian Spit at the beginning of the 19th century. His success encouraged the then Prussian authorities to organize afforestation works on the Curonian Spit (Universal Lithuanian Encyclopaedia, 2001). At the same time, it was understood that constant source of sand is the sea, and it must be prevented from further drifting into the territory by building a foredune ridge. It took one hundred years from the initial professional recommendations provided by dune expert Søren Bjørn (1744–1819) in 1803 until the 98 km long foredune ridge over the entire length of the Curonian Spit coast was completed in 1904 (Curonian Spit National Park Directorate, 2023). Nowadays foredune ridge is managed keeping the traditions, using natural materials, and working with natural process of sand accumulation. It is one of the most essential elements of the UNESCO cultural landscape. Any physical disturbance (P2.1.), physical loss (P2.2) due to constructions, especially those resulting from housing, tourism infrastructure (A8.1) and transport (e.g. road building) infrastructure (A6.2) are prohibited. Every year, after severe storms, damaged areas of the ridge are covered with pine branches (habitat restoration Ctrl.1.2.1). Tourism and leisure activities (A.8.2) cause severe physical disturbance (P2.1) and increase risk of foredune ridge break, dune plant trampling, therefore the main preventive action is regulation of numbers of visitors via the car ticked entrance to the municipality territory (Ctrl. 1.3.1.), fostering awareness of nature and impacts via constant advertisement of world heritage value of the landscape, establishment of visitor's centre and nature school (Ctrl. 6.1). To protect the dunes from trampling by tourists and vacationers, stairs (over 70 units per 50km coastline), footpaths, and sand fences are installed (Curonian Spit NP Directorate, 2023).

Climate change caused pressures: extreme winds and elevated sea water levels (P4.3., P4.5) increase the risk of dune damage. This risk is further exacerbated by rising temperatures (P4.1), especially during the winter period, when the permafrost that firmly binds the sand disappears. Milder winters and prolongated vegetation season stimulate the dune overgrowth (Taminskas et al., 2020, Šimanauskienė et al., 2022). The spread and overgrowth by invasive plant species (P1.1.) is recognised and management actions are implemented. The participation of local residents and volunteers in eradicating unwanted dune plants and restoring habitats (Ctrl.1.2.1) is particularly important. For a stakeholder education and engagement (Ctrl 6.1. & 6.2.) the publication was issued explaining invasive plant vectors, presenting species, and eradication measures (Curonian Spit NP Directorate, 2023).

NATURA 2000 Priority Action Framework (PAF) is a standard requirement across EU country to implement EU Birds and Habitat directive, developed by each country in 7 years periodicity (Ctrl4.1). According to PAF for the current period 2021–2027 the funding was allocated to the following measures aiming to protect and restore habitats types — embryonic shifting dunes 2110 and white dunes 2120: (i) eradication of alien invasive species; (ii) measures for capturing sand deposited by the sea, setting up and restoration of branch frameworks and sand fences (Ctrl2.2.14); (iii) preparation and implementation of habitat restoration plan for sand dune plants (*Dianthus arenarius subsp. arenarius* L., *Botrychium simplex* E. Hitchc., *Linaria loeselii* Schweigg.). The estimated management costs equal ~3.6 million EUR over 7 years. If constant management efforts were interrupted or reduced due to a lack of funding, irresponsible management or any other forces (incl. transboundary misconduct from the Russian side) it would lead to rapid degradation of foredune ridge with multiple consequences for nature (C1.4 & C1.5), economy (C2.1, C2.2, C2.3 & C2.4), and society (C3.1, C3.3, C3.4), as listed on the right-hand side of the bow-tie diagram (Fig. 2). The most severe consequences would be large costs for reconstruction, deteriorated condition of NATURA 2000 habitat, ultimately the loss of UNESCO status.

