Towards effective conservation and governance of Pontocaspian biodiversity in the Black Sea region

Gogaladze, A.

Towards effective conservation and governance of Pontocaspian biodiversity in the Black Sea region

Aleksandre Gogaladze

Towards effective conservation and governance of Pontocaspian biodiversity in the Black Sea region

Aleksandre Gogaladze

Naturalis Biodiversity Center
Leiden University
2021

This research was sponsored by the PRIDE (Pontocaspian RIse and DEmise) project, which received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No. 642973.

ISBN/EAN: 978-90-5191-197-8

Author contact: aaleksandre.g@gmail.com

Editorial formatting by S. van de Velde.

Printed in the Netherlands by ProefschriftMaken.

Front cover: Danube Delta. Credits: CalinStan. Stockillustraties ID: 817544008. Datum van uploaden: 17 juli 2017. Categorieën: Stockillustraties | Donau.
Back cover: Sociogram. Image credits: gaisonok. Stockillustraties ID: 874626310. Datum van uploaden: 16 november 2017. Categorieën: Stockillustraties | Abstract.

Towards effective conservation and governance of Pontocaspian biodiversity in the Black Sea region

Proefschrift

ter verkrijging van
de graad van doctor aan de Universiteit Leiden, op gezag van rector magnificus prof.dr.ir. H. Bijl, volgens besluit van het college voor promoties te verdedigen op dinsdag 30 november 2021
klokke 10:00 uur

door

Aleksandre Gogaladze
geboren te Tbilisi, Georgië
in 1990

Promotor
Prof. Dr. J.C. Biesmeijer (Naturalis Biodiversity Center & Universiteit Leiden)

Copromotor
Dr. N. Raes (Naturalis Biodiversity Center & Universiteit Leiden)
Dr. F.P. Wesselingh (Naturalis Biodiversity Center & Universiteit Utrecht)

Promotiecommissie
Prof. Dr. G.R. de Snoo (Universiteit Leiden) - Voorzitter
Prof. Dr. P.M. van Bodegom (Universiteit Leiden) - Secretaris

Overige commissieleden
Prof. Dr. T. Wilke (Justus-Liebig-Universität Gießen)
Dr. M. Seddon (IUCN SSC Mollusc Specialist Group)
Prof. Dr. E. Turnhout (Wageningen University & Research)
Prof. Dr. D. Tarkhnishvili (Ilia State University)

Contents

List of Abbreviations

BD	Birds Directive
BSB	Black Sea Basin
BSEC	Black Sea Economic Cooperation
BSIMAP	Black Sea Integrated monitoring and Assessment Programme
BSRDB	Black Sea Red Data Book
BU	Bulgaria
CBD	Convention on Biological Diversity
CEP	Caspian Environment Program
CF	Conceptual Framework
CITES	Convention on the International Trade in Endangered Species of Wild Fauna and
CMS	Convention on the Conservation of Migratory Species of Wild Animals
COP	Conference of the Parties
DD	Danube Delta
DRPC	Danube River Protection Convention
EEA	European Environment Agency
EN	Emerald Network
ENP	European Neighbourhood Policy
EU	European Union
EUNIS	European Nature Information System
HD	Habitats Directive
IBA	Important Bird Area
ICPDR	International Commission for the Protection of the Danube River
IER	International Environmental Regime
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IUCN	International Union for Conservation of Nature
NBSAP	National Biodiversity Strategy and Action Plan
NGO	Nongovernmental Organization
MD	Moldova
MDG	Millennium Development Goals
MSFD	Marine Strategy Framework Directive
OECD	Organisation for Economic Co-operation and Development
PA	Protected Area

PC	Pontocaspian
PRIDE	Pontocaspian Biodiversity Rise and Demise
RDBU	Red Data Book of Ukraine
RO	Romania
RU	Russia
SCI	Site of Community Importance
SDGs	Sustainable Development Goals
SNA	Social Network Analysis
SPA	Special Protection Area
UA	Ukraine
UN	United Nations
UNDP	United Nations Development Programme
UNECE	United Nations Economic Commission for Europe
UNESCO	United Nations Educational, Scientific and Cultural Organization
WDPA	World Database on Protected Areas
WFD	Water Framework Directive
WHC	World Heritage Convention
WOA	World Ocean Assessments
WWF	World Wide Foundation

1

GENERAL INTRODUCTION

Biodiversity decline is one of the greatest challenges that humankind is facing today and broad consensus exists on the urgent need of global, large-scale interventions for nature conservation. The current rate of biodiversity loss is unprecedented in the history of the earth (Barnosky et al. 2011). The global wildlife population has fallen by 68% in the last 40 years as a result of human activities (WWF 2020), and almost 75% of the earth's surface has been altered (Kotiaho and Halme 2018). This already has alarming consequences, threatening our economy and social development (World Economic Forum 2020). The cost of inaction is expected to grow even more in the future (OECD 2019). Despite the recognition of dire effects of biodiversity loss, the conservation efforts and interventions of different governments, institutions and stakeholders are still fragmented and lack the coordination and financial means to address the current biodiversity crisis (Díaz et al. 2019; OECD 2019). Ideally, biodiversity and its values to humankind should be recognized and mainstreamed as part of other challenges such as climate change, food security, and circular economy (CBD 2020; Díaz et al. 2019). A prerequisite for this is a well-coordinated, inclusive and integrated governance system that takes the responsibility, and accepts the costs of an effective nature conservation plan (OECD 2019; Waldron et al. 2013). In addition, the available scientific knowledge should be mobilized and additional knowledge generated to help shape such a strategy and monitor its progress.

A legal base for such a large-scale, effective conservation regime already exists, since the signing of the Convention on Biological Diversity (CBD 1992) in Rio de Janeiro by 150 countries. According to the Fifth Global Biodiversity Outlook, which is a periodic report of the CBD, by 2020 partial progress has been made towards the achievement of some of the Aichi Biodiversity Targets. However, the business-as-usual scenario promises further loss of biodiversity and ecosystem services calling for an urgent need for the transformative changes necessary to attain the 2050 Vision for Biodiversity (CBD 2020). European Union (EU) has already agreed and adopted such a transformative post-2020 global framework at the 15th Conference of the Parties (COP) to the CBD, by setting out an EU Biodiversity Strategy for 2030 (European Commission 2020). This Strategy aims to "ensure that Europe's biodiversity will be on the path to recovery by 2030 for the benefit of people, the planet, the climate and our economy, in line with the 2030 Agenda for Sustainable Development and with the objectives of the Paris Agreement on Climate Change" (European Commission 2020).

Fresh and brackish water ecosystems are particularly vulnerable and may well be the most endangered ecosystems on earth (Dudgeon 2012; Dudgeon et al. 2006; Reid et al. 2019; Sala et al. 2000). This is firstly due to high species richness in freshwater ecosystems (Dudgeon et al. 2006; Lundberg et al. 2000), and secondly, due to the concentrated human developments around fresh and brackish water ecosystems (Dudgeon 2012; National Research Council 2000; Vitousek 1997). Brackish environments are transitional zones between marine and freshwater ecosystems, such as the estuaries, lagoons and coastal ponds, which are characterized by the instability of their chemical and physical properties, most importantly the salinity conditions (Cognetti and Maltagliati 2000). These ecosystems are less species-rich compared to marine and freshwater ecosystems (Barnes 1989), but they are highly productive and important ecosystems in terms of their functions, physical and chemical properties, and the animal and plant life that they support (Matthews 1993).

Pontocaspian (PC) ecosystem is a prominent example of brackish water ecosystems. PC biota comprises endemic aquatic ecological communities and species that are confined to the north-eastern part of the Black Sea Basin (BSB) and the entire Caspian Sea (Krijgsman et al. 2019). This biota includes vertebrates such as the charismatic sturgeon species and the Caspian seal (Pusa capsica) but also lesser-known invertebrate groups, e.g., crustaceans, mollusks and annelid worms, and planktonic groups such as diatoms and dinoflagellates (Grigorovich et al. 2003; Marret et al. 2004; Starobogatov 1970). Scientific knowledge on PC species population trends is limited. However, PC habitats in the Black Sea and Caspian Sea Basins are known to have experienced major modifications by human activities, such as habitat fragmentation, pollution and introduction of invasive alien species. This resulted in strong decline of PC species in various places throughout their native range (Lattuada et al. 2019; Markovsky 1953, 1954a, b, 1955; Popa et al. 2009; Velde et al. 2019). Outside their native range, some of the PC species are amongst the 'worst' invasive species, rapidly spreading throughout European and American inland waters (Ketelaars 2004; Reid and Orlova 2002; Ricciardi and MacIsaac 2000), causing large-scale ecological and high economic impacts (Benson and Boydstun 1995; N'Guyen 2016; Pimentel et al. 2005). This calls for a global need for effective PC biodiversity management within, as well as beyond its native range. This thesis deals with the challenges towards effective conservation of PC species in their native range.

Biodiversity change, either positive or negative, is caused by the direct and/or indirect drivers of change (Díaz et al. 2015). Some direct drivers are of natural origin, e.g., earthquakes and tsunamis, some of the droughts and floods. Others have an anthropogenic origin, for example intensive agriculture, overfishing and introduction of invasive alien species (Díaz et al. 2015). Indirect drivers refer to the ways in which people, organizations and societies interact with each other and with nature (Díaz et al. 2015; Salafsky et al. 2002). Examples of such drivers are environmental laws and policies, conservation awareness, conservation governance systems, as well as institutional alignments. Globally, five major direct drivers of biodiversity decline have been identified, namely (in order of importance) changes in land and sea use, overexploitation, climate change, pollution, and invasive alien species (Díaz et al. 2019).

Direct and indirect drivers of PC biodiversity change in their native range are poorly known due to the taxonomic uncertainties, transient boundaries of PC habitats and lack of knowledge on the status and trends of PC populations (Sands et al. 2020; Wesselingh et al. 2019), coupled with the complex socio-political context within which PC biodiversity conservation is embedded (see below). Thorough, global threat analysis studies, like those conducted for freshwater ecosystems, are lacking for brackish PC habitats and species. Anthropogenic threats driving the global freshwater biodiversity decline have been reviewed by Dudgeon et al. (2006) who identified a) overexploitation, b) water pollution, c) flow modification, d) destruction or degradation of habitat and e) invasion by exotic species, as five direct anthropogenic drivers of population decline and range reduction of freshwater species worldwide. With the advancements of human society, however, which in geological terms is referred to as 'Anthropocene' (Crutzen 2016), new and/or previously unrecognised threats have emerged. Reid et al. (2019) updated our knowledge of such emerging threats to freshwater biodiversity by documenting 12 threats that either intensified since Dudgeon et al. (2006) published their work, or are entirely novel. As PC habitats range from marine to freshwater settings in the BSB, threats documented by Dudgeon et al. (2006) and Reid et al. (2019) are relevant and may inform PC biodiversity conservation planning. However, a comprehensive understanding of the specific threats to the unique, brackish PC biodiversity is necessary to inform the PC biodiversity conservation planning.

Direct threat analyses studies that have been conducted in the PC habitats have been focused on either individual countries (Aliyeva et al. 2013; Stanica et al. 2007; Tudor et al. 2006; Varnosfaderany et al. 2015) or selected target species (Burada et al. 2014; Dmitrieva et al. 2013; Poorbagher et al. 2017). However, PC habitats have a patchy distribution and cross the national boundaries, while the PC taxa encompass diverse and very different taxonomic groups such as vertebrates, invertebrates and algae. Therefore, PC ecosystems could benefit from a large-scale, transboundary studies on individual and cumulative effects of human pressures, similar to that conducted by Lattuada et al. (2019) for the Caspian Sea basin. These authors assessed the Caspian Sea basin-wide individual and combined effects of critical anthropogenic pressures on the local ecoregions and found that both cumulative and individual pressure scores were unevenly distributed across the Caspian Sea. They identified the most important individual pressures to be invasive species, chemical pollution and poaching. Similar studies for the PC areas in the BSB are limited to individual PC habitats, see e.g., Burada et al. (2014); Son et al. (2020); Stanica et al. (2007) and Tudor et al. (2006).

Biodiversity conservation is a complex socio-political process involving different dimensions and interests of various stakeholders and end users; as such, the response to the current PC biodiversity crisis can only be a product of human action and organization (Brechin et al. 2002; Durham et al. 2014). Effective PC conservation planning must therefore include social, political and ecological considerations (Ban et al. 2013). Most biodiversity hotspots, including the PC region, are socially and politically dynamic and challenging environments involving countries with diverse histories, economic and political situations, cultures, languages and priorities. PC areas, like most coastal environments in the world, are an important resource for local communities. Therefore, interventions of conservation programs, often produce adverse social impacts and exacerbate the local ecological problems (The World Bank study team 2014). Besides the local fisheries and fisherman in the PC areas, whose livelihoods directly depend on fishing, there are a number of other stakeholder groups including the local agrarian communities, business sectors, such as touristic agencies and recreational centers, the military and the local researchers and conservation planners (CEP 2002; ECODIT LLC 2017; The World Bank study team 2014). Understanding the local stakeholder landscape, their needs and interactions, as well as the additional social variables such as their conservation awareness, attitudes towards nature conservation, motivation to collaborate or participate in conservation actions and their financial status, are critically important to inform conservation planning and management interventions.

The Danube Delta shared between Romania and Ukraine in the north-western BSB, is a prime PC hotspot (chapter 2). With its PC habitats, transnational location and complex socioeconomic and political characters the Danube Delta is an excellent model system for the wider PC region to understand challenges of effective PC biodiversity conservation. The Danube Delta includes the lower stretch of the Danube River, its 3 branches – Chilia, Sulina and Sf. Gheorghe, Razim-Sinoe Lake complex and the adjacent Black Sea coastal ecosystems in Ukraine and Romania (see chapter 2). The delta is internationally recognized as Europe's largest water purification system and an important wildlife habitat (Baboianu 2016). The management of Danube Delta is, however, embedded in highly complex social and political systems, that involve different interests of various stakeholders and different levels of governance (The World Bank study team 2014). For example, Danube Delta as a 'Waterflow Habitat' is a designated Ramsar site in Ukraine and Romania. Additionally, within the UNESCO Man and Biosphere Program, it is declared as a "Danube Delta transboundary Biosphere Reserve Ukraine and Romania". Furthermore, the Danube Delta is protected and managed through the Danube River Protection Convention (1994) and Bern Convention (1979). Additionally, natural resources in Danube Delta are highly sought after by the local inhabitants who live in small villages and rely on direct exploitation of natural resources (Gastescu 2009; The World Bank study team 2014). The unemployment rates within Danube Delta are higher than that of average country-wide rates in both Ukraine and Romania (Koyano 2008). Therefore, conservation planning within the Danube Delta is a challenging task, and the conservation interventions often result in conflicts with local communities and stakeholders (The World Bank study team 2014).

Ukraine and Romania that share the responsibility for effective conservation of species and ecosystems within the Danube Delta (ICPDR 2015, 2020) have different socio-political and economic backgrounds that may affect the outcomes for PC biodiversity conservation. Romania is an EU member state since 2007, while Ukraine is signatory to an EU-association agreement. Consequently, Romania is legally bound to EU Directives, including the Habitats Directive (HD) and Birds Directive (BD), respecting at the same time the national conservation legislation, while

Ukraine is currently in the process of approximation to the EU acquis to meet the conditionality requirements of the accession to the EU (Szarek-Mason 2010). The accession of a country to the EU does not only mean the approximation of the national legislation to the EU acquis, but also development and adoption of institutions and structures by which legally binding legislation can be effectively implemented (Börzel 2009; Carmin and VanDeveer 2004). This process is referred to as 'Europeanization'. Europeanization is known to have encouraged shifting of the old hierarchical governance system in Romania, where state actors would make decisions (Buzogány 2015; Kluvankova-Oravska et al. 2009; Wesselink et al. 2011), towards the new norms which empower different stakeholders to participate in environmental decision making and conservation planning (Dimitrova and Buzogány 2014; Stringer and Paavola 2013). Challenges remain however, due to lack of previous experiences with inclusive governance systems in Romania (Stringer and Paavola 2013). Furthermore, Europeanization resulted in new opportunities to finance biodiversity conservation and to build the European network of protected areas such as the Natura 2000 sites (Buzogány 2015). For comparison, in Ukraine a network of protected areas is built known as the Emerald Network (EN), which is part of implementation of the Bern Convention, as well as the EU conditionality requirements. Natura 2000 and EN are practically the same, providing opportunities for conservation of habitats and species of Resolutions 4 and 6 of the Bern Convention (EN), and all areas that are protected under the HD and BD (Natura 2000). The main difference is that EN is developed for non-European countries and those who are not full members of the European Union (EU) as well as for countries of Eastern European partnership. If such country becomes a member of EU, its EN automatically becomes a Natura 2000 network. In Ukraine, the national legislation on Emerald Network is currently under development; this process started in 2009 (Ministry of Ecology and Natural Resources of Ukraine 2018). Romania, however had to transpose the provisions of the BD and HD into its national conservation legislation before the accession to the EU (Ministry of Environment and Climate Change of Romania 2014). The legal bases for PC biodiversity conservation in Ukraine and Romania may therefore be different and needs to be understood whether they provide sufficient base for conservation.

National and international conservation agendas are controlled by the combined and interrelated interests of conservation policy, science and public opinion (De Klemm and Shine 1993). As a result, the choice of biotic communities or individual species as conservation priorities is often based on anthropomorphic factors, i.e., preference for protection of more 'charismatic' taxa (e.g., PC sturgeon species and a PC seal); and anthropocentric factors, i.e., choice of species with high economic value (e.g., Pontic shad species) (Male and Bean 2005). Based on a study on national red lists from 53 European and Mediterranean countries, Azam et al. (2016) showed that the choice of taxonomic groups for inclusion in the assessments is also greatly influenced by expert availability, data availability and funding opportunities. Despite the high diversity of invertebrate species and their importance to ecosystems and mankind, the universal trend is to focus on conservation of vertebrate species rather than invertebrate species. Invertebrate species are also often ignored in scientific projects, legal documents and conservation plans (De Klemm and Shine 1993; Glowka et al. 1998; Martín-López et al. 2009). Seven impediments have been identified globally to the effective conservation of invertebrate species (Cardoso et al. 2011) which also apply to PC biodiversity. These are 1) public dilemma – invertebrate species are usually unknown to general public, 2) political dilemma – policy-makers and stakeholders are often unaware of the conservation needs of invertebrate species (see e.g. Gogaladze et al. 2020a; Gogaladze et al. 2020b), 3) scientific dilemma – knowledge on invertebrate species is lacking and research is not adequately funded, 4) Linnean shortfall – many of the invertebrate species have not been described (Hortal et al. 2015), 5) Wallacean shortfall – distribution of known invertebrate species is largely unknown (Hortal et al. 2015), 6) Prestonian shortfall – invertebrate species abundance and population trends are not known (Hortal et al. 2015), 7) Hutchinsonian shortfall – invertebrate life history traits, functional roles and sensitivity to changes in the environment are largely unknown (Hortal et al. 2015).

Pontocaspian biodiversity conservation is obstructed by a plethora of challenges. Knowledge on PC invertebrate species identities and numbers, abundance and population trends, life history traits and functional roles, as well as sensitivity to environmental changes are lacking on all - public, political and scientific levels (Wesselingh et al. 2019). The current status of PC biodiversity trends in the BSB is poorly known due to taxonomic uncertainty, the lack of standardized observation data and the transient boundaries of PC habitats (Anistratenko et al. 2020; Sands et al. 2020; Son 2011a, b, c, d, e, f; Son and Cioboiu 2011; Wesselingh et al. 2019). This is further hampered by language barriers (Russia, Ukraine, Romania, Moldova and Bulgaria share PC habitats and species in the BSB and reporting has mostly been done in their respective languages and in unpublished reports), and the complex economic and political situation. Current conservation schemes and approaches, engagement and incentives of relevant stakeholder organizations to act together, legal and political frameworks and the conservation governance systems to address PC biodiversity conservation and management are also poorly known. Furthermore, due to the transnational nature of PC biodiversity distribution, cross-border cooperation and joint efforts are critically important to achieve effective conservation. However, a cross-border cooperation framework is lacking with regard to PC invertebrate diversity. When it comes to PC vertebrate species, such as PC sturgeons or herring species, the public, political and scientific knowledge is more comprehensive and conservation efforts clearer, but they face their own challenges such as poaching and weak law enforcement (Bloesch et al. 2006; ECODIT LLC 2017; ICPDR 2015, 2020).

This PhD project is part of the EU Horizon 2020 Innovative Training Network - Pontocaspian Biodiversity Rise and Demise (PRIDE) program (https://pontocaspian.eu/). PRIDE comprised a large scientific network involving 15 early-stage researchers and 25 institutions. The program aimed to understand the past, present and future of PC biodiversity dynamics in the Black Sea - Caspian Sea region and to investigate PC biodiversity awareness and pathways to effective conservation. It had an interdisciplinary approach involving earth and life sciences as well as social sciences.

The overall aim of this thesis is to contribute to the establishment of effective PC biodiversity conservation regime in the BSB by answering scientific questions to set the research and policy agenda required for improving PC biodiversity data collection, promoting PC biodiversity awareness and establishing a meaningful conservation regime. Specifically, the thesis aims to answer the following research questions:

1) What are the current status and trends in PC invertebrate species and populations in the BSB?
2) What are the direct anthropogenic drivers of PC biodiversity change (either positive or negative)?
3) Are there areas in the BSB that can support viable PC populations today, that could be considered as priority areas in conservation planning?
4) Does the current legal and political framework provide adequate protection to the PC biodiversity in the Danube Delta - a prime PC biodiversity hotspot shared between Romania and Ukraine?
5) Who are the practitioners and stakeholders of PC biodiversity conservation in Romania and Ukraine?
6) How are the stakeholder networks arranged in Romania and Ukraine?
7) Are stakeholder institutional alignments optimal for PC biodiversity conservation in these neighboring countries?
8) What social variables, external to the stakeholder network properties help or hamper PC biodiversity conservation in Romania and Ukraine?

Addressing these questions will shed light to the current state of PC biodiversity in the Black Sea Basin, current conservation capacity of institutional designs and governance architectures and shortfalls in effective PC biodiversity conservation actions.

1.1 Thesis outline

This thesis consists in total of 6 chapters (Fig. 1.1) with the first chapter providing the general introduction and outline of the thesis and the last chapter concluding my findings which are presented in 4 papers (chapters 2-5). Chapter 2 studies PC species and population trends and identifies the direct anthropogenic drivers of the PC invertebrate biodiversity change throughout the entire north and north-eastern Black Sea Basin, based on literature review and practitioner reflections. Chapters three, four and five address indirect anthropogenic drivers of PC biodiversity change. In chapter three we explore the political domain of conservation science, assessing the current legal basis and its effectiveness for PC biodiversity conservation. Chapters four and five address the social dimensions of biodiversity conservation and effective governance systems. Specifically, they deal with institutional alignment, which encompasses all formal interactions

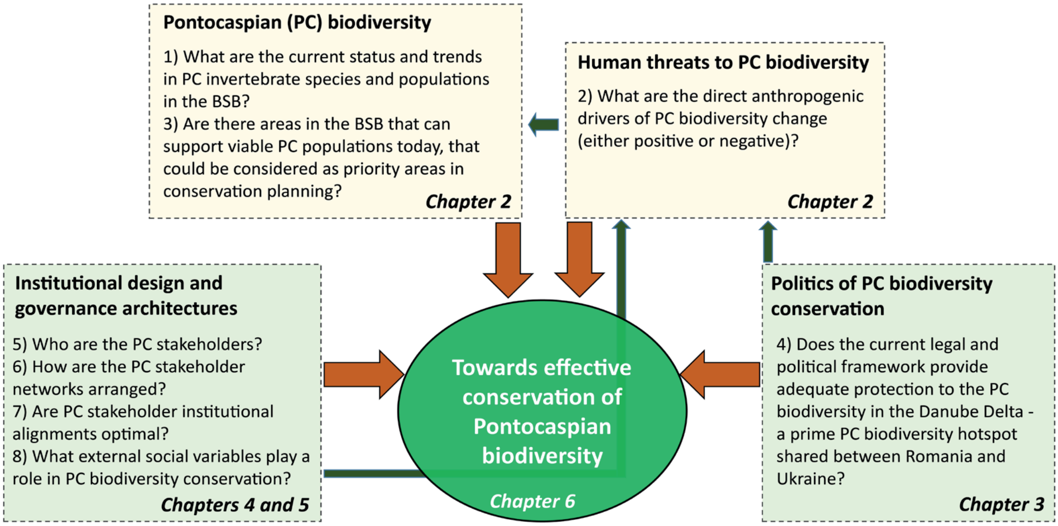


Figure 1.1 Structure of the thesis.

among the stakeholder organizations, including the exchange of scientific information, collaboration and authority/power relations, and their outcomes for conservation governance.

Chapter 2. Decline of unique Pontocaspian biodiversity in the Black Sea Basin: a review.

Lack of an overview of the status and trends of PC species, populations and communities hampers the assessment of risks and limits the design of effective conservation strategies. This chapter assesses the loss of PC habitats and species in the Black Sea - Azov Sea Basin in the past century, using PC molluscs as a model group, and identifies direct anthropogenic drivers of PC biodiversity change. We found that PC biota is severely affected by human activities in the BSB, which resulted in local extinctions, declining numbers and disappearing PC mollusc communities in all study regions. Four regions, namely, the Danube Delta – Razim Lake system (RO, UA), Dniester Liman (UA, MD), Dnieper-South Bug Estuary (UA) and Taganrog Bay-Don Delta (UA, RU) still contain ecological conditions to support PC communities and host threatened endemic PC mollusc species. We identified five direct anthropogenic drivers of change causing the decline in PC biodiversity throughout the BSB. These are 1) damming of rivers, 2) habitat modifications affecting salinity gradients, 3) pollution and eutrophication, 4) invasive alien species and 5) climate change.

Chapter 3. Legal framework for Pontocaspian biodiversity conservation in the Danube Delta (Romania and Ukraine).

Biodiversity conservation benefits from a clear and transparent legal and political framework. This framework is complex, operating on different levels of governance from multi-governmental United Nations (UN) Conventions to national and sub-national laws and practices. Consequently, a single species or a single population is often governed by different rules and regulations, especially if its distribution crosses national borders. Pontocaspian biodiversity has a patchy distribution that spans across the coastal areas of the north and north-western Black Sea Basin as well as the entire Caspian Sea Basin, that exposes them to diverse governments and governance systems. In this chapter we use the Danube Delta, shared between Romania and Ukraine, as a case system to assess the effectiveness of current legal framework to support the PC biodiversity conservation. We examined what was delivered in terms of policies on PC biodiversity conservation on global, EU, and individual country levels in Romania and Ukraine, and how effective the outcomes were. Additionally, we explored whether conservation of 'flagship' and 'umbrella' species such as sturgeons supported the associated lesser-known PC invertebrate species. We show that both PC habitats and invertebrate species are poorly represented in international and national legal documents. Protected areas cover large parts of PC habitats; however, management plans are either not in place or fail to address the PC biodiversity, providing incidental, therefore sub-optimal conservation. Additionally, the current PC biodiversity related legal landscape lacks coherence (mutual reinforcement) on both horizontal (between Romania and Ukraine) and vertical (between Romania and EU as well as Ukraine and EU) levels. Finally, there is little overlap in the distribution of sturgeon species and the invertebrate PC biota and a mismatch between the regulatory scope of sturgeon-related laws and conservation needs of PC invertebrate species. Therefore, a surrogate approach using the umbrella sturgeon species does not work for PC invertebrate species. We end with suggestions and recommendations for improved legal and political framework towards effective PC biodiversity conservation.

Chapter 4. Using social network analysis to assess the Pontocaspian biodiversity conservation capacity in Ukraine.

Effective collaboration between stakeholder organizations, defined as high levels of information exchange and coordination of joint actions, is essential for adequate implementation of biodiversity conservation measures. In this chapter we investigated the interorganizational network of stakeholders in Ukraine, and studied the implications of network properties for the conservation of Pontocaspian biodiversity. We identified a structurally optimal - well-connected and centralized network in Ukraine, with high numbers of reciprocated links and inclusive, participatory governance system. However, the strong network did not translate into effective conservation of Pontocaspian biodiversity because of the subordinate role of this biota in the interorganizational interactions, likely due to lack of knowledge on these taxa. Social variables, such as funding scarcity and legal constraints were found to further limit the effectiveness of conservation actions. We conclude that with the current stakeholder landscape in Ukraine, it can be expected that improved knowledge on PC species and better understanding/awareness, combined with increased research funding and more consistent conservation policy could quickly translate into increased and improved conservation actions.

Chapter 5. Social network analysis and the implications for Pontocaspian biodiversity conservation in Romania and Ukraine: A comparative study.

Different network structures of stakeholder organizations suit different conservation contexts and phases, and the suitability of structures as well as the network properties change over time. Romania and Ukraine have a common responsibility to address the conservation of Pontocaspian biodiversity. The two countries, however have different socio-political and legal conservation frameworks, which may result in differences in the social network structure of stakeholder institutions with different outcomes for PC biodiversity conservation. This chapter compares the institutional alignments in Romania and Ukraine and examines the outcomes of identified network properties for PC biodiversity conservation. We found that in Romania there is a room for improvement in the network structure through e.g., more involvement of governmental and nongovernmental organizations and increased involvement of central stakeholders to initiate conservation actions. When in contact, stakeholder organizations rarely discussed PC biodiversity conservation. Furthermore, social variables, such as lack of funding, hierarchical and a non-inclusive system of conservation governance, political constraints and continuous institutional reforms in the public sector hampered collaboration resulting in suboptimal conservation actions. Consequently, similar to Ukrainian network, the Romanian institutional alignment translates into sub-optimal conservation actions. However, the roads to optimal conservation are different in Romania and Ukraine.

2

Decline of unique Pontocaspian biodiversity in the Black Sea Basin: a review

Published as:

Gogaladze, A., Son, M.O., Lattuada, M., Anistratenko, V.V., Syomin, V.L., Pavel, A.B., Popa, O.P., Popa, L.O., Poorten, J. ter, Biesmeijer, J.C., Raes, N., Wilke, T., Sands, A.F., Trichkova, T., Hubenov, Z.K., Vinarski, M.V., Anistratenko, O.Y., Alexenko, T.L., Wesselingh, F.P. Decline of unique Pontocaspian biodiversity in the Black Sea Basin: a review. Ecology and Evolution 11(19):12923-12947. https://doi.org/10.1002/ece3.8022

Abstract

The unique aquatic Pontocaspian (PC) biota of the Black Sea Basin (BSB) is in decline. Lack of detailed knowledge on the status and trends of species, populations and communities hampers a thorough risk assessment and precludes effective conservation. This paper aims to review PC biodiversity trends using endemic molluscs as a model group. We aim to assess changes in PC habitats, community structure and species distribution in the Black Sea Basin (Bulgaria, Romania, Moldova, Ukraine and Russia) over the past century and to identify direct anthropogenic threats. Presence/absence data of target mollusc species was assembled from literature, reports and personal observations. PC biodiversity trends in the NW Black Sea Basin coastal regions were established by comparing 20th and 21st century occurrences. Direct drivers of habitat and biodiversity change were identified and documented. Our results show that a very strong decline of PC species and communities during the past century is driven by a) damming of rivers, b) habitat modifications negatively affecting salinity gradients, c) pollution and eutrophication, d) invasive alien species and e) climate change. Four out of 10 studied regions, namely, the Danube Delta – Razim Lake system, Dniester Liman, Dnieper-South Bug Estuary and Taganrog Bay-Don Delta contain the entire spectrum of ecological conditions to support PC communities and still host threatened endemic PC mollusc species. Distribution data is incomplete, but the scale of deterioration of PC species and communities is evident from the assembled data, as are major direct threats. PC biodiversity in the BSB is profoundly affected by human activities. Standardised observation and collection data as well as precise definition of PC biota and habitats are necessary for targeted conservation actions. This study will help to set the research and policy agenda required to improve data collection to accommodate effective conservation of the unique PC biota.

2.1 Introduction

Pontocaspian (PC) biota forms a unique, endemic ecological community, that occurs in transitional brackish habitats between freshwater and marine habitats in the Black Sea region (Anistratenko 2007b; Mordukhay-Boltovskoy 1960; Sowinsky 1904). Globally, very little endemic biodiversity exists in brackish water systems due to the lack of longevity of these dynamic habitats. PC biota evolved in anomalohaline lakes and marginal seas of the Caspian-Black Sea region over the past few million years (Krijgsman et al. 2019; Starobogatov 1970). Within the Black Sea Basin (BSB) that includes the Azov Sea, PC species live in river deltas, lowland lakes and estuaries in the northern coastal zones. Current status and trends of PC biodiversity in the BSB is poorly known due to taxonomic uncertainty, lack of standardized observation data and the transient boundaries of PC habitats (Anistratenko et al. 2020; Sands et al. 2020; Son 2011a, b, c, d, e, f; Son and Cioboiu 2011; Wesselingh et al. 2019). This is further hampered by language barriers (Russia, Ukraine, Romania, Moldova and Bulgaria share PC habitats and species in the BSB and reporting has mostly been done in their respective languages and in unpublished reports), and the complex economic and political situation. While a comprehensive view of PC population trends is lacking, it is clear that Black Sea coastal areas have faced a variety of anthropogenic modifications, which were reported to result in strong reductions in PC species numbers and their abundances in various places (Alexenko and Shevchenko 2016; Markovsky 1953, 1954a, b, 1955; Popa et al. 2009; Velde et al. 2019).

The PC biota comprises vertebrate, e.g., fish, as well as a variety of invertebrate taxa, e.g., molluscs, crustaceans and worms. Molluscs are particularly well suited to study the changing fate of the PC biota in the BSB (see e.g. Son et al. 2020; Velde et al. 2019). They are well represented in museum collections, their shells can indicate previous occurrences of species (Fig. 2.1), they occur in all benthic PC habitats and several of the species are good environmental indicators (i.e., sensitive to oxygen, salinity, water flow and sedimentation regimes: e.g., Kijashko (2013); Latypov (2015); Mordukhay-Boltovskoy (1960); Velde et al. (2019); Zhadin (1952)). Within the group, some species are characterized by narrow distribution ranges corresponding to narrow ecological tolerance limits. Other species, such as dreissenid bivalves, are opportunistic and have become major invaders elsewhere (Orlova et al. 2005). The taxonomic status of several PC mollusc species is not resolved due to large morphological variability (see e.g. Fig. 2.2a and b) and is hampered by the paucity or absence of living material for novel DNA-based research (Wesselingh et al. 2019). However, a network of PC mollusc specialists has been established in the past years as part of the EU funded Innovative Training Network "PRIDE" (www.pontocaspian.eu) that is actively targeting taxonomic uncertainties, which is an ongoing effort and provides an essential taxonomic base for this study.