Eutrophication of the lagoon and coastal waters. Eutrophication of the Curonian Lagoon and Lithuanian coastal waters is caused by an excessive nitrogen and phosphorus load (P3.1). The human activities producing nutrient load or deposition include agriculture (A5.3), point source (WWTP) and urban wastewater (P3.2.), wastewater coming from the households not connected to centralized sewage system (A7.3), growing sector of tourism infrastructure and secondary houses in the coastal area producing higher quantity of wastewater (A8.1, A8.2), airborne nitrogen deposition generated by industry, transport and shipping (A6.1. & A6.2), and to lesser extent from pond aquaculture (A5.2.). A disrupted canalized river continuum (A.1.2.) contributes to reduced capacity of nutrient retention in the watershed. Besides the daily nutrient inputs, either direct into the lagoon or coastal waters or via river loads, there is also a significant nutrient pool that has accumulated historically in the Curonian Lagoon sediments, especially in the southern confined area. Therefore, significant phosphorus releases co-occur with algal bloom and the onset of hypoxia and anoxia associated to the breakdown of algal biomass (Bartoli et al., 2018). Increased trophic status leads to habitat degradation and threatens species. E.g. HELCOM red list habitats ‚Baltic photic muddy sediment dominated by *Unionidae*‘ and ‚Baltic photic sand dominated by *Charales*‘ (HELCOM (2013) are vulnerable to eutrophication. Although the growth depth of dominant species *Chara contraria* in the Curonian lagoon has increased to 2m, indicating good ecological status of transitional waters (according to WFD criteria), scientists still are concerned about red listed species *Chara baltica*, *Tolypella nidifica*, *Chara canescens* (Bučas et al., 2016).
Eutrophication process of the lagoon has multiple consequences to nature and society (Fig. 2). Firstly, the loss or reduction of the provision of fish (C1.2.1.) and decrease in the total value of landings, which become dominated by low economic value species like bream and roach (C2.3.). Algal blooms deplete oxygen levels, resulting in fish kills, or reduced growth rates under stress conditions. There is also significant long-term change in fish assemblage and food web structure: decline in average trophic level of the fish community (HELCOM, 2006). However, the major shift has occurred decades ago; the historical catch data show, that the most abundant generations of roach appeared between 1972 and 1978, considered with highest nutrient load to the lagoon (Švagždys, 2010). The fish community is still dominated by cyprinids, which are typical for a eutrophic water body. Although catches of bream and roach account for 60-70% of all commercial catches, they represent only 40% of the total catch value (Lesutiene et al., 2022).
Secondly, eutrophication has economic and cultural consequences for society by reducing the water body's potential for recreation. Low bathing water quality results in decreased economic value of the lagoon and coastal beaches affected by outflow from the lagoon (C2.3.) (Overlingė et al., 2020). Algal blooms negatively affect aesthetic view (C3.1), may limit access to water leisure activities and sports or reduce the enjoyment and duration of these activities (C3.4).
Thirdly, impacts on nature governance (C1.5.) are severe and have international implications, as the Curonian Lagoon is connected to the Baltic Sea where eutrophication is the major challenge. Environmental initiatives and measures aiming to reduce nutrient inputs in Lithuania started only after the restoration of independence in 1990, after many years of Soviet occupation and political neglect of the environmental degradation. Lithuania became a contracting party to the Helsinki Commission in 1992, and multiple measures targeting urban wastewater treatment were implemented, significantly reducing the phosphorus inputs. According to the Baltic Sea Action Plan (Ctrl4.3.6 broad scale strategy), Lithuania has

committed to implement all necessary measures by 2027 to reduce its nitrogen and phosphorus throughputs from the Curonian Lagoon within allowed nutrient input ceilings (NIC) of 25,878 t of TN and 703 t of TP per year by 2030 (HELCOM 2021). Although significant phosphorus reduction is achieved, there is still reduction of 30-50% to be achieved to reach NIC. The situation with nitrogen is much more severe, the trend is increasing and reduction of more than 50% is needed to reach the NIC (HELCOM, 2023). There is a high risk of failing to achieve this strategic goal, as well as the EU WFD goal of attaining good ecological status for all inland water bodies by 2027 (EC, 2025) and Good Environmental Status (GES) of marine waters according to MSFD. Climate change adds challenges to water protection goals, complicating the issue (Plungė et al., 2023, Čerkasova et al., 2024).

The systematic effort to improve the inland water ecological status following EU WFD framework is through the implementation of individual River Basin Management Plans (RBMPs) and Programmes of Measures (PoMs). Current measures for reduction of diffuse agricultural pollution include revision of agricultural practices through the fertilizer application and nutrient monitoring in soil (Ctrl3.1), farmer education and engagement (Ctrl 6.1. & 6.2.), improving fertilization planning methodology by creating a database for fertilizer consumption (Ctrl3.2.). Measures for reduction of point (urban) pollution include reconstruction of WWTPs and development of wastewater infrastructure (Ctrl. 5.1), revision of pollution permits and other national legislation (Ctrl4.2.). Regulated (straightened) river channels in Lithuania account for 82.6% of the total channel length. Measures for improvement of hydrological conditions naturalisation of regulated rivers stretches restoration of wetlands is still in a very early stage (Ctrl2.2.1 nature-based solutions). Ministry of Environment reported, the width of coastal protection (riparian) zones established under the new procedures, effective from 2023, increased by 14,065.7 hectares (Ctrl2.2.12). The largest coastal protection zone is set for the eastern shore of the Curonian Lagoon at 100 m.