The aim of this paper is to review distribution trends of PC biota (using molluscs as a model group) in the BSB by comparing historical (20th century) and modern (21st century) occurrences. Furthermore, we aim to identify the direct anthropogenic threats to their existence and survival (sensu Díaz et al. 2015), viz. processes and settings resulting from human decisions and actions that have direct implications for turnover/decline of PC biota, such as uncontrolled influx of

Figure 2.1. Shells show the decline of PC biota. (a) Shell beach on Popina Island in northern part of Lake Razim, Romania located in prime PC habitat (LOP, sept. 2015). (b) PC shell residues showing the extinct *Hypanis plicata* (no. 1), extirpated *Adacna fragilis* (no. 2), and declining *Monodacna colorata* (no. 3). In the past decades, freshwater taxa such as Viviparus acerosus (no. 4) and Unio pictorum (no. 5) became very abundant while PC species declined. Length of large Unio valve is c 8 cm.

sewage, invasion of alien species and establishment of large dammed reservoirs in river basins, among others (e.g. Lattuada et al. 2020; Lattuada et al. 2019; Semenchenko et al. 2015; Shiganova 2011). PC biodiversity is also affected by indirect anthropogenic drivers such as the organization and interaction within and between societies, stakeholders and people and their interactions with nature. For the BSB these are treated elsewhere (e.g. Gogaladze et al. 2020a; Gogaladze et al. 2020b). Based on this review we outline follow-up approaches to develop a conservation strategy that applies to the entire PC benthic biota in the BSB.

Figure 2.2. Overview of the PC mollusc species from the Northern and North-Western BSB. (a) *Monodacna colorata* (Eichwald, 1829), typical form. Beglitza beach, Taganrog Bay, Azov Sea (Russia). Photo FPW.

(continuation of Figure 2.2.) L 22 mm. (b) *Monodacna colorata* (Eichwald, 1829), forma pontica. Lake Razim (Romania). Photo FPW. L 20 mm. (c) *Hypanis plicata* (Eichwald, 1829). Lake Razim (Romania). Photo FPW. L 24 mm. (d) *Adacna fragilis* Milaschewitsch, 1908. Merzhanovo, Taganrog Bay, Azov Sea (Russia). Leg. M. Kurkay, 10.2018, photo JJP. L 17.3 mm. (e) *Adacna vitrea glabra* Ostroumov, 1905. Don River, Tsimlyansk Reservoir (Russia). Photo MOS. L 11 mm. (f) *Dreissena bugensis* Andrussov, 1897. Merzhanovo, Taganrog Bay, Azov Sea (Russia). Photo FPW. L 14 mm. (g) *Dreissena polymorpha* (Pallas, 1771). Southern Bug Liman (Ukraine). Photo MOS. L 21 mm. (h) *Theodoxus fluviatilis* (Linnaeus, 1758) Dnieper River, Kherson Region (Ukraine). Photo VVA. W 8.1 mm. (i) *Theodoxus velox* V. Anistratenko in O. Anistratenko et al., 1999. Dnieper River Delta, Zburjevskiy Liman, Kherson Region (Ukraine). Photo VVA. W 8.4 mm. (j) *Theodoxus danubialis* (Pfeiffer, 1828). Gergweis, Vils River (Germany). Photo AFS. W 10.2 mm. (k) *Theodoxus major* Issel, 1865. Astrakhan, Volga River (Russia). Photo AFS. W 5.5 mm. (l) *Laevicaspia ismailensis* (Golikov and Starobogatov, 1966). Lake Kugurlui or Yalpug (Ukraine). Illustration reproduced from Kantor and Sysoev (2006), plate 50, Fig. A. L 5.6 mm. (m) *Laevicaspia lincta* (Milaschewitsch, 1908). Lower Dnieper, Kherson (Ukraine). Photo VVA. H 8.97 mm. (n) *Clessiniola variabilis* (Eichwald, 1838). Lower Dnieper, Kherson (Ukraine). Photo VVA. H 7.10 mm. (o) *Clathrocaspia logvinenkoi* (Golikov and Starobogatov, 1966). Lower Don River near Rostov-on-Don (Russia). Photo VVA. H 1.58 mm. (p) *Clathrocaspia knipowitschii* (Makarov, 1938). Lower Dnieper, Kherson (Ukraine). Photo VVA. H 1.99 mm.

2.2 Methods and background

2.2.1 Pontocaspian mollusc species in the BSB

We define Pontocaspian (PC) mollusc species as extant, endemic, fully aquatic species, which evolved in the Black Sea and Caspian Sea Basins during the Quaternary, where they became adapted to a range of anomalohaline salinity regimes that characterized these basins. Most of the PC species evolved from ancestral species that radiated in the Late Miocene and Pliocene Paratethyan Basins (Krijgsman et al. 2019). The common historical origin of PC species and related ecological adaptations distinguish this group from other groups such as Palearctic freshwater species groups and several opportunistic marine species occurring in the PC region today (Anistratenko 2007b; Sowinsky 1904; Starobogatov 1970; Wesselingh et al. 2019; Zhadin 1952).

The historical distribution of PC mollusc families in the BSB has been subject of various studies, viz. Hydrobiidae (Alexenko and Starobogatov 1987; Anistratenko 2007a, b, 2008; Golikov and Starobogatov 1966, 1972; Grossu 1962; Makarov 1938; Sitnikova and Starobogatov 1999; Wilke et al. 2007); Neritidae (Anistratenko et al. 1999; Anistratenko et al. 2011; Anistratenko et al. 2020; Anistratenko et al. 2017; Golikov and Starobogatov 1966, 1972; Lindholm 1908; Makarov 1938; Mordukhay-Boltovskoy 1960; Sands et al. 2020); Lymnocardiinae (Anistratenko et al. 2011; Borcea 1926a, b; Grossu 1973; Makarov 1938; Milaschewitsch 1916; Munasypova-Motyash 2006; Ostroumov 1898; Popa et al. 2009) and Dreissenidae (Andrussov 1897; Rosenberg and Ludyanskiy 1994; Son 2007b). This review is based on endemic and native PC mollusc species (Table 2.1, Fig. 2.2) that have been reported alive from BSB coastal habitats in the 20^{th} and 21^{st} centuries

Table 2.1. Taxonomic status of PC mollusc species from the Black Sea Basin (BSB) with confirmed living 20th and 21st century occurrences. 1Wesselingh et al. (2019); 2 Sands et al. (2020); 3Son et al. (2020); 4Appendix 2.1.

(Sub) Family	Species	Author	Status
Lymnocardiinae	*Adacna fragilis*	Milaschewitsch, 1908	BSB endemic[4]
Lymnocardiinae	*Adacna vitrea glabra*	Ostroumov, 1905	Caspian invasive[3,4]
Lymnocardiinae	*Hypanis plicata*	(Eichwald, 1829)	PC endemic[1]
Lymnocardiinae	*Monodacna colorata*	(Eichwald, 1829)	BSB endemic (20th century), now invasive in Caspian basin
Dreissenidae	*Dreissena bugensis*	Andrussov, 1897	BSB endemic (<20th century), now global invasive
Dreissenidae	*Dreissena polymorpha*	(Pallas, 1771)	Native[1]
Neritidae	*Theodoxus danubialis*	(Pfeiffer, 1828)	Native[1,2]
Neritidae	*Theodoxus fluviatilis*	(Linnaeus, 1758)	Native[1,2]
Neritidae	*Theodoxus major*	Issel, 1865	PC native[2]
Neritidae	*Theodoxus velox*	V. Anistratenko in O. Anistratenko et al., 1999	PC native[2]
Hydrobiidae	*Clathrocaspia knipowitschii*	(Makarov, 1938)	BSB endemic (20th century), now possibly invasive in Danube catchment[1]
Hydrobiidae	*Clathrocaspia logvinenkoi*	(Golikov and Starobogatov, 1966)	BSB endemic[1]
Hydrobiidae	*Clessiniola variabilis*	(Eichwald, 1838)	PC endemic[1]
Hydrobiidae	*Laevicaspia lincta*	(Milaschewitsch, 1908)	BSB endemic[1]
Hydrobiidae	*Laevicaspia ismailensis*	(Golikov and Starobogatov, 1966)	BSB endemic[1]
Hydrobiidae	*Turricaspia chersonica*	Alexenko and Starobogatov, 1987	BSB endemic

(following taxonomy of Wesselingh et al. (2019) and Sands et al. (2020) with a taxonomical update in Appendix 2.1).

2.2.2 Habitats of Pontocaspian species and communities in the BSB

PC communities occur(ed) in coastal plains in areas influenced by the Black Sea and Azov Sea, such as lower stretches of rivers, lagoons, delta areas, estuaries/limans and bays (Figs. 2.3 and 2.4). Limans (a particular landform common to the Northern Black Sea) are estuaries or lagoons mostly or entirely separated from the sea by sand barrier systems and have lagoonal, lake, bay and estuarine properties. Some PC groups, such as *Theodoxus* and *Dreissena* species, are tolerant to a wide array of environmental conditions and have far larger distribution ranges than lymnocardiine and/or hydrobiid species - they are abundant in rivers and lakes, also outside the BSB drainage systems (Sands et al. 2020; Zhadin 1952). We define optimum PC habitats as waterbodies (lakes, estuaries, bays, river stretches) where at least one endemic PC species of two different families co-occur (Table 2.1). Our definition will need expansion when other groups in addition to molluscs are included. Optimum PC habitats contain(ed) communities dominated by PC species within the coastal zone, mostly in oligohaline settings (Alexenko and Starobogatov 1987; Anistratenko 2007b; Anistratenko

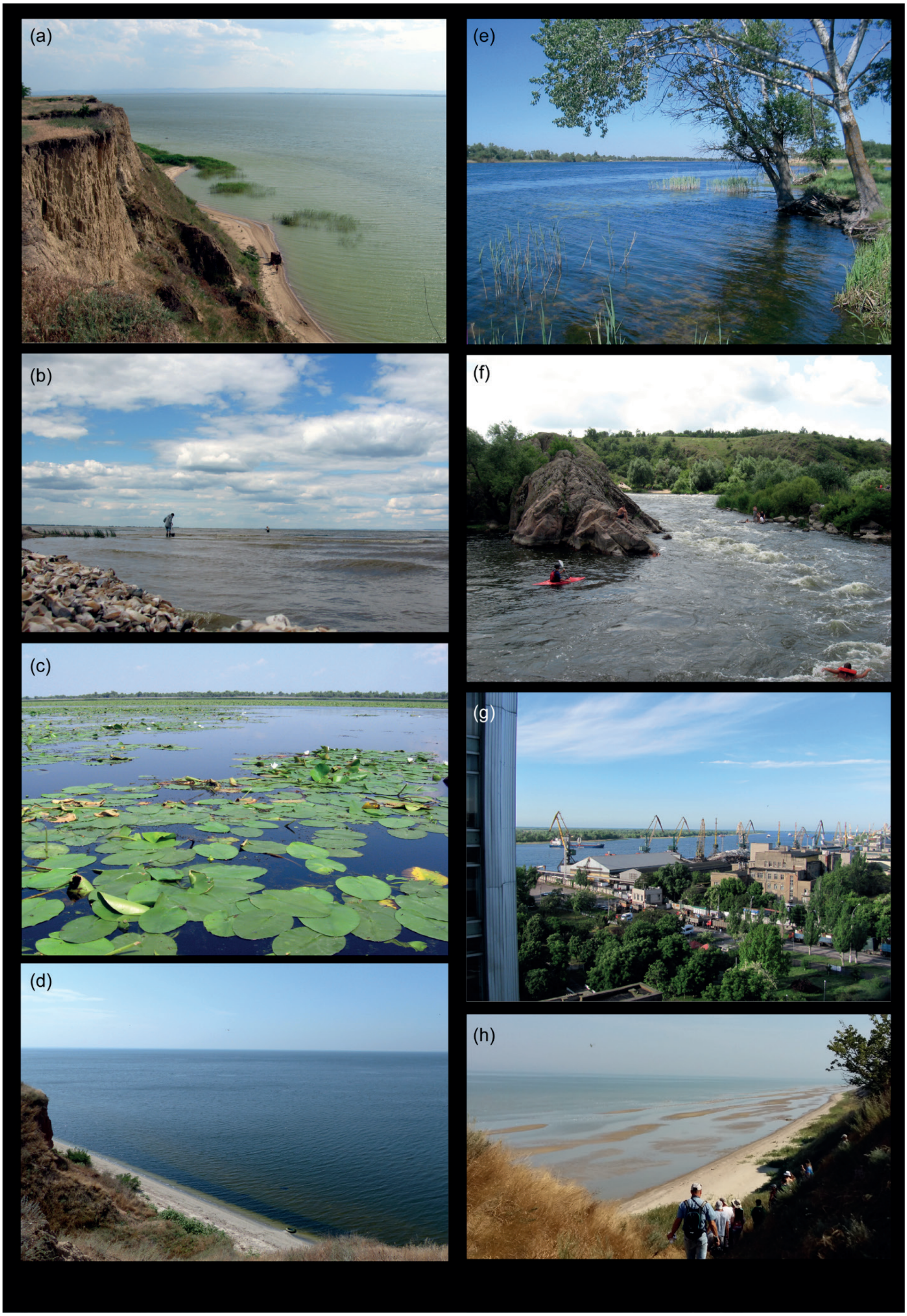


Figure 2.3. Examples of PC habitats in the BSB. (a) Lake Yalpug, Ukraine (Mikhail Son, June 2009). This large lake is still a prime PC habitat, however eutrophication is noticeable. The reed vegetation zone along

(continuation of Figure 2.3.) the shore is a habitat for PC hydrobiid species. (b) Dniester Liman, Ukraine (VVA, June 2016). The small, waves are actively forming shell ridges along the liman near Belgorod-Dnestrovsky that are mainly composed of *Monodacna* and *Dreissena* shells. *Theodoxus* and mostly juvenile *Monodacna* are still living in the area, hydrobiids are represented by fresh empty shells. (c) Lake Beloie in Dniester Delta, Ukraine (photo MOS, July 2009). Smaller deltaic lakes and river floodplain lakes, such as shown in this image, hosted a combination of freshwater and PC species in the past (< 20th century), but PC species have mostly disappeared from these habitats in the past century. (d) Dnieper Liman, Aleksandrovka, Ukraine (VVA, June 2016). Sandy bottom of the distal sector of the liman. Freshwater species are dominant here. Large quantities of empty shells of PC species such as hydrobiid, *Theodoxus* and *Monodacna* spp. are indicative of their former abundance in the region. (e) Dnieper Delta, Konka Branch (MOS, May 2007). Wide riverine channel upstream the estuary. All groups of PC molluscs are present in this habitat. (f) Rapids of the Southern Bug River, Migia Canyon, Ukraine (MOS, July 2009). These rapids form a natural upper boundary for the distribution of most PC taxa. (g) Kherson cargo Harbour, Ukraine (VVA, May 2016). The harbours are important vectors for invasive species and the dredging required to ensure access to sea has various impact on PC habitats in the estuaries and limans. (h) Taganrog Bay at Semibalki, Russia (FPW, September 2017). The view shows the shallow nature of the bay and the sandy character of the sediments. Here, large populations of *Monodacna colorata* and *Adacna fragilis* occur.

et al. 2011; Makarov 1938; Munasypova-Motyash 2006; Starobogatov 1970; Zhadin 1952). Densities of PC molluscs are variable. *Dreissena* and *Monodacna* can dominate communities, but most of the PC hydrobiids have patchy occurrences (Alexenko and Kucheryava 2019; Alexenko and Starobogatov 1987; Anistratenko and Anistratenko 2018).

Three main PC community types have been described during the 20th century from the different regions: (1) *Dreissena* communities, (2) *Dreissena-Monodacna* communities and (3) *Adacna-Hypanis-Monodacna* communities. *Dreissena*-dominated communities are common in rivers (often with *Theodoxus* species present) within and outside the PC region but also occur as secondary species-depleted communities in estuaries in all BSB PC regions (Markovsky 1953, 1954a, 1955; Mordukhay-Boltovskoy 1960; Zhadin 1931). Several *Dreissena* subcommunities have been proposed and all are characterised by the absence of *Monodacna*. The *Dreissena-Monodacna* communities form species-rich communities in freshwater to oligohaline settings at the core of estuaries in all BSB PC regions, and are locally dominated by either *Monodacna* or *Dreissena* species (Markovsky 1953, 1954a, 1955; Mordukhay-Boltovskoy 1960). *Adacna-Hypanis-Monodacna* dominated communities were common in the oligohaline-mesohaline zones in all BSB PC regions (Markovsky 1953, 1954a, 1955; Mordukhay-Boltovskoy 1960; Shokhin et al. 2006; Zhadin 1931). These communities were relatively species poor, contained *Adacna fragilis*, *Monodacna colorata* and *Hypanis plicata* and with the demise of the latter in the BSB these communities vanished. Within the central-eastern parts of the Taganrog Bay today an impoverished version of the community

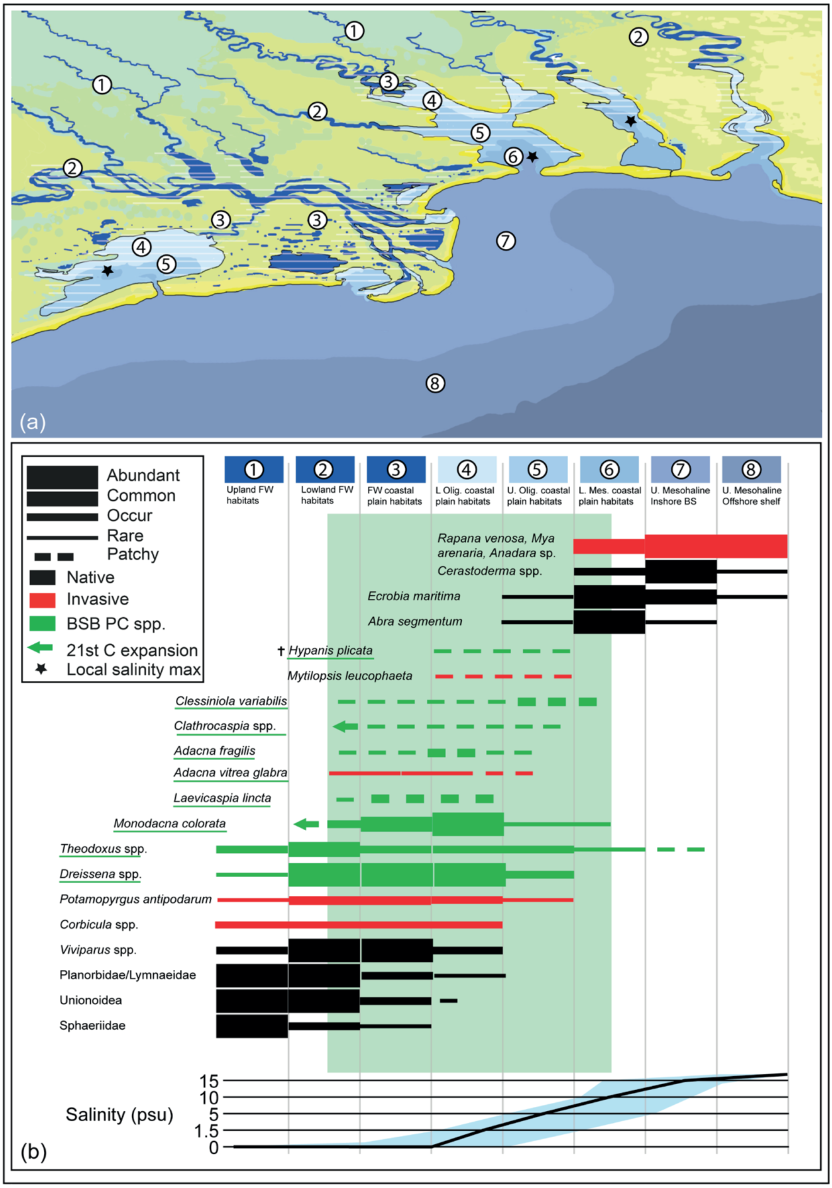


Figure 2.4. Simplified model of coastal landscapes depicting habitats of selected PC (green underlined) and other abundant mollusc species in the north-western Black Sea coastal zone for the 20th-21st century. The optimum PC habitats are shaded (above) and indicated in green (below). FW - fresh water, U - Upper, L - Lower, Olig - Oligohaline, Mes - Mesohaline. Our model summarised personal observations as well as published accounts. In each sub-basin in the BSB the salinity gradients and habitat successions are complex. In some areas local salinity maxima occur that are the result of excessive evaporation rather than a simple freshwater to marine gradient.

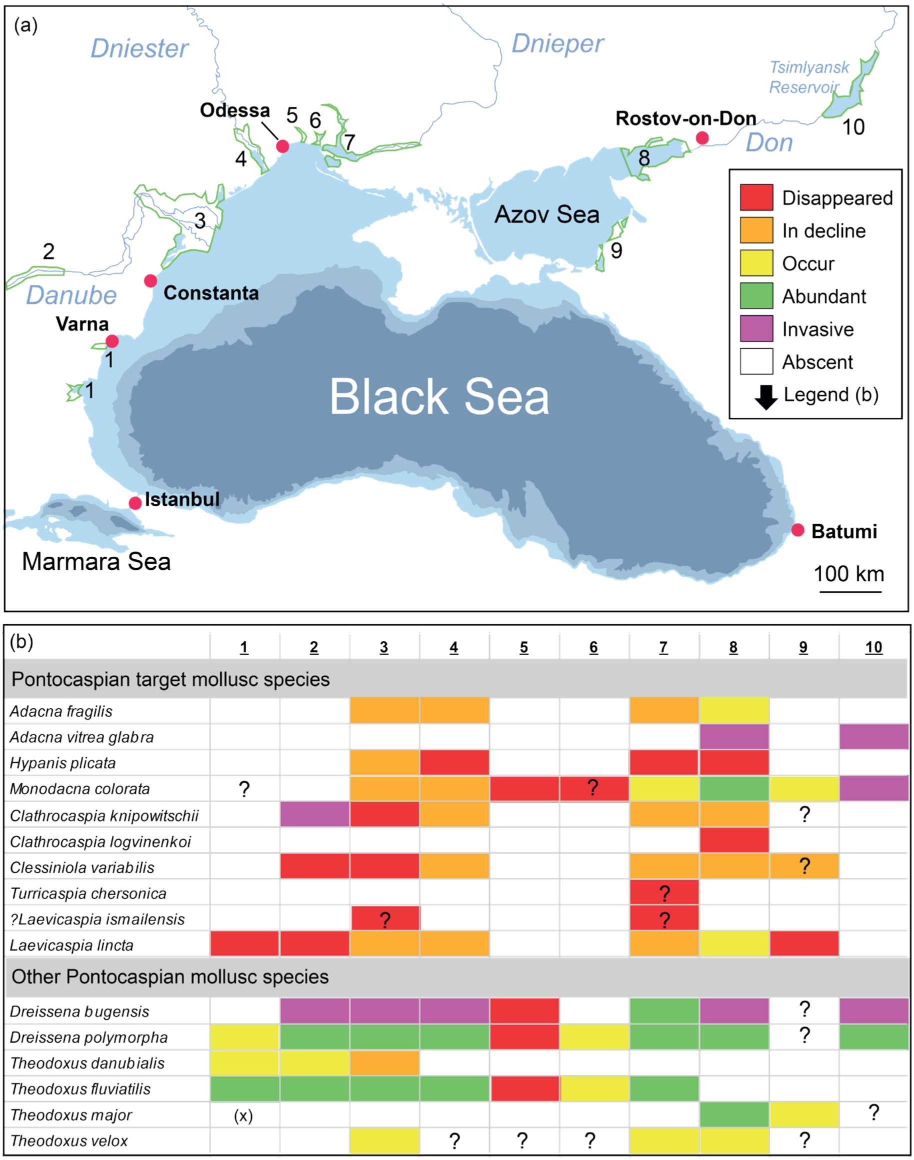


Figure 2.5. (a) PC species occurrences in the BSB. 1. Bulgarian coastal lagoons and limans, 2. Lower Danube River, 3. Danube Delta – Razim, 4. Dniester Liman, 5. Tiligul Liman, 6. Berezan Liman, 7. Dnieper-Bug Estuary, 8. Taganrog Bay – Don Delta, 9. SE Azov Sea coast, 10. Tsimlyansk Reservoir. (b) Status of PC mollusc species. "Decline" stands for diminished distribution range within an area and/or declining abundances in the past century. "Invasive" stands for 21st century introductions. Question marks denote areas with insufficient observations (such as southeast Azov coast) or taxonomic groups that require re-examination (*Theodoxus* species). *Earlier reports of this species likely to be misidentifications of *Theodoxus fluviatilis* and/or *T. danubialis* (AFS, PO).

exists (lacking *Hypanis*) that is often termed *Monodacna* community (Nekrasova 1972; Stark 1960; Vorobyev 1949). Optimum conditions for that community are fresh or oligohaline (up to 5 psu), sandy, shelly or moderately silty grounds in the bay, and low current areas in the outer Don river indicative of good oxygenation and moderate hydrodynamics. Within the PC habitats previously local very dense aggregates of PC gastropod occurrences existed, that may be interpreted as communities or subcommunities. *Clessiniola variabilis* dominated communities have been mentioned from shallow waters with variable salinities in the Dniester and Dnieper-Bug regions (Markovsky 1953, 1954a) but we have not encountered such aggregates in the past decades. *Laevicaspia lincta* dominated communities (mentioned from Dniester and Kuchurgan Liman, Katlabukh, Yalpug and Dnieper by Markovsky 1953; Markovsky 1954a, 1955; Olivari 1953; and observed in Razim Lake by Wilke et al. 2007 as late as in 2003) were a common feature in freshwater areas and occasionally low oligohaline settings with abundant *Dreissena*.

2.2.3 PC habitat mapping

We retrieved freshwater habitat polygons from HydroLAKES dataset (https://www.hydrosheds.org/pages/hydrolakes) to map the PC habitats in the BSB using QGIS 3.10 "A Coruña". We manually edited those polygons that did not cover the PC habitats, such as swamps and marshes, based on published literature and expert knowledge. We also manually drew lagoons and bays of Pontocaspian habitats which are not part of the HydroLAKES based on published accounts and expert opinion. Given the densely aggregated small lakes in the Danube Delta with surface areas lesser than 0.2 km2 we merged the Chilia branch of Danube River and outer delta lakes both upstream and downstream of Vilkovo (Table A2.2.1 and Appendix 2.3).

2.3 Results

2.3.1 Status and trends of PC species in BSB

Ten regions in the BSB contain 20th and/or 21st century occurrences of endemic PC species (Fig. 2.5). Historical (20th century) and modern (21st century) distributions of PC target taxa are summarised in Appendix 2.2. PC habitat polygon shapefiles as well as the attributes describing historical (20th century) and modern (21st century) distributions of PC target taxa are provided in Appendix 2.3. Data derived from published accounts and personal observations (PO) of the authors (ABP – Ana Bianca Pavel, AFS – Arthur Francis Sands, FPW – Frank P. Wesselingh; LOP – Luis Ovidiu Popa, MOS – Mikhail O. Son, MVV - Maxim V Vinarski, OPP – Oana Paula Popa, OYA – Olga Yu Anistratenko, TT - Teodora Trichkova, TW – Thomas Wilke, VLS – Vitali L. Syomin, VVA – Vitaliy V. Anistratenko).

Bulgarian coastal lagoons and limans

The Bulgarian Black Sea coast contains 31 wetland areas such as lakes, marshes and lower river floodplain areas (Varbanov 2002), from where living PC species and shells have been reported

(Georgiev and Hubenov 2013; Hubenov 2007, 2015; Sands et al. 2019; Appendix 2.2). *Theodoxus fluviatilis* has been reported from more than 15 wetlands (Hubenov 2015), while *Dreissena polymorpha* occurred in about ten wetlands in the past, and currently is confirmed from five of these native habitats (Hubenov 2015; Vidinova et al. 2016). *Theodoxus major* (reported as T. pallasi) occurred in Lake Varna before salinization in the first half of the 20th century (Drensky 1947; Kaneva-Abadjieva 1957) and is now considered extinct in Bulgaria (Hubenov 2015). Living specimens of *Laevicaspia lincta* (reported as *Micromelania lincta*) were recorded in Lake Mandra (June 1944) and Lake Beloslav (August 1945) by Drensky (1947). The species was considered rare for Bulgaria (Drensky 1947), and since then no further occurrences have been recorded (Hubenov 2015). PC cardiids have been reported only as shells in the Bulgarian coastal wetlands. Kaneva-Abadjieva (1957) found single shells of *Monodacna colorata* at different parts and depths of Lake Varna, assuming that the species was present there before salinity regime change in the first half of the 20th century. Shells of *L. lincta*, *M. colorata* and *Hypanis plicata* (reported as *Adacna relicta* and *A. plicata relicta*) have been reported from the Black Sea littoral sediments by Valkanov (1957b), Marinov (1990), and (Hubenov 2015), and shells of *Clessiniola variabilis* – by Genov and Peychev (2001), and (Hubenov 2015). It is unclear whether these littoral shells represent possible 20th century occurrences, as older Holocene and even Late Pleistocene occurrences are well known from shallow deposits in the Black Sea coastal and shelf areas (Velde et al. 2019).

The Bulgarian Black Sea coastal wetlands have been exposed to a variety of strong anthropogenic pressures owing to agricultural, recreational, urban and industrial development over the past two centuries (Hubenov 2015; Trichkova 2007). Increased eutrophication as well as substantial variation in physico-chemical parameters such as salinity, oxygen content, mineral content and temperature in the wetlands have caused very strong changes in benthic invertebrate communities (Trichkova 2007). Some of the past habitats sustaining PC species have completely changed. For example, Lake Varna was connected to the sea through a navigation canal in 1909 and to Lake Beloslav in 1923. Later, in 1975, a bigger canal and a sea port were built, increasing salinity within both lakes, driving the loss of their natural fauna, including PC species (Trichkova 2007; Varbanov 2002). Benthic invertebrate biota in other wetlands (e.g. Durankulak, Shabla-Ezerets, Burgas, Mandra, and Dyavolsko Blato Marsh) declined or vanished due to restriction or complete disconnection from the Black Sea because of damming, and/or due to intensive fish-farming activities, overfishing, and household and industrial pollution (summarised in Hubenov 2015; and Trichkova 2007).

Lower Danube River

Theodoxus and *Dreissena* are and have been common in the Danube River (Angelov 2000; Russev 1966; Sands et al. 2019; Trichkova et al. 2019). In the Bulgarian sector, PC hydrobiid shells were reported in the 20th century. In June 1958, empty shells of *Laevicaspia lincta* (reported as *Micromelania lincta*) were recorded at Oryahovo (678 rkm) by Russev (1966). Shells of *Clessiniola*

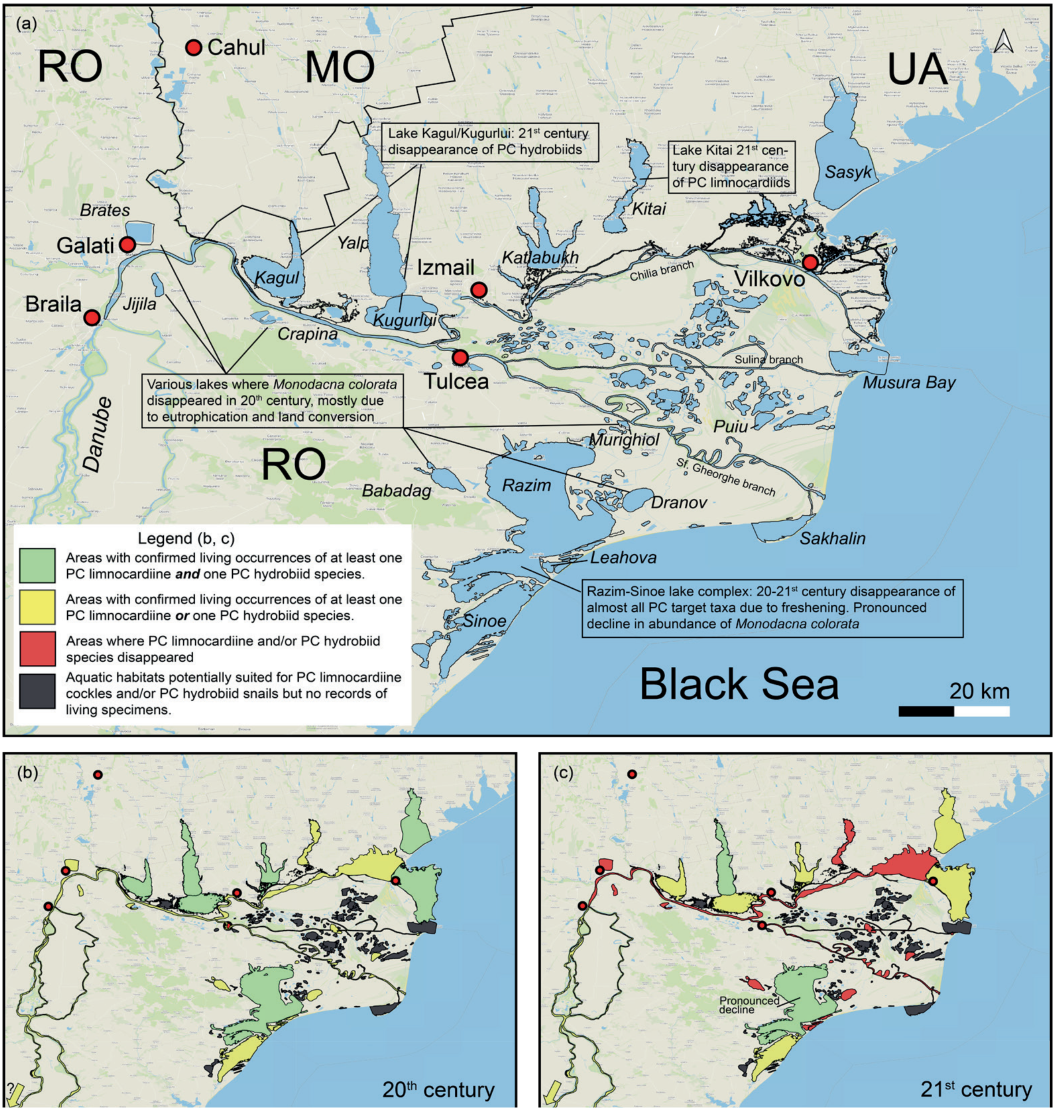


Figure 2.6. PC habitats in the Danube Delta region. (a) Regional overview and major trends, (b) 20th century occurrences, (c) 21st century occurrences. See data in Appendix 2.2, Table A2.2.1, outline of subareas in Fig. A2.2.1. PC taxa still appear in Razim Lake complex in 21st century (hence the green colour), but hydrobiid species have not been reported after 2003 and lymnocardiine species have strongly declined in abundance (Monodacna colorata) or disappeared (*Adacna* and *Hypanis* spp.). Map is projected in EPSG Projection 4326 - WGS 84.

variabilis were found upstream of Lom (474 rkm) in September 1957, at Ruse (493 rkm) in October 1959, and upstream of Silistra (381 rkm) in June 1963 (Russev 1966). No 21st century records exist of these PC hydrobiids from the Bulgarian Danube River stretch. However, recently a *Clathrocaspia* species has been described as Caspia milae in Boeters et al. (2015) from Vardim Island in the Bulgarian sector of the Danube, whose identity is subject to further study (see Appendix 2.1).

The main threats to the aquatic molluscs in general and the PC fauna in the Lower Danube River in particular, are the loss and degradation of habitats, pollution, and introduction of invasive alien species (Trichkova et al. 2019). Throughout the years, the Danube River has been contaminated by urban, industrial and agricultural waste and experienced increasing economic activities such as ship traffic (Russev and Naidenow 1978). A major threat in the 21st century has become the introduction, establishment and spread of invasive alien species (Paunović and Csányi 2018). In recent years, owing to the increase in abundance and biomass of the newly introduced invasive alien mussels *Corbicula fluminea*, *Sinanodonta woodiana*, and *Dreissena bugensis*, benthic habitats in the Bulgarian sector of the Danube River completely changed (Hubenov 2001, 2006; Hubenov and Trichkova 2007; Hubenov et al. 2012, 2013), which may have potential adverse impact on several PC species. Additionally, the invasive mussels may directly impact PC species through competition and fouling.