Social and economic incentives related to agriculture, as well as the acceptance of control measures should be improved. Majority of farmers still remain sceptical about overall economic viability of organic farming practices (Ctrl2.2.2 & C2.2.3) as there is a lack of significant market incentives for organic products. The area dedicated to organic farming in Lithuania represents about 8% of the total utilized agricultural land is significantly lower than the EU’s 25% target for 2030 (EC, 2025). While farmers can acknowledge advantages from improved crop rotation, planting cover crops (Ctrl2.2.5) and reduced tillage frequency and depth, they are reluctant to convert arable land to grassland (Ctrl2.2.4 & C.2.2.5). This was one of the reasons for protests in January 2024 in the capital Vilnius – the demonstration which lasted four days, involving farmers driving their tractors to the city streets. Protests significantly contributed to rising awareness of environmental problems and management conflicts.

Climate change related pressures (P4.1, P4.2., P4.3) i.e. increasing temperature, precipitation and Nemunas River discharge will significantly contribute to increasing nutrient loads from the watershed (Čerkasova et al., 2024). The recent modelling study, integrating climate change scenarios showed, that intensified global warming requires more agricultural land conversion to grasslands, or use of winter crops as second more cost-efficient measure, whereas other measures are insufficient to reach NIC (Plungė et al., 2023). In addition, the coastal municipalities are facing increasing frequencies of flood events due to rainfall and high-water levels in the lower reaches of the rivers (P4.3). It highly impact wastewater treatment of WWTP and domestic septic systems in the flooded areas, which requires investments (Ctrl5.1) to adapt these systems. In November 2023, the municipal water company serving Klaipėda, secured a €25 million loan from the European Investment Bank to support its 2023-2026 investment program. Technological upgrades should help to adapt to climate change challenges related to rainfall and flooding events (smartwatermagazine.com).

Conclusions

We believe that management of biodiversity loss issues requires that multiple state authorities and stakeholder groups share information and responsibility for the environmental protection and preservation of the livelihood.

Escalation factors which were not discussed throughout the description could be critical as related to the global geopolitical realities and may have deteriorating effect on mitigation measures. That is primarily related to the change of political priorities towards energetics, international trade and defence and security issues. As many of the control measures are related to the implementation of the Green Deal policy targets, the risk of weakening of the EU and member states commitments to these targets could turn the escalation factors (E1. Finance available to enhance control measures, E2 Shifts in public perception, E3 legislation by member states) the negative way.