Danube Delta – Razim

The Danube Delta (up to its apex near Galati), the neighbouring drowned valley lakes both on the Romanian side (e.g., Brates, Crapina, Jijila) and the Ukrainian side (Yalpug, Katlabukh, Kagul, Kitai), as well as the coastal Razim-Sinoe lake complex to the south of the delta and Sasyk lake to the north make up a large (c 6000 km2) and varied area that hosts many PC species (Fig. 2.6). Lake Sasyk was historically separated from the Danube Delta, but was included when, in 1978, a feeder channel from the Danube was constructed. Most of the Danube-Razim region consists of freshwater habitats (river channels, floodplain and delta lakes, drowned river valleys, swamps) but, important, salinity gradients towards mesohaline settings occur in the outer delta and in the coastal lagoons and lakes. The maximum depth within the Razim Lagoon complex is 3.5 metres (Velde et al. 2019).

The Danube Delta region historically harbours a diverse PC mollusc fauna (Markovsky 1955; Mordukhay-Boltovskoy 1960; Popa et al. 2009; Velde et al. 2019) with twelve PC species (Fig. 2.6). Common PC mollusc species are *Monodacna colorata*, *Theodoxus fluviatilis* and *Dreissena polymorpha*. All three lymnocardiine species recorded in the 20th century have disappeared in Romanian lakes, with the exception of the Razim-Sinoe (Popa et al. 2009; Velde et al. 2019), where *M. colorata* and *Adacna fragilis* have 21st century records. However, annual fieldwork in the Razim complex has shown that their abundance has strongly declined in the past 15 years (Popa et al. 2009). One species (*Hypanis plicata*) has not been found alive since 1974. Within the lakes and lagoons very close to the Black Sea coast *A. fragilis* has been a common occurrence in the 20th century (Borcea 1926b; Grossu 1962; Markovsky 1955), but the species has declined recently (Popa et al. 2009). Velde et al. (2019) showed that the Razim communities have almost entirely been

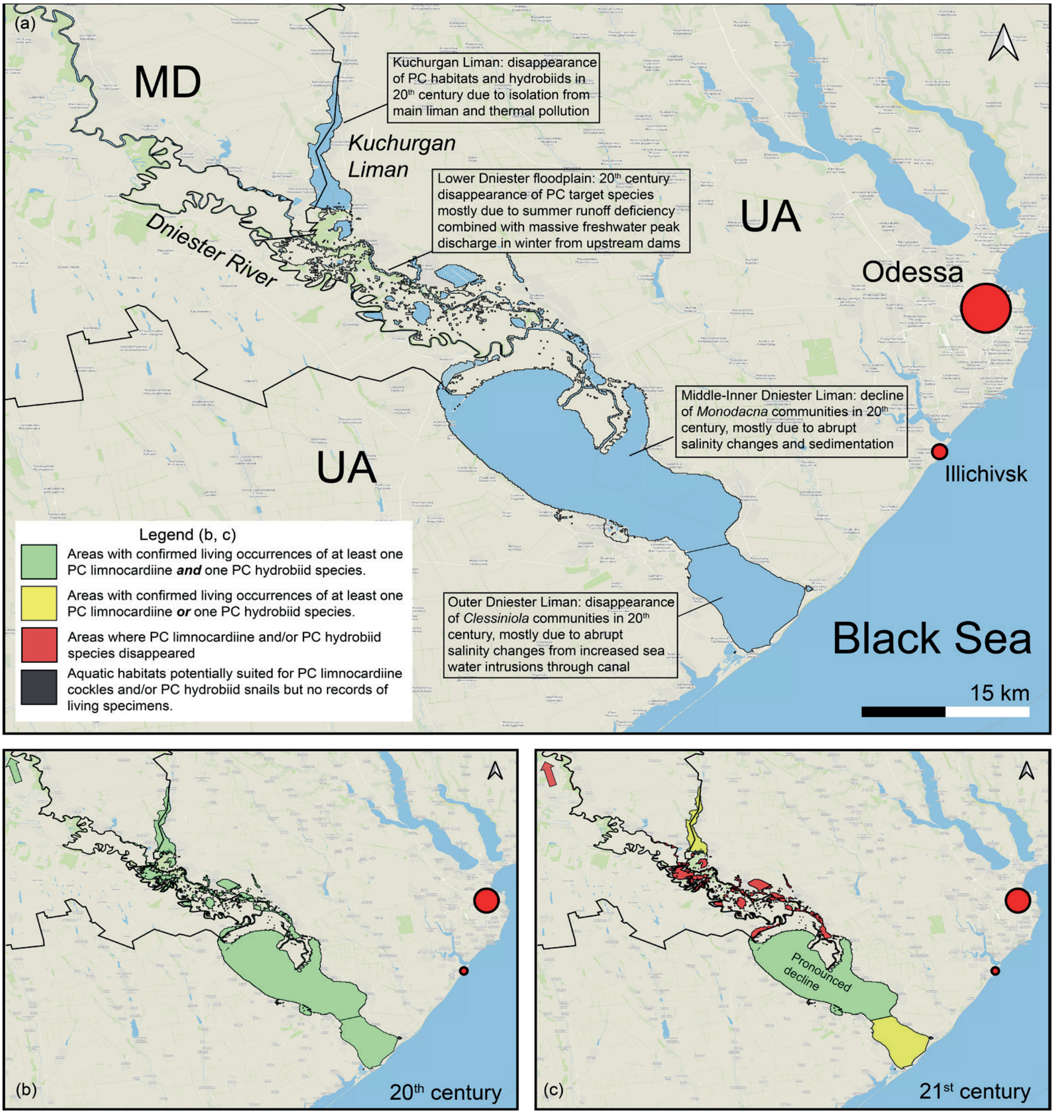


Figure 2.7. PC habitats and trends in the Dniester Liman. (a) Regional overview and major trends, (b) 20th century occurrences, (c) 21st century occurrences. See data in Appendix 2.2, Table A2.2.2, outline of subareas in Fig. A2.2.2. Map is projected in EPSG Projection 4326 - WGS 84.

replaced by freshwater communities in the past decades. In Romania, PC hydrobiid species were reported mostly from the Razim-Sinoe complex and low salinity habitats near the mouth of the Danube distributaries (Grossu 1956). In most cases, these records represent empty shells and their historical distribution (e.g. 20th century occurrence) is not well known. In the past decade no living specimens were encountered apart from a 2003 record of *Laevicaspia lincta* (Wilke et al. 2007).

In the Ukrainian part of the Danube Delta, in the Kitai Lake PC communities have recently disappeared completely and PC species abundances in this lake and in other lakes are decreasing (MOS and VVA, PO). Distribution ranges of *Laevicaspia lincta* and *Adacna fragilis* decreased compared to occurrences reported over a century ago (Markovsky 1953, 1954a, b, 1955; Milaschewitsch 1916; Ostroumov 1898). The latter species became rare in its native NW Black Sea coastal range (Lyashenko et al. 2012; Munasypova-Motyash 2006), but became temporarily abundant (along with *Monodacna colorata*) in Lake Sasyk when the lake was connected with the Danube River, via a canal, in 1978 (Khalaim and Son 2016). Previously, Lake Sasyk hosted marine communities, but after the connection with the Danube River was established, two PC communities became common there, viz. *Dreissena* communities in the shore zones and *Monodacna* communities in deeper parts. *Laevicaspia ismailensis* may have disappeared from lakes Yalpug and Kugurlui (VVA, MOS, PO).

Several causes have been proposed for the decline of PC species and communities in the Danube-Razim region. Eutrophication and conversion of inland lakes were linked by Popa et al. (2009) to the disappearance of lymnocardiine species. Velde et al. (2019) related the breakdown of the salinity gradients in the Razim-Sinoe lake complex, due to rerouting of Danube waters as well as closing Black Sea inlets in the second half of the 20th century, to the collapse of PC communities and disappearance of species. Recently, invasive Corbicula species have been expanding in the Danube Delta area (Pavel et al. 2017) and potential interactions of this successful invasive (Crespo et al. 2015) with PC species is reason for concern.

Dniester Liman

The lower Dniester, comprising the Dniester Delta and Liman as well as the Kuchurgan Liman (Fig. 2.7) and the lower Dniester River up to Dubăsari Dam (Moldova) historically hosts a rich PC fauna with 10 mollusc species (Grinbart 1953a; Markovsky 1953; Son 2007b). The Dniester Liman is about 45 km long, with a surface area of about 400 km2 and maximum depth is 2.7 m. In the 20th century the Liman was subdivided into an inner freshwater-oligohaline zone (up to 0.5 psu), a middle oligohaline zone (up to 4 psu) and an outer mesohaline zone (salinities typically between 4 and 9 psu with episodic lowering during peak floods (Markovsky 1953). Salinity regimes changed due to human interference. A deep-water sea canal has enabled sea water intrusions during storm surges. In the Upper Dniester basin, a system of fish ladders decimated natural flow regimes (Zhulidov et al. 2015). In general, the Lower Dniester basin is characterized by problems of seasonal runoff deficiency and associated degradation of floodplain ecosystems, common to all large PC rivers with cascades of dams (Shevtsova 2000). However, the episodic release of large amounts of fresh water from reservoirs in the feeding rivers causes strong episodic freshening of the inner and middle parts of the Dniester system, thereby sharply steepening the salinity gradient and minimizing optimum salinity areas of PC biota. The Kuchurgan Liman (a part of the Dniester Liman that became cut off by the prograding river delta) was turned into cooling pond for the power station and has thus

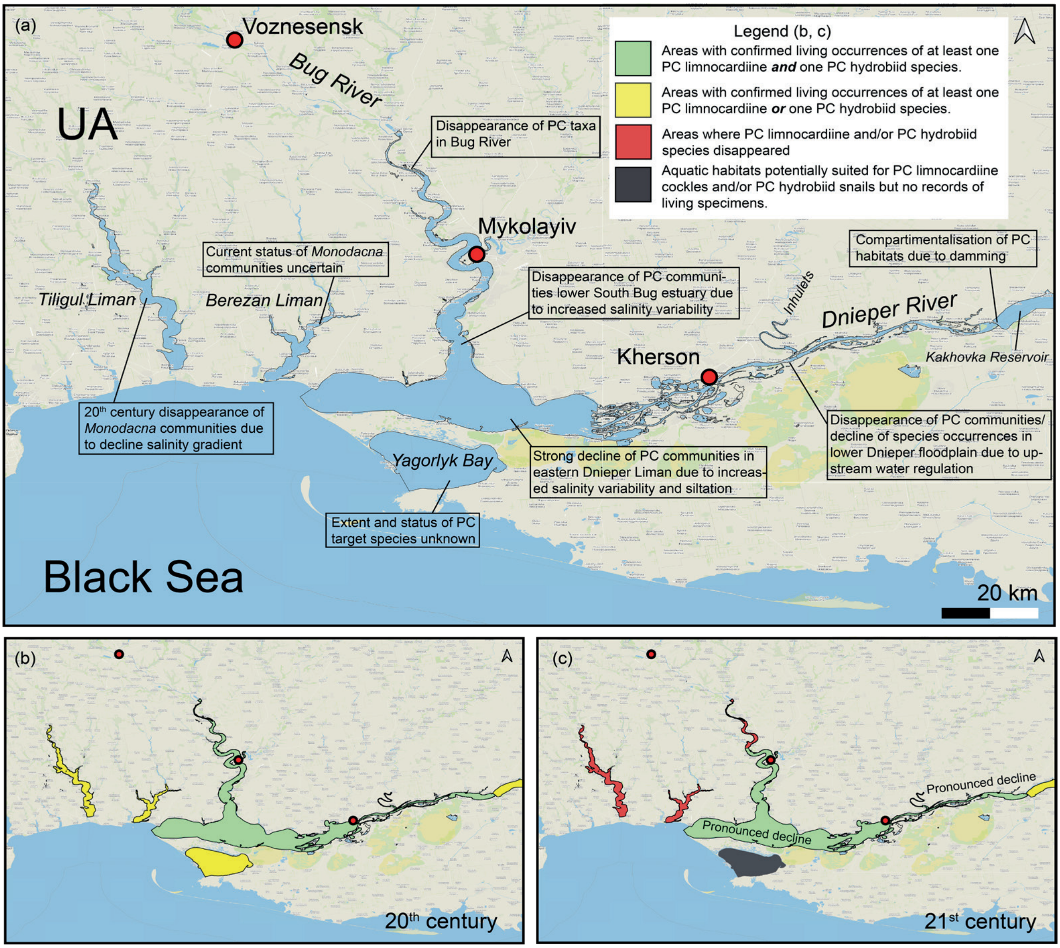


Figure 2.8. PC habitats and trends in the Dnieper-Bug Estuary and adjacent Tiligul and Berezan Limans. (a) Regional overview and major trends, (b) 20th century occurrences, (c) 21st century occurrences. See data in Appendix 2.2, Table A2.2.3, outline of subareas in Fig. A2.2.3. Map is projected in EPSG Projection 4326 - WGS 84.

become impacted by thermal pollution.

The distribution range of PC communities in the Dniester Delta declined in the early 20th century before the start of large-scale anthropogenic modifications, such as construction of dams and canals, and thermal pollution (Grinbart 1953a; Markovsky 1953). According to our observations (MOS, VVA), lymnocardiine and hydrobiid PC species have completely disappeared in floodplain lakes, and among molluscs only the most tolerant *Dreissena* and *Theodoxus* species have survived in river channels. In the past decades, the Dniester Liman communities dominated by *Adacna fragilis* and *Hypanis plicata* have vanished. On species level, *A. fragilis*, *Monodacna colorata* and *Laevicaspia lincta* have very strongly reduced distribution ranges and/or abundances, and

H. plicata and *Clathrocaspia knipowitchii* are possibly extinct in the Dniester area (VVA, PO).

Dam construction has been a major driver for Dniester floodplain ecosystem demise (Shevtsova 2000), which has been further affected by an increase in water extraction, climate change and organic pollution. Increased episodic intrusions of seawater and variability of freshwater inflow from the catchments has severely impacted the salinity gradients. Salinity increase in estuaries under the conditions of climate change and artificial flood-changing constructions is a global trend (Rahel and Olden 2008). In freshwater and oligohaline zones, among numerous alien species, two (the Dnieper-Bug PC species *Dreissena bugensis* and the New Zealand derived Potamopyrgus antipodarum) affected the original PC communities (Son 2007a, 2008). In the lower zone of the Dniester Liman alien species (especially *Mytilopsis leucophaeta*) occupy the vacant niches of PC species, which are not adapted to rapid salinity changes (Zhulidov et al. 2015). These invasive species took advantage of the PC species decline, and have not been demonstrated to drive the decline and disappearance of PC communities.

Tiligul Liman

The Tiligul Liman is an 80 km long estuary that is up to 19 m deep (Fig. 2.8). It was disconnected from the Black Sea in the 18-19th century due to the formation of a coastal barrier, but a canal still provides limited water exchange. In 1960s the liman contained freshwater and brackish mesohaline zones, and salinity increased after canal construction combined with excessive evaporation. The Tiligul Liman drainage consists of steppe rivers that are dry during summer and therefore unsuited for PC species. Historically, Tiligul Liman contained few PC species. The specific ecological community which used to live here was dominated by PC (i.e. *Monodacna colorata*) and marine cardiids (Grinbart 1953b). *Dreissena polymorpha*, *M. colorata* and the *Theodoxus* species that lived in the Liman have disappeared (Moroz et al. 1986; Son 2007b) as a result of a human-driven salinity increase.

Berezan Liman

The Berezan Liman is 26 km long, with a surface area of c 60 km2 and a maximum depth of 26 m, which is connected to the Black Sea by a canal (Fig. 2.8). The liman has many bays that have very different hydrological settings. The Solonets Tuzly Bay became separated and transformed into a hypersaline lake in the 20th century. In several places, dams have been erected to create isolated areas for aquaculture impeding water exchange. Most rivers draining into the Berezan liman are steppe rivers that dry out during summer rendering them unsuitable for PC species with the exception of the lower Berezan River, where *Dreissena polymorpha* occurs (Son 2007b). Salinities within the Berezan Liman historically ranged between about 3–6 psu but was depressed by an influx of low saline waters during peak discharges from the adjacent Dnieper-Bug estuary through a channel connecting the liman to the Black Sea (Grinbart 1955).

Figure 2.9. PC habitats and trends in the Taganrog Bay-Don Delta region. (a) Regional overview and major trends, (b) 20th century occurrences, (c) 21st century occurrences. See data in Appendix 2.2, Table A2.2.4, outline of subareas in Fig. A2.2.4. Map is projected in EPSG Projection 4326 - WGS 84.

In the earlier part of the 20th century Berezan Liman was dominated by *Monodacna colorata*, as well as *Theodoxus* species (Grinbart 1953b), and further contained *Dreissena polymorpha*. In recent times *M. colorata* has disappeared in several visited sites (MOS, PO), but some areas within the estuary have not been explored; other PC species still occur in this liman (Son 2007b).

Dnieper-Bug Estuary

The Dnieper-Bug Estuary contains the South Bug Estuary and Bug River up to Novaya Odessa City, and the Dnieper Liman, Delta and lower Dnieper River up to the Kahovka Dam (Fig. 2.8). The Dnieper Estuary is 55 km long and on the Black Sea side is limited by a constriction at the north end of the Kinburn Spit. To the south side the Yagorlyk Bay may also be included into the Dnieper-Bug complex. The Bug estuary is 47 km long. The Dnieper-Bug estuary has a maximum depth of 22 m. The central areas have mostly silty bottoms and the shore zones are mostly sandy with occasional rocky outcrops. Before the 19th century, the Dnieper-Bug estuary had a salinity gradient similar to the Dniester Liman. Within the outer zone variable salinities occurred with an average 4 psu. However, increased regulation of the river basins and construction of shipping channels resulted in large scale changes of the salinity regimes. Hydropower dam construction in the 1950s restricted freshwater input resulting in strong salinity increase (with freshwater and oligohaline areas badly affected), but also resulted in episodic massive release of fresh water. Afterwards, salinities gradually lowered and the initial gradient more or less returned (Shatova et al. 2009). However, a combination of weak river flow and strong western winds pushes at times mesohaline Black Sea waters through the Bugsko-Dneprovsko-Lymansky Canal upstream to Mykolayiv Port and Kherson Port (Dotsenko and Ivanov 2010). This dramatically changed salinity regimes and increased variability, especially in the narrow Bug Liman.

The Dnieper-Bug Estuary is historically a major centre of PC biodiversity in the Black Sea Basin (Fig. 2.4). A diverse PC fauna containing some local endemic species existed here in the early 20th century (Borcea 1926a, b; Golikov and Starobogatov 1966, 1972; Grossu 1956, 1962; Markovsky 1954a; Milaschewitsch 1916; Mordukhay-Boltovskoy 1960; Scarlato and Starobogatov 1972a). Some PC species, including *Clessiniola variabilis* were recorded in the Yagorlyk bay on the south side of the Dnieper-Bug estuary (Anistratenko 1996) and *Laevicaspia lincta* in the upper Dnieper delta near Kherson (Wilke et al. 2007). The Dnieper Liman has been severely affected by the construction of a cascade of dams along the Dnieper River leading to the severe decline of PC communities. The communities only remained in the eastern part of the Liman adjacent to the delta (Moroz and Alexenko 1983). According to our observations (VVA: 2016-2019), the range of PC communities also decreased in the estuarine part of the southern Bug (Upper South Bug Liman and Lower South Bug River). Communities declined, and some species became very rare or went locally extinct such as *Adacna fragilis*, *Hypanis plicata*, *Turricaspia chersonica*, *Clathrocaspia knipowitchii*.

Since the construction of the cascade of reservoirs on the Dnieper River in the 1930–1970s, the water flow rate decreased markedly and the accumulation of silt increased. Algal blooms have become more frequent in the reservoirs and estuaries of the Dnieper, bottom oxygen content decreased and lead to local anoxic conditions (Romanenko 1987; Zakonnov et al. 2019). Together with progressive siltation at the bottom of reservoirs, the area of hard substrates, on which *Dreissena* associations and communities of higher aquatic vegetation can occur, was reduced too (e.g. Alexenko and Shevchenko 2016). This resulted in a gradual but widespread reduction of habitats suitable for PC gastropod species such as Clathrocaspia species that rely on dreissenid bivalves to deposit their eggs (Alexenko and Kucheryava 2019; Alexenko and Shevchenko 2016).

Taganrog Bay – Don Delta

The Taganrog Bay, adjacent Mius and Yevsk Limans and Don River Delta (Fig. 2.9) form the main PC biodiversity hotspot in the NE Black Sea Basin with a rich fauna and different types of PC-dominated communities (Mordukhay-Boltovskoy 1960). Taganrog Bay is a large (5600 km2) and shallow (0–2 m depth in the eastern part, down to 9–10 m in the west) bay (Ecological Atlas 2019; Zhidkova et al. 2018). It hosts a major salinity gradient from mostly freshwater at its eastern end, to 8–15 psu at the western end. PC communities flourish in fresh water to lower mesohaline settings (0–5 psu) in areas with occasional influx of salinities up to 8 psu. The bay floor is mostly silty in the central areas and sandy in the margins and shell accumulations are common. Near large ports (Taganrog, Mariupol, Yeysk), black jelly-like anthropogenic sediments with high concentrations of petrochemicals and other pollutants occur (Bespalov 2005). The upper sediment layer in the bay is commonly disturbed by storm waves. Wind is a major factor determining water circulation and therefore, salinity distribution in the bay (Matishov and Grigorenko 2017). Strong western storms can push mesohaline waters to the eastern end of the bay and even occasionally flood the adjacent Don Delta with 4-5 psu waters (Matishov and Grigorenko 2017). Other drivers affecting the salinity gradient in the bay are the river flow volume and Black Sea water advections (Matishov and Grigorenko 2017). Two large limans adjoin the bay approximately in its middle. The Mius Liman (33-40 km long and only 1 m deep: Vishnevetskiy and Popruzhniy 2018) to the north is a drowned estuary with average salinities between 0.9-1.8 psu (Kreneva et al. 2013). The Yeysk Liman to the south is an open estuary with hydrological conditions similar to the adjacent Taganrog Bay. Benthic fauna is different here due to small nature of this water body (Nabozhenko and Kovalenko 2011). The Don is a regulated river with a mostly sandy bottom. It has some very deep pits (down to 22 m deep) where PC biota occur, but to date no PC molluscs have been mentioned.

The Inner Taganrog Bay hosts *Dreissena* and *Monodacna* communities. *Adacna fragilis* is also common. In the outer delta areas, a rich PC fauna of 11 species occurred until recently together with freshwater species, e.g. unionid mussels, planorbid snails and Lithoglyphus naticoides. The outer delta-bay transitional zone hosts the only known occurrences of the extremely rare *Clathrocaspia logvinenkoi* (Anistratenko 2007b). Historically PC species were common in the Taganrog Bay and the outer Don River Delta. In early 2000, communities were changing (Shokhin et al. 2006) but later works showed the persistence of, slightly altered but nevertheless diverse, *Monodacna colorata* communities in the inner and central bay area (Nabozhenko 2008) and the Yeysk Liman (Nabozhenko and Kovalenko 2011).

Until recently, Taganrog Bay remained relatively unaffected by invasive species. However, the introduction of three exotic polychaete species in 2013–2015 resulted in considerable changes in the bottom communities of the Taganrog Bay and the Don Delta by 2017–2018 (Bick et al. 2018;

Syomin et al. 2017). Within a few years after introduction, the alien polychaete Marenzelleria neglecta became dominant in PC habitats in the eastern part of the Taganrog Bay. However, its sharp increase so far was not accompanied by considerable shifts in *Monodacna* abundance or species structure of corresponding communities. Corbicula cf. fluminea, which was first found in the Don River in 2017 (Zhivoglyadova et al. 2018), is considered one of the most aggressive invasive species tending to lead to negative environmental consequences (Bespalaya et al. 2018; Crespo et al. 2015) and can therefore be potentially hazardous exotic species for PC molluscs in the fresh and oligohaline zones. Recently, the brackish water mussel Mytilopsis leucophaeta was reported from the inner Taganrog Bay (Zhulidov et al. 2015), which, if capable to survive low winter temperatures, can disrupt PC habitats similar as in the Dniester Liman.

The Taganrog Bay and the Don River are located in a densely populated area with intensive shipping, agricultural and industrial activity. Dredging and dumping are common in the eastern Taganrog Bay, where artificial fairways subject to permanent siltation are present. Continuous dredging also occurs in the Don River, especially in the delta. The Lower Don and the Taganrog Bay waters are strongly eutrophicated due to the sewage discharge and terrigenous nutrients from agricultural fertilizers (Matishov 2005; Moses et al. 2012). Large industrial ports – Taganrog and Mariupol – are sources of local toxic contamination as well. A considerable threat is the Bagayevskiy waterworks facility which is planned to be put into operation in 2023 (http://bguzel.ru/). According to preliminary estimates, it will lead to wide-scale changes in the Lower Don ecosystem (Dubinina and Zhukova 2016; Krivoshey 2016).

SE Azov Sea coast

The area includes the coastal zone of the Temryuk Bay northwards to Primorsko-Akhtarsk, and the estuaries and channels of the Kuban Delta. The marine part has typical features of the southern Sea of Azov, with mesohaline conditions and faunas, sandy beaches and silty and shelly sediments at depths over 2 m (Simonov and Altman 1991). The estuaries and channels of the Kuban Delta contain waters from fresh-lower mesohaline, and are mostly shallow (average depth within 0.5-1.8 m), with various bottom sediments (e.g. silt, shells and sand) (Nagalevsky and Nagalevsky 2013). Little recent information is available on the PC species occurrences from the area. *Monodacna colorata* was recorded in environmental impact assessments for oil exploration from the Kurchanskiy, Konovalovskiy, Kulikovskiy and Polyakov Limans (Korpakova et al. 2007) and the Temryuk Bay itself (Korpakova et al. 2008). Also, *Dreissena polymorpha* communities with relatively high biomass of the dominant species were mentioned across the area (Korpakova et al. 2010). No recent records of PC hydrobiid species are known from the region, even though their general presence in the area was reported by Golikov and Starobogatov (1972).

As the PC species occurrences are poorly known, we have no insights into their trends, but the area is subject to severe anthropogenic modifications. These include invasive species (Syomin et al. 2020), oil/gas exploration and production in Temryuk Bay whose infrastructure caused considerable habitat damage (Nagalevsky and Lobko 2017), and the shallowing and siltation in the estuaries of the Kuban Delta area resulting from hydraulic engineering and pollution by the drainage waters from the rice fields released into the water system. Some limans have been transformed in aquaculture ponds losing PC habitats.

Tsimlyansk Reservoir

A recent expansion of *Monodacna colorata* and *Adacna vitrea glabra* upstream into the Tsimlyansk Reservoir in the Don River has been documented by Son et al. (2020). The latter species was imported by ship traffic from the Caspian Sea through the Volga-Don Canal. *Monodacna colorata* expanded from Taganrog Bay and has now moved through the Volga-Don Canal upstream in the Volga River (AFS and MVV, PO 2017). Species-rich *Dreissena* communities with high biomass containing PC crustaceans, bryozoans, polychaetes and hydrozoans are common on hard and sandy substrata in the reservoir (Bulysheva et al. 2019).

2.3.2 Threats

Five direct threats have been shown or postulated to drive the decline of PC communities and species (for references see below). These are a) damming of rivers, b) modification of marine and freshwater influx in coastal areas, c) invasive alien species, d) pollution/eutrophication and e) climate change.

Damming of rivers

Damming of rivers (IUCN threat category 7.2 Dams & water management/use) is common in almost all major PC rivers. The construction of dams and large-scale water irrigation systems resulted in modifications of river flow regimes that affected PC species and communities (Lyashenko et al. 2012; Semenchenko et al. 2015; Son 2007b). Many PC species are sensitive to oxygen availability and river flow regimes (Mordukhay-Boltovskoy 1960). The newly built structures, such as cascades at reservoir dams, and cement-lined canals and riverbanks, provided new habitats for some *Theodoxus*/*Dreissena* species (Semenchenko et al. 2016; Semenchenko et al. 2015; Son 2007b). At the same time, soft-bottom or vagile species that are dependent on intermittent flow regimes (e.g. hydrobiids) declined with the newly erected barriers (Son 2007a). In river networks, the damming resulted in compartmentalisation and disappearance of small river basins and the degradation of floodplains and deltas of larger rivers. Within the estuaries damming led to isolation, local salinization resulting in reduction of prime PC habitat. Silt accumulation and loss of hard substrate and vegetation as a result of restricted river flow by damming has created adverse conditions for PC communities in the Dnieper River (Romanenko 1987; Zakonnov et al. 2019) resulting in declining habitat area (Alexenko and Kucheryava 2019; Alexenko and Shevchenko 2016). Such deterioration also applies to other rivers of the NW Black Sea region (South Bug, Dniester), as well as the lower Don River and Taganrog Bay (Anistratenko et al. 2011; Shokhin et al. 2006). Siltation should be considered as an important, perhaps even a key factor triggering habitat reduction threatening PC biota.

The modification of marine and freshwater influx in coastal areas

Modification of marine and freshwater influx in coastal areas (IUCN threat category 7.3 Other ecosystem modifications) affects natural salinity regimes and gradients that sustain(ed) PC species and communities in the coastal zone. It concerns (a) restriction of Black Sea water input through coastal barrier erection and closing of inlets, (b) increasing freshwater influx through diversion canals from adjacent rivers, (c) increased river discharge variability as a result of upstream water withdrawal and episodic release (worsened by increased summer droughts and peak flooding) and (d) increased marine influx through the construction and dredging of shipping lanes and breaching of coastal barriers. Each region contains a specific combination of factors affecting salinity gradients and regimes that sustain PC species and communities, but overall, the variability has strongly increased. In many of the PC areas, (episodic) influx of mesohaline Black Sea waters increased as a result of canal and shipping lane construction and dredging. Especially deep-water shipping canals that require regular dredging, resulted in massive seawater intrusion into estuaries and river deltas during storm surges causing rapid salinity fluctuations. The impact may be magnified due to large-scale water withdrawal upstream from these estuaries and river deltas. In several regions, breaching of sand barriers and spits resulted in a strong salinity increase and break down of the pre-existing stable gradients (Mikhailov and Gorin 2012). Other estuaries and bays have become isolated hypersaline lakes as a result of their separation from the major limans either by natural or by man-made interventions (Vinogradov et al. 2014). These hypersaline lakes (including the entire Tiligul Liman) are hostile to PC species. The break-down of salinity gradients in Danube coastal lake systems due to closing of Black Sea inlets and river diversion has been a major factor driving the demise of PC species and communities there (Son 2007b; Velde et al. 2019). PC species in the non-tidal Black Sea basin estuaries live in a wide salinity gradient but often occur in the relatively constant salinity regimes of the bottom water layers (Khlebovich 1974). Populations of PC species have local acclimatization optima and are negatively affected by rapid salinity fluctuations even when occurring within the limits of their autecological tolerance (Orlova 1987; Orlova et al. 1998; Zhulidov et al. 2018). Increasing salinity variability is especially beneficial to generalist alien and native species (Shiganova 2011; Zhulidov et al. 2018).

Invasive alien species

Invasive species (IUCN threat category 8.1 Invasive non-native/alien species/diseases) are an ongoing concern for PC biota and (Alexandrov et al. 2007; Bij de Vaate et al. 2002; Son 2007a). PC communities have been replaced by communities dominated by invasive *Mytilopsis leucophaeata, Potamopyrgus antipodarum*, *Rhithropanopeus harrisii* and other euryhaline species (Son 2008; Son et al. 2013; Zhulidov et al. 2018) in the outer part of the Dniester Liman and upper Bug-Ingul estuarine zone in areas previously inhabited by *Clessiniola*, limnocardiine and other PC species. Community turnover can be very rapid, as shown by Syomin et al. (2017) for the Taganrog Bay. In some of the lower estuaries, increased salinity has resulted in the replacement of PC communities by marine communities deriving from the Black Sea (Zhulidov et al. 2018). These marine communities are heavily affected by three invasive mollusc species, especially in the NW Black Sea: Mya arenaria, Rapana venosa and *Anadara* sp. (see for taxonomy discussion of the latter Anistratenko et al. (2014); Anistratenko and Khaliman (2006); Krapal et al. (2015)). In areas with strong freshening, such as the Razim-Sinoe system, freshwater mollusc species including non-native bivalves (*Sinanodonta woodiana*, *Corbicula fluminea*) and viviparids expanded at the cost of PC species (Popa and Murariu 2009; Velde et al. 2019). Some PC species have become invasive themselves. The Quagga mussel *Dreissena bugensis*, expanded in the second half of the 20th century from its native NW BSB range into all PC habitats, but also into all major western-central European inland water systems and even North America (Lyashenko et al. 2012; Son 2007a, b). The BSB species *Monodacna colorata* has recently been introduced into the Volga and Caspian basins as well as Lake Balkash (Kazakhstan) (Son et al. 2020; Wesselingh et al. 2019). A native Caspian subspecies, *Adacna vitrea glabra* recently expanded into the Don River drainage and has a large impact on local benthic species and communities (Son et al. 2020). Increased shipping activity between the Volga and Don river systems increase the introduction risk of Caspian PC species in the BSB.

Pollution and eutrophication

Pollution and eutrophication (IUCN threat categories 9.3.1 Nutrient loads, 9.3.3 Herbicides & pesticides, 9.6.2 Thermal pollution) are rampant throughout the region, resulting from large-scale industrial and agricultural activities in the PC river basins (Lyashenko et al. 2012; Semenchenko et al. 2015). Organic pollution and eutrophication negatively affect PC communities and species that are sensitive to oxygen regimes (Mordukhay-Boltovskoy 1960; Popa et al. 2009). Thermal pollution is a local threat to Kuchurgan Estuary and the lower Dnieper River by simultaneously affecting the PC species communities and creating preferable conditions for alien species (Protasov et al. 2013; Son 2007a; Son et al. 2013). Eutrophication has been proposed as a driver for the demise of lymnocardiine species in many lakes in the Danube Delta area (Popa et al. 2009) and also appears to negatively affect communities in Lake Sasyk at the northern end of the Danube Delta, yet pollution levels in the Razim-Sinoe system were found to be low (Catianis et al. 2018).

Climate change

Direct impact of climate change (IUCN threat categories 11.1 Habitat shifting & alteration, 11.2 Droughts, 11.4 Storms & flooding) on PC communities and habitats has been demonstrated in the BSB. In the Taganrog Bay, influx of mesohaline Black Sea waters increased as a result of shortage of freshwater flow due to insufficient river flow regulation at the background of climate change (Matishov et al. 2017). Increased summer droughts as well as peak flooding is making inflowing river discharge more unpredictable and during prolonged summers rivers may even cease to deliver fresh water to the PC habitats. This is already affecting areas within the Dniester and Dnieper regions and the Tiligul and Berezan Limans. Projected climate change with higher temperatures, increased periodic drought as well as very high peak discharge in the catchments can be expected to further increase the instability of PC habitats. Additionally, projected sea level rise will affect coastal lagoons and estuaries (Velde et al. 2019).