References

1. *Andrašūnas, V., Ivanauskas, E., Švagždys, A. & Razinkovas-Baziukas, A. 2022. Assessment of Four Major Fish Species Stocks in the Lithuanian and Russian Parts of Curonian Lagoon (SE Baltic Sea) Using CMSY Method. Fishes, 7, 9. doi.org/10.3390/fishes7010009.*
2. *Angelini, F., Pollayil, M.J., Rivieccio, G., Caria, M. C., Bagella S. & Garabini M. (2024) Robotic monitoring of dunes: a dataset from the EU habitats 2110 and 2120 in Sardinia (Italy). Sci Data 11, 238. doi.org/10.1038/s41597-024-03063-z*
3. *Bartoli, M., Žilius, M., Bresciani, M., Vaičiūtė, D., Vybernaite-Lubiene, I., Petkuviene, J., Giordani, G., Daunys, D., Ruginis, T., Benelli, S., Giardino, C., Bukaveckas, P. A., Zemlys, P., Griniene, E., Gasiunaite, Z. R., Lesutiene, J., Pilkaitytė, R., & Baziukas-Razinkovas, A. (2018). Drivers of cyanobacterial blooms in a hypertrophic lagoon. Frontiers in Marine Science, 5, 434. doi.org/10.3389/fmars.2018.00434*
4. *Bossier S., Nielsen J. R. & Neuenfeldt S. (2020). Exploring trophic interactions and cascades in the Baltic Sea using a complex end-to-end ecosystem model with extensive food web integration Ecological Modelling 436. doi.org/10.1016/j.ecolmodel.2020.109281.*
5. *Bučas M. et al., 2016. Monitoring of macrophytobenthos in the Curonian Lagoon and the Baltic Sea and assessment of ecological status based on macrophytes. Report Retrieved from [Makrofitu_tyrimu_ataskaita_20161493844564223.pdf]*
6. *Curonian Spit National Park Directorate, 2023. Protective fordune ridge. https://nerija.lrv.lt/lt/apie-nacionalini-parka/krastovaizdis/apsauginis-pajurio-kopagubris/. Accessed 19 Mar. 2025*
7. *Curonian Spit National Park Directorate, 2023 Retrieved from [https://nerija.lrv.lt/media/viesa/saugykla/2024/3/142aWi9RoRo.pdf]*
8. *Čerkasova, N. Mėžinė, J. Idzelytė, R. Lesutienė, J. Ertürk, A. Umgiesser, G. (2024) Exploring variability in climate change projections on the Nemunas River and Curonian Lagoon: Coupled SWAT and SHYFEM modeling approach. Ocean Sci. 2024, 20, 1123–1147. doi.org/10.5194/os-20-1123-2024.*
9. *Dagys, M. (2021) Sibirinė gaga. Polysticta stelleri (Palas, 1769) – In: Rašomavičius, V., (ed.). Red Data Book of Lithuania. Animals, plants, fungi. – Vilnius, p. 233.*
10. *Daunys D., Šiaulys A., Bučas M., Staponkus R. (2025). Criteria for Good Conservation Status and Conservation Objectives for the Values of Lithuania's Baltic Sea Natura 2000 Sites (Reefs, River Lamprey). Report in Lithuanian.*
11. *EC, 2025. Country-specific staff working documents on the implementation of the third River Basin Management Plans, second Flood Hazard and Risk Maps and second Flood Risk Management Plans. Retrieved from [https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=SWD%3A2025%3A28%3AFIN&qid=1738746144581]. Brussels.*
12. *Estes, J.A., Terborgh, J., Brashares, J.S., Power, M.E., Berger, J., Bond, W.J. Carpenter, S.R., Essington, T.E., Holt, R.D., Jackson, J.B.C., Marquis, R.J. & Oksanen, L. (2011). Trophic downgrading of planet earth. Science, 333 (6040), 301 – 306.*
13. *HELCOM (2006). Changing Communities of Baltic Coastal Fish Executive summary: Assessment of coastal fish in the Baltic Sea Balt. Sea Environ. Proc. No. 103 B. Retrieved from [https://helcom.fi/wp-content/uploads/2019/08/BSEP103b.pdf*

14. *HELCOM (2013). HELCOM Red List Biotope Information Sheets (BIS)*
15. *HELCOM (2013). HELCOM Red List: 1170 Reefs. Retrieved from [https://helcom.fi/wp-content/uploads/2019/08/HELCOM-Red-List-1170-Reefs.pdf].*
16. *HELCOM (2021). Baltic Sea Action Plan 2021 Update. Available online: https://helcom.fi/wp-content/uploads/2021/10/Baltic-Sea-Action-Plan-2021-update.pdf (accessed on 20 March 2025)*
17. *HELCOM (2023). Nutrient Input Ceiling (NIC) assessment 1995-2020 - Technical report Retrieved from [https://helcom.fi/wp-content/uploads/2023/12/Nutrient-Input-Ceilings-assessment-1995-2020-technical-report.pdf]*
18. *HELCOM (2024). HELCOM Metadata Catalogue. Retrieved March 13, 2025, from https://metadata.helcom.fi*
19. *Kotta J., Nurkse K., Puntila R., Ojaveer H. (2016) Shipping and natural environmental conditions determine the distribution of the invasive non-indigenous round goby Neogobius melanostomus in a regional sea. Estuarine Coastal and Shelf Science, 169, 15–24.*
20. *Lesutienė J., Andrašūnas V., Čerkasova N., Gasiūnaitė Z.R., Idzelytė R., Ivanauskas E., Kaziukonytė K., Mėžinė J., Vilkevičiūtė J., 2022. Gairės Pamario seniūnijų ekosisteminių paslaugų valdymui klimato ir globalios kaitos kon-tekste. Klaipėdos universitetas. Klaipėda. doi.org/10.5281/zenodo.6546247.*
21. *Ministry of Environment, 2024. Retrieved from [https://am.lrv.lt/lt/naujienos/verslines-zvejybos-vidaus-vandenyse-tvarkos-aprase-daug-naujoviu/]*
22. *Overlingė D., Kataržytė M., Vaičiūtė D., Gyraitė G., Gečaitė I., Jonikaitė E., & Mazur-Marzec H. (2020). Are there concerns regarding cHAB in coastal bathing waters affected by freshwater-brackish continuum? Marine Pollution Bulletin, 159, doi.org/10.1016/j.marpolbul.2020.111500*
23. *Plungė, S., Gudas, M., Povilaitis, A., & Piniewski, M. (2023). Evaluation of the costs of agricultural diffuse water pollution abatement in the context of Lithuania's water protection goals and climate change. Environmental Management, 71, 755–772. doi.org/10.1007/s00267-022-01745-1*
24. *Rašomavičius, V., (ed.). 2021: Red Data Book of Lithuania. Animals, plants, fungi. – Vilnius.*
25. *Samrtwatermagazine.com (2023). EIB provides €25M loan to Lithuanian Municipal Water Company for infrastructure investmenthttps. Retrieved from [smartwatermagazine.com/news/european-investment-bank/eib-provides-eu25m-loan-lithuanian-municipal-water-company?utm_source=chatgpt.com]*
26. *Skabeikis, A., Morkūne, R., Bacevičius, E., Lesutiene, J., Morkūnas, J., Poškiene, A., Šiaulys, A. (2019). Effect of round goby (Neogobius melanostomus) invasion on blue mussel (Mytilus edulis trossulus) population and winter diet of the long-tailed duck (Clangula hyemalis), Biological Invasions, 21, 911–923. doi.org/10.1007/s10530-018-1869-y.*
27. *Sinkevičienė Z., Bučas M., Ilginė R., Vaičiūtė D., Kataržytė M., Petkuvienė J. (2017). Charophytes in the estuarine Curonian Lagoon: Have the changes in diversity, abundance and distribution occurred since the late 1940s? Oceanological and Hydrobiological Studies, 46(2), eISSN 1897-3191.*
28. *Šiaulys, A., M. Bučas (2015). Biological valorisation of benthic habitats in the SE Baltic Sea. Ecological Informatics 30 (2015): 300-304.*
29. *Šiaulys A., Bučas M., Šaškov A., Daunys D. & Medelytė S. (2023). NATURA 2000 TINKLUI PRIKLAUSANČIŲ JŪROS RIFŲ (1170) BUVEINIŲ BALTIJOS JŪROJE IR MAKROFITŲ BALTIJOS JŪROJE BEI KURŠIŲ MARIOSE TYRIMAI 2021 METAIS, report.*
30. *Šimanauskienė, R., Linkevičienė, R., Povilanskas, R., Satkūnas, J., Veteikis, D., Baubinienė, A., & Taminskas, J. (2022). Curonian Spit Coastal Dunes Landscape: Climate Driven Change Calls for the Management Optimization. Land, 11(6), 877. doi.org/10.3390/land11060877*
31. *Švagždys A. (2010). Impact of Environmental and Anthropogenical Factors on Fish Catch Variation in the Curonian Lagoon Phd thesis. Retrieved from [https://apc.ku.lt/en/wp-content/uploads/2018/05/ASvagzdys2005-2010.pdf]*
32. *Taminskas, J., Šimanauskienė, R., Linkevičienė, R., Volungevičius, J., Slavinskienė, G., Povilanskas, R., & Satkūnas, J. (2020). Impact of Hydro-Climatic Changes on Coastal Dunes Landscape According to Normalized Difference Vegetation Index (The Case Study of Curonian Spit). Water, 12(11), 3234. doi.org/10.3390/w12113234.*
33. *Umgiesser, G., Zemlys, P., Erturk, A., Razinkova-Baziukas, A., Mėžinė, J., & Ferrarin, C. (2016) Seasonal renewal time variability in the Curonian Lagoon caused by atmospheric and hydrographical forcing, Ocean Science, 12, 391–402, doi.org/10.5194/os-12-391-2016.*
34. *Universal Lithuanian Encyclopedia (2001). Dovidas Gotlybas Kùvertas. In Universal Lithuanian Encyclopedia. Center for Science and Encyclopedic Publishing. Accessed 19 Mar. 2025.*
35. *Wolski, T. & Wiśniewski, B. (2021) Characteristics and Long-Term Variability of Occurrences of Storm Surges in the Baltic Sea. Atmosphere, 12, 1679. doi.org/10.3390/atmos12121679.*