2.4 Discussion – towards effective conservation of PC biota in the BSB

The combined evidence of this review paper indicates a decline of PC mollusc species and their communities throughout the BSB. However, while the decline seems evident, its ecological consequences are not. It is largely unknown to what extent the species associated with the PC taxa (e.g. their parasites or predators) may be affected by their demise. The decline in abundance and apparent fragmentation (and isolation) of populations is a problem in itself, but may drive genetic depletion, which should also be another reason for concern. Data on genetic diversity of PC species in the BSB is scarce, and little understanding exists on patterns and processes of gene flow between populations, even though it may be an important determinant of PC biodiversity maintenance (Audzijonyte et al. 2017; Audzijonyte et al. 2006).

The first step towards effective conservation is improving a) scientific knowledge on PC biodiversity at community, species and genetic levels, and b) understanding population and community dynamics as well as species distributions and their ecological tolerances (Cardoso et al. 2011). Recurring and standardised collection and observation efforts are paramount as a basis for establishing trends. These efforts shall be cross-country collaborative efforts given the transnational character of the PC species and habitats. Furthermore, an improved taxonomical base from integrated morphological-genetic studies is required, whenever the limited amount of living specimens allow for such approaches. Such studies should extend beyond mollusc species and include other groups of PC invertebrate and vertebrate taxa. For many important PC invertebrate groups (such as copepods, amphipods, decapods) no up-to-date taxonomic overview exists (Table 2.2) and they contain disputed species. Historical distribution data are often imprecise and also hampered by uncertainty in identifications (see Appendix 2.1). Updated taxonomy will enable targeted research into autecological tolerances and species responses to disturbances. Furthermore, the extinction risk of species should be updated through IUCN assessments, as many of the taxa concerned are currently data deficient to perform such analyses (e.g. see Wesselingh et al. 2019). New data on PC populations, species and communities will enable a more inclusive and comprehensive definition of PC habitats and their inclusion in conservation schemes.

Secondly, our proposed optimum PC habitats shall be validated using the quantitative data on up-to-date PC population sizes, and standardised threat analyses shall be performed such as conducted by Lattuada et al. (2019) for the Caspian Sea, and Birstein et al. (2006), and Vassilev (2006) for sturgeon habitats. Threat analyses should focus on four PC regions in the BSB (Danube

Table 2.2. Approximate species richness for various invertebrate PC groups in the BSB.

PC group	Number of species	Author
Cnidaria	2-4 spp.	(Mordukhay-Boltovskoy, 1960)
Crustacea – Amphipoda	40-45 spp.	(Mordukhay-Boltovskoy, 1960)
Crustacea – Copepoda	12 spp.	(Monchenko, 2003)
Crustacea – Cumacea	11 spp.	(Mordukhay-Boltovskoy, 1960)
Crustacea – Decapoda	2 spp.	(Policar et al., 2018)
Crustacea – Mysidae	9 spp.	(Audzijonyte, Daneliya, Mugue, & Väinölä, 2008)
Hyrudinea	1 sp.	(Mordukhay-Boltovskoy, 1960)
Mollusca – Bivalvia	6 spp.	This work
Mollusca – Gastropoda	10 spp.	This work
Polychaeta	3 spp.	(Kiseleva, 2004)

Delta – Razim Lake system, Dniester Liman, Dnieper-South Bug Estuary and Taganrog Bay-Don Delta) that contain target species and environmental conditions which can, and in cases do support the survival of PC communities (Table 2.1, Fig. 2.2). Quantitative knowledge on population sizes of PC species is lacking both for molluscs and other groups. Especially, crustaceans contain large numbers of PC species (Table 2.2), and their inclusion would greatly improve the definition of optimum PC habitats. Our proposed optimum PC habitats are therefore indicative for the moment.

The final step should be assessing some of the indirect anthropogenic drivers of PC biodiversity change that are causing the identified direct drivers of decline, such as institutional arrangements and legal landscape, following the IPBES Conceptual Framework (Díaz et al. 2015). Institutional alignment and responsibilities to address PC biodiversity conservation and governance has been studied by Gogaladze et al. (2020a); Gogaladze et al. (2020b), which showed that this biota is not a priority for conservation planning in Ukraine and Romania. Future studies are required to understand legal arrangements of countries sharing the PC biodiversity and their outcomes for conservation. Currently, some parts of optimum PC habitats are covered by national and/or large transnational protected areas such as the Danube Delta Biosphere Reserve shared by Ukraine and Romania. Other parts are covered by Emerald sites (https://emerald.eea.europa.eu/), Natura 2000 sites (https://Natura2000.eea.europa.eu/) and/or by Ramsar sites (https://www.protectedplanet.net/166893). Coverage of optimum PC habitats by protected areas may provide (incidental) protection to PC communities and species, but has not resulted in targeted conservation to date. Assignment of optimum PC habitats to IUCN category IV: Habitats/species management area (Dudley 2008) can be a useful approach. The IUCN protected area management categories provide a global framework for sorting the variety of protected area management aims. Category IV aims to "maintain, conserve and restore species and habitats" (https://www.iucn.org/theme/protected-areas/about/protected-areas-categories/category-iv-habitatspecies-management-area). Such categorization can take place in different phases of establishing a protected area, such as the initial phase: before the protected area is established and category has to be decided, or in later phase: after the protected area has already been established and category decided, but management aim is to address emerging conservation priorities (Dudley 2008). Managing and mitigating the wholesale decline of the unique PC biota in the BSB will require longstanding commitment from various stakeholders in the specific PC countries.

2.5 Conclusions

PC mollusc species and communities in the Black Sea Basin have suffered a severe decline over the past century. Five major drivers for the decline are identified. However, basic distribution data and integrated approaches to mitigate the decline are lacking. Some species have gone extinct and several others are under increased risk of extinction and entire communities have vanished as well. The identification of optimum PC habitats will enable targeted conservation action. Sustained, transnational collaboration is required to improve conservation of PC species, communities and their habitats in the BSB. Only then can the effective conservation of the unique and threatened PC biota be achieved in the Black Sea Basin.

Acknowledgments

This paper resulted from the PRIDE program that received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement number 642973. Vitaliy V Anistratenko and Olga Yu Anistratenko were supported by the German Research Foundation (DFG, grant no. WI1902/16). Vitaly L Syomin was supported by the state assignment of IO RAS, theme No. 0149-2019-0014. Finally, we acknowledge Prof. Dr. Frank Riedel from Freie Universität Berlin for sharing relevant observations with us.

Data accessibility statement

All data that support the findings of this study are provided in supplementary files. PC habitat polygon shapefiles as well as the attributes describing historical (20th century) and modern (21st century) distributions of PC target taxa are available at https://figshare.com/s/5400c1df29da026c399f (private link).

Appendices

Appendix 2.1 - Update on the taxonomic status of BSB Pontocaspian mollusc species

Appendix 2.2 - Pontocaspian species occurrences in the BSB in 20th and 21st centuries

Appendix 2.3 - Pontocaspian habitat polygon shapefiles

Appendix 2.1. Update on the taxonomic status of BSB Pontocaspian mollusc species

The Pontocaspian mollusc species list (Wesselingh et al. 2019) listed and discussed species whose status at the time were agreed upon ("accepted") by the various authors, and species whose status was considered to be uncertain, based on a review of existing data. Currently several taxonomic studies have been completed or are under way that will provide further clarification. Here a brief summary of the taxonomy of the BSB PC mollusc species is given.

Neritidae – The recent revision of *Theodoxus* species (Sands et al. 2020) clarified the species delimitation of this genus and showed the presence of four *Theodoxus* species in the BSB (*T. danubialis*, *T. fluviatilis*, *T. velox* and *T. major*, the latter listed as *T. pallasi* in Wesselingh et al. (2019)). However, they also showed that discrimination based on shell morphology is not always sufficient and that some historical records should be re-evaluated. Especially, the confirmation of *T. major* and *T. velox* occurrences in the BSB can be expected to change with further study.

Hydrobiidae – The taxonomic status of PC hydrobiid snails is subject of a number of ongoing studies that will lead to further clarification for species boundaries (e.g. Anistratenko/Neubauer et al. in prep.). A molecular study on the identity of BSB *Clathrocaspia* species is currently under way to assess the status and potential synonymy of four species listed by Wesselingh et al. (2019) (TW & VVA, pers. comm.). The status of two of the smooth PC hydrobiid species listed from the BSB by Wesselingh et al. (2019) (?*Laevicaspia ismailensis* (accepted) and *Turricaspia chersonica* (uncertain)) requires further study involving molecular analyses and study of type material to assess possible conspecifity and establish the generic assignemnt (VVA, pers. comm.). The status of *Laevicaspia lincta* and *Clessiniola variabilis* is undisputed.

Cardiidae – After Wesselingh et al. (2019) published the PC species list, further material of BSB *Adacna fragilis* has been inspected in order to assess its status (listed as uncertain in the publication). The range of morphological variation of the BSB material (especially the almost equilateral shell, the pallial sinus not extending the vertical midline, the more pronounced and well demarcated ribs, especially on the median part of the shell, and the smaller adult size) as well as the salinity preferences differ from the resembling Caspian *Adacna laeviuscula* and merits a separation of the two species. There is full agreement to change the status of *Adacna fragilis* to accepted species among the authors. The species *Adacna glabra* reported by Son et al. (2020) from the Don River was considered as an uncertain status subspecies of *Adacna vitrea* by Wesselingh et al. (2019), who argued for molecular confirmation. However, a review of the distribution range, ecological tolerance and shell characters shows that it is likely that *A. glabra* is closely related to, but at the same time distinct from *A. vitrea*. *Adacna glabra* differs by having somewhat stronger developed ribs with a rather pointed rib crest and the often whitish colour of the shell. We adopt for the moment the distinction proposed by Kijashko (Kijashko in Bogutskaya et al. (2013)) and consider *A. vitrea* vitrea and *A. vitrea glabra* as subspecies whose status will need molecular corroboration.

Dreissenidae – The taxonomy and status of the two BSB dreissenid species (*Dreissena polymorpha* and *D. bugensis*) is undisputed.

Appendix 2.2. Pontocaspian species occurrences in the BSB in 20th and 21st centuries.

Table A2.2.1. Sub-areas within the Danube-Razim and Bulgarian coastal wetlands. ID numbers of the sub-areas are used in Figures A2.2.1-4 for display (see below). + indicates the presence and – the absence of the relevant PC mollusc target taxa in 20th and 21st centuries. C stands for century. PO stands for personal observation. PC habitat map of the Danube Delta region (Fig. 2.6 in the manuscript) and the Danube Delta shapefile (Appendix 2.3) are based on the data in this table.

Country	ID	Sub-area	PC Cardiidae 20th C	PC Hydrobiidae 20th C	PC Cardiidae 21st C	PC Hydrobiidae 21st C	Remarks
UA	1	Lake Kagul	+ Markovsky (1955)	+ Markovsky (1955)	+ Dzhurtubaev et al. (2017); Munasypova-Motyash (2006)	- Dzhurtubaev et al. (2017)	
UA	2	Northern floodplain lakes west of Izmail	- Markovsky (1955)	- Markovsky (1955)	- MOS (PO)	- MOS (PO)	PC taxa (*Dreissena*, *Theodoxus*) present
UA	3	Lake Yalpug	+ Markovsky (1955); VVA (PO)	+ Markovsky (1955); VVA (PO)	+ Munasypova-Motyash (2006); MOS, VVA (PO)	+ MOS (PO)	
UA	4	Lake Kugurlui	+ Markovsky (1955)	+ Markovsky (1955)	+ Dzhurtubaev et al. (2018)	- Dzhurtubaev et al. (2018)	
UA	5	Lake Katlabukh	+ Markovsky (1955)	+ Markovsky (1955)	+ MOS (PO)	- MOS (PO)	
UA	6	Lake Kitai	+ Markovsky (1955)	- Markovsky (1955)	- MOS (PO)	- MOS (PO)	
UA	7	Lake Sasyk	+ Markovsky (1955)	+ Markovsky (1955)	+ Khalaim and Son (2016); Munasypova-Motyash (2006); MOS, VVA (PO)		Limnocardiid invasion end 20th
UA	8	Northern floodplain lakes east of Izmail	- Markovsky (1955)	- Markovsky (1955)	- MOS (PO)	- MOS (PO)	PC taxa (*Dreissena*, *Theodoxus*) present
ROU, BG	9	Upstream Danube River, Brailla-Gura Vai section	- Ignat et al. (1997), Vădineanu et al. (2000)	- Ignat et al. (1997), Vădineanu et al. (2000); + Likely present (dead shells) Russev (1966)	- ABP (PO), ICPDR (2008, 2015); Stoica et al. (2014); Stoica et al. (2012); Stoica et al. (2013)	+ Boeters et al. (2015); ICPDR (2008, 2015); Stoica et al. (2014); Stoica et al. (2012); Stoica et al. (2013); - ABP (PO)	PC taxa Romania: (*Dreissena*, *Theodoxus*) present (Angelov 2000; Drensky 1947; Russev 1966; Wohlberedt 1911); TT (2012-2019, PO); ABP (PO)
ROU	10	Danube River, Braila-Tulcea section	+ Popa et al. (2009)	- Markovsky (1955); Ignat et al. (1997); Vădineanu et al. (2000)	- Popa et al. (2009); ABP (PO); ICPDR (2008, 2015); Stoica et al. (2014); Stoica et al. (2012); Stoica et al. (2013)	- ABP (PO), ICPDR (2008, 2015); Stoica et al. (2014); Stoica et al. (2012); Stoica et al. (2013)	PC taxa (*Dreissena*, *Theodoxus*) present ABP (PO)
ROU, UA	11	Chilia branch and outer delta lakes, upstream from Vilkovo	+ Markovsky (1955)	- Markovsky (1955), - Ignat et al. (1997); Vădineanu et al. (2000)	- ABP (PO), ICPDR (2008, 2015); Stoica et al. (2014); Stoica et al. (2012); Stoica et al. (2013)	- ABP (PO), ICPDR (2008, 2015); Stoica et al. (2014); Stoica et al. (2012); Stoica et al. (2013)	PC taxa (*Dreissena*, *Theodoxus*) present ABP (PO)

(Continuation Table A2.2.1.)

Country	ID	Sub-area	PC Cardiidae 20th C	PC Hydrobiidae 20th C	PC Cardiidae 21st C	PC Hydrobiidae 21st C	Remarks
ROU, UA	12	Chilia branch and outer delta lakes downstream from Vilkovo	+ Markovsky (1955)	+ Markovsky (1955)	+ MOS (PO)	- MOS (PO)	PC taxa (*Dreissena*, *Theodoxus*) present ABP (PO)
ROU	13	Sulina branch of Danube River	+ Likely present (dead shells) ABP (PO)	- Ignat et al. (1997); Vădineanu et al. (2000)	- ABP (PO); ICPDR (2008, 2015); Stoica et al. (2014); Stoica et al. (2012); Stoica et al. (2013)	- ABP (PO), ICPDR (2008, 2015); Stoica et al. (2014); Stoica et al. (2012); Stoica et al. (2013)	PC taxa (*Dreissena*, *Theodoxus*) present ABP (PO)
ROU	14	Sf. Gheorghe branch of Danube River	+ Popa et al. (2009)	- Ignat et al. (1997); Vădineanu et al. (2000)	- Popa et al. (2009); ICPDR (2008, 2015); Stoica et al. (2014); Stoica et al. (2012); Stoica et al. (2013), ABP (PO)	- ICPDR (2008, 2015); Stoica et al. (2014); Stoica et al. (2012); Stoica et al. (2013), ABP (PO)	PC taxa (*Dreissena*, *Theodoxus*) present ABP (PO)
ROU	15	Lake Brates	+ Popa et al. (2009)	Data deficient	- Popa et al. (2009)	Data deficient	
ROU	16	Lake Jijila	+ Popa et al. (2009)	Data deficient	- Popa et al. (2009)	Data deficient	
ROU	17	Lake Crapina	+ Popa et al. (2009)	Data deficient	- Popa et al. (2009	Data deficient	
ROU	18	Floodplain lakes between Chilia and Sulina branches	- Ignat et al. (1997); Vădineanu et al. (2000)	- Ignat et al. (1997); Vădineanu et al. (2000)	- ABP (PO), ICPDR (2008, 2015); Stoica et al. (2014); Stoica et al. (2012); Stoica et al. (2013)	- ABP (PO) 2015, Stoica et al. (2014); Stoica et al. (2012); Stoica et al. (2013)	PC taxa (*Dreissena*, *Theodoxus*) present
ROU	19	Floodplain lakes between Sulina and Sf. Gheorghe branches	- Ignat et al. (1997); Vădineanu et al. (2000)	- Ignat et al. (1997); Vădineanu et al. (2000)	- ABP (PO), ICPDR (2008, 2015); Stoica et al. (2014); Stoica et al. (2012); Stoica et al. (2013)	- ABP (PO), ICPDR (2008, 2015); Stoica et al. (2014); Stoica et al. (2012); Stoica et al. (2013)	PC taxa (*Dreissena*, *Theodoxus*) present ABP (PO)
ROU	20	Lake Puiu	+ Popa et al. (2009)	- ABP (PO)	- Popa et al. (2009)	- ABP (PO)	
ROU	21	Floodplain lakes south to Sf. Gheorghe branch	- Ignat et al. (1997); Vădineanu et al. (2000)	- Ignat et al. (1997); Vădineanu et al. (2000)	- ABP (PO), ICPDR (2008, 2015); Stoica et al. (2014); Stoica et al. (2012); Stoica et al. (2013)	- ABP (PO), ICPDR (2008, 2015); Stoica et al. (2014); Stoica et al. (2012); Stoica et al. (2013)	PC taxa (*Dreissena*, *Theodoxus*) present ABP (PO)

(Continuation Table A2.2.1.)

Country	**ID**	**Sub-area**	PC Cardiidae 20th C	**PC Hydrobiidae 20th C**	**PC Cardiidae 21st C**	**PC Hydrobiidae 21st C**	**Remarks**
ROU	22	Lake Murighiol	+ Popa et al. (2009)	- ABP (PO)	- Popa et al. (2009)	- ABP (PO)	
ROU	23	Lake Dranov	+ Popa et al. (2009)	- ABP (PO)	- Popa et al. (2009)	- ABP (PO)	
ROU	24	Sakhalin area	- Gomoiu and Skolka (1996); Gomoiu and Skolka (1998)	- Gomoiu and Skolka (1996); Gomoiu and Skolka (1998)	- Pavel et al. (2019)	- Pavel et al. (2019)	
ROU	25	Musura Bay	- Gomoiu and Skolka (1996); Gomoiu and Skolka (1998)	- Gomoiu and Skolka (1996); Gomoiu and Skolka (1998)	- Pavel et al. (2019)	- Pavel et al. (2019)	PC taxa (*Dreissena*, *Theodoxus*) present Pavel et al., 2019
ROU	26	Lake Razim-Golovita	+ Popa et al. (2009); Teodorescu-Leonte et al. (1956); Teodorescu-Leonte (1966); Teodorescu-Leonte and Leonte (1969); Teodorescu-Leonte (1977).	- Grossu (1986); + Velde et al. (2019)	+ Popa et al. (2009), + ABP (PO); Paraschiv et al. (2010a); Paraschiv et al. (2010b); Velde et al. (2019)	+ Wilke et al. 2007; - ABP (PO)	PC taxa (*Dreissena*, *Theodoxus*) present ABP, FPW (PO); PC hydrobiids have only been reported once in 21th century (2003; Wilke et al. 2007) and not found in later years
ROU	27	Lake Sinoe	-+ Popa et al. (2009); Teodorescu-Leonte et al. (1956); Teodorescu-Leonte (1966); Teodorescu-Leonte and Leonte (1969); Teodorescu-Leonte (1977).	- Velde et al. (2019)	+ Popa et al. (2009), + ABP (PO); Paraschiv et al. (2010a); Paraschiv et al. (2010b)	- ABP (PO)	
ROU	28	Lake Babadag	+ Popa et al (2009)	Data deficient	- Popa et al. (2009), - ABP (PO)	- ABP (PO)	
ROU	29	Lake Leahova	+ Popa et al (2009)	Data deficient	- Popa et al. (2009), - ABP (PO)	- ABP (PO)	
ROU	30	Coastal lakes near Sinoe	Data deficient	Data deficient	Data deficient	Data deficient	
BG	NA	Lake Durankulak	- Angelov (2000); Kovachev et al. (1999)	- Angelov (2000); Kovachev et al. (1999)	- Hubenov (2015); Vidinova et al. (2016)	- Hubenov (2015); Vidinova et al. (2016)	PC taxa (*Dreissena*, *Theodoxus*) present (Angelov 2000; Kovachev et al. 1999); TT (2010, 2014, PO)
BG	NA	Lake Shabla-Ezerets	- Angelov (2000); Kovachev et al. (1999)	- Angelov (2000); Kovachev et al. (1999)	- Hubenov (2015); Vidinova et al. (2016)	- Hubenov (2015); Vidinova et al. (2016)	PC taxa (*Dreissena*, *Theodoxus*) present (Angelov 2000; Kovachev et al. 1999; Valkanov 1941); TT (2010, 2014, PO)
BG	NA	Lake Beloslav	-- Drensky	- Drensky	Hubenov	Hubenov	PC taxa (*Dreissena*, *Theodoxus*) present (Angelov 2000; Drensky 1947; Valkanov 1957a)
ROU	30	Coastal lakes near Sinoe	Data deficient	Data deficient	Data deficient	Data deficient	

(Continuation Table A2.2.1.)

Country	ID	Sub-area	PC Cardiidae 20th C	PC Hydrobiidae 20th C	PC Cardiidae 21st C	PC Hydrobiidae 21st C	Remarks
BG	NA	Lake Durankulak	- Angelov (2000); Kovachev et al. (1999)	- Angelov (2000); Kovachev et al. (1999)	- Hubenov (2015); Vidinova et al. (2016)	- Hubenov (2015); Vidinova et al. (2016)	PC taxa (*Dreissena*, *Theodoxus*) present (Angelov 2000; Kovachev et al. 1999); TT (2010, 2014, PO)
BG	NA	Lake Shabla-Ezerets	- Angelov (2000); Kovachev et al. (1999)	- Angelov (2000); Kovachev et al. (1999)	- Hubenov (2015); Vidinova et al. (2016)	- Hubenov (2015); Vidinova et al. (2016)	PC taxa (*Dreissena*, *Theodoxus*) present (Angelov 2000; Kovachev et al. 1999; Valkanov 1941); TT (2010, 2014, PO)
BG	NA	Lake Beloslav	-- Drensky	- Drensky	Hubenov	Hubenov	PC taxa (*Dreissena*, *Theodoxus*) present (Angelov 2000; Drensky 1947; Valkanov 1957a)
BG	NA	Lake Varna	+ Kaneva-Abadjieva (1957)	- Kaneva-Abadjieva (1957)	- Hubenov (2015); Vidinova et al. (2016)	- Hubenov (2015); Vidinova et al. (2016)	PC taxa (*Dreissena*, *Theodoxus*) present (Angelov 2000; Drensky 1947; Wohlberedt 1911
BG	NA	Kamchiya River Mouth and backwaters	- Angelov (2000); Valkanov (1957a)	- Angelov (2000); Valkanov (1957a)	- Hubenov (2015)	- Hubenov (2015)	PC taxa (*Dreissena*, *Theodoxus*) present (Angelov 2000; Valkanov 1957a); TT (2010, 2011, 2014, PO)
BG	NA	Lake Burgas (Vaya)	- Angelov (2000); Drensky (1947); Valkanov (1957a)	- Angelov (2000); Drensky (1947); Valkanov (1957a)	- Pandourski (2001); Vidinova et al. (2016)	- Pandourski (2001); Vidinova et al. (2016)	PC taxa (*Theodoxus*) present (Angelov 2000; Valkanov 1957a)
BG	NA	Lake Mandra	- Drensky (1947); Mihailova-Neikova (1961)	+ Drensky (1947, L. lincta live, June 1944); Mihailova-Neikova (1961)	- Hubenov (2015); Vidinova et al. (2016)	- Pandourski (2001); Vidinova et al. (2016)	PC taxa (*Dreissena*, *Theodoxus*) present (Angelov 2000; Valkanov 1957a); TT (2010, 2011, 2014, PO)
BG	NA	Ropotamo River Mouth	- Angelov (2000); Valkanov (1957a)	- Angelov (2000); Valkanov (1957a)	- Hubenov (2015)	- Hubenov (2015)	PC taxa (*Theodoxus*) present (Angelov 2000; Valkanov 1957a)
BG	NA	Dyavolsko Blato Marsh	- Angelov (2000); Valkanov (1957a)	- Angelov (2000); Valkanov (1957a)	- Hubenov (2015)	- Hubenov (2015)	
BG	NA	Karaagach River Mouth and Marsh	- Angelov (2000); Valkanov (1957a)	- Angelov (2000); Valkanov (1957a)	- Hubenov (2015)	- Hubenov (2015)	PC taxa (*Theodoxus*) present (Valkanov 1957a)
BG	NA	Veleka River Mouth	- Angelov (2000); Valkanov (1957a)	- Angelov (2000); Valkanov (1957a)	- Hubenov (2015)	- Hubenov (2015)	PC taxa (*Theodoxus*) present (Valkanov 1957a)
BG	NA	Silistar River Mouth	- Angelov (2000); Valkanov (1957a)	- Angelov (2000); Valkanov (1957a)	- Hubenov (2015)	- Hubenov (2015)	PC taxa (*Theodoxus*) present (Valkanov 1957a)
BG	NA	Rezovska Reka River Mouth	- Angelov (2000); Valkanov (1957a)	- Angelov (2000); Valkanov (1957a)	- Hubenov (2015)	- Hubenov (2015)	PC taxa (*Theodoxus*) present (Valkanov 1957a)

Table A2.2.2. Sub-areas within the Dniester Liman. ID numbers of the sub-areas are used in Figures A2.2.1-4 for display (see below). + indicates the presence and – the absence of the relevant PC mollusc target taxa in 20th and 21st centuries. C stands for century. PO stands for personal observation. PC habitat map of the Dniester Liman (Fig. 2.7 in the manuscript) and the Dniester Liman shapefile (Appendix 2.3) are based on the data in this table.

Country	ID	Sub-area	PC Cardiidae 20th C	PC Hydrobiidae 20th C	PC Cardiidae 21st C	PC Hydrobiidae 21st C	Remarks
UA	1	Outer Dniester Liman	+ Grinbart (1953a); Markovsky (1953); Son (2007a)	+ Grinbart (1953a); Markovsky (1953); Son (2007a)	+ MOS, OYA, VVA (PO)	- MOS, OYA, VVA (PO)	PC taxa (*Theodoxus*) present
UA	2	Middle-Inner Dniester Liman	+ Grinbart (1953a); Markovsky (1953); Son (2007a)	+ Grinbart (1953a); Markovsky (1953); Son (2007a)	+ Munasypova-Motyash (2006); MOS, OYA, VVA (PO)	+ MOS, OYA, VVA (PO)	PC taxa (*Dreissena*, *Theodoxus*) present
UA	3	Lower Dniester Floodplain	+ Grinbart (1953a); Markovsky (1953); Son (2007a)	+ Grinbart (1953a); Son (2007a)	- MOS, OYA, VVA (PO)	- MOS, OYA, VVA (PO)	PC taxa (*Dreissena*, *Theodoxus*) present
UA, MD	4	Kuchurgan Liman	+ Grinbart (1953a); Markovsky (1953); Son (2007a)	+ Grinbart (1953a); Markovsky (1953); Son (2007a)	+ Filipenko (2011), MOS, VVA (PO)	- Filipenko (2011), MOS, VVA (PO)	
MD	5	Dniester River from Cioburciu to Dubasari	+ Cartea Roșie a Republicii Moldova (2015); Munjiu (2012)	- Balashov et al. (2013)	- Cartea Roșie a Republicii Moldova (2015)	- Balashov et al. (2013)	PC taxa (*Dreissena*, *Theodoxus*) present

Table A2.2.3. Sub-areas within the Dnieper-Bug Estuary. ID numbers of the sub-areas are used in Figures A2.2.1-4 for display (see below). + indicates the presence and – the absence of the relevant PC mollusc target taxa in 20th and 21st centuries. C stands for century. PO stands for personal observation. PC habitat map of the Dnieper-Bug Estuary (Fig. 2.8 in the manuscript) and the Dnieper-Bug Estuary shapefile (Appendix 2.3) are based on the data in this table.

Country	ID	Sub-area	PC Cardiidae 20th C	PC Hydrobiidae 20th C	PC Cardiidae 21st C	PC Hydrobiidae 21st C	Remarks
UA	1	Tiligul Liman	+ Grinbart (1953b)	- Grinbart (1953b)	- Son (2007a)	- MOS (PO)	PC taxa (*Dreissena*, *Theodoxus*) present
UA	2	Berezan Liman	+ Grinbart (1953b)		- Son (2007a)	- MOS (PO)	PC taxa (*Dreissena*, *Theodoxus*) present
UA	3	Bug River upstream from Mykolaiv	+ Markovsky (1954a)	+ Markovsky (1954a)	- MOS (PO)	- MOS (PO)	PC taxa (*Dreissena*, *Theodoxus*) present
UA	4	Dnieper - South Bug Estuary	+ Markovsky (1954a); Zhadin (1931)	+ Markovsky (1954a)	+ Alexenko (2004); Munasypova-Motyash (2006); MOS, OYA, VVA (PO)	+ Alexenko (2004); MOS, OYA, VVA (PO)	
UA	5	Lower Dnieper -downstream from Inhulets	+ Markovsky (1954a)	+ Markovsky (1954a)	+ Alexenko (2004); OYA, VVA (PO)	+ Alexenko (2004); Wilke et al. (2007); MOS, OYA, VVA (PO)	
UA	6	Lower Dnieper – from Inhulets to Kakhovka Reservoir	+ Markovsky (1954a); TA (PO)	+ Markovsky (1954a); TA, VVA (PO)	+ TA, VVA (PO)	+ TA, VVA (PO)	Common 20st century occurrence of hydrobiids, only sporadic 21st century occurrence of hydrobiids (TA, PO)
UA	7	Dnieper upstream from Kakhovka Reservoir	+ Munasypova-Motyash (2006); VVA (PO)	Data deficient	+ Munasypova-Motyash (2006); Semenchenko et al. (2016)	Data deficient	PC taxa (*Dreissena*, *Theodoxus*) present 21st C
UA	8	Yagorlyk Bay	Data deficient	+ Anistratenko (1996)	Data deficient	Data deficient	PC taxa (*Dreissena*, *Theodoxus*) present 21st C

Table A2.2.4. Sub-areas within the Taganrog Bay-Don Delta. ID numbers of the sub-areas are used in Figures A2.2.1-4 for display (see below). + indicates the presence and – the absence of the relevant PC mollusc target taxa in 20th and 21st centuries. C stands for century. PO stands for personal observation. PC habitat map of the Taganrog Bay-Don Delta (Fig. 2.9 in the manuscript) and the Taganrog Bay-Don Delta shapefile (Appendix 2.3) are based on the data in this table and Table A2.2.5 below.

Country	ID	Sub-area	PC Cardiidae 20th C	PC Hydrobiidae 20th C	PC Cardiidae 21st C	PC Hydrobiidae 21st C	Remarks
UA, RU	1	Taganrog Bay/ outer Don Delta	+ Mordukhay-Boltovskoy (1960); Scarlato and Starobogatov (1972b); Stark (1960); Vorobyev (1949); Nekrasova (1972)	+ Anistratenko (2007a); Golikov and Starobogatov (1972); Mordukhay-Boltovskoy (1960)	+ Nabozhenko (2005); Nabozhenko (2008); Shokhin et al. (2006)	+ Kovalenko (2009) ¥	¥ highly abundant in the Don River Delta, Kalancha channel, deep pit in 2 km upstream from mouth
RU	2	Mius Liman	+ Mordukhay-Boltovskoy (1960)	Data deficient, but given abundant records in 200 (TW, PO) likely present	+ VLS, 2003, 2006 (PO)	+ Wilke et al. (2007); Frank Riedel (PO), 2016	Likely presence of PC taxa in 20th C given the common occurrence in observations in 2000
RU	3	Lower Don up to Manych confluence	+ Mordukhay-Boltovskoy (1960)	Data deficient	+ Nabozhenko (2008)	Data deficient	PC taxa (*Dreissena*, *Theodoxus*) present 20-21st C (Zhivoglyadova and Frolenko 2017); VLS, 2017-2019 (PO)
RU	4	Tsimlyansk Reservoir	+ Scarlato and Starobogatov (1972b)	- Son et al. (2020)	+ Son et al. (2020)	- Son et al. (2020)	PC taxa (*Dreissena*, *Theodoxus*) present 21st Century (Bulysheva et al. 2019); VLS, 2018-2019 (PO)

Table A2.2.5. Sub-areas within the SE Azov Sea coast. ID numbers of the sub-areas are used in Figures A2.2.1-4 for display (see below). + indicates the presence of the relevant PC mollusc target taxa in 20th and 21st centuries. C stands for century. PC habitat map of the Taganrog Bay-Don Delta (Fig. 2.9 in the manuscript) and the Taganrog Bay-Don Delta shapefile (Appendix 2.3) are based on the data in this table and Table A2.2.4 above.

Country	ID	Sub-area	PC Cardiidae 20th C	PC Hydrobiidae 20th C	PC Cardiidae 21st C	PC Hydrobiidae 21st C	Remarks
RU	5	Coastal limans Kuban delta incl. Akhtarsk Liman	+ Mordukhay-Boltovskoy (1960)	+ Golikov and Starobogatov (1972)	+ Korpakova et al. (2007); Korpakova et al. (2008)	Data deficient	*Dreissena* community present (Korpakova et al. 2010)

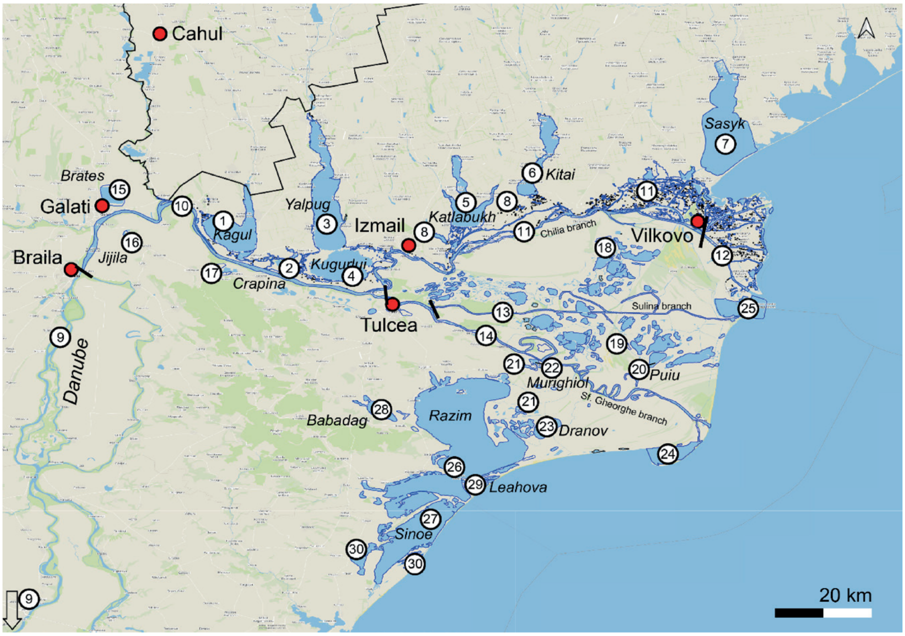


Figure A2.2.1. Danube-Razim and Bulgarian coastal wetlands. See IDs of the sub-areas in Table A2.2.1. Map is projected in EPSG Projection 4326 - WGS 84.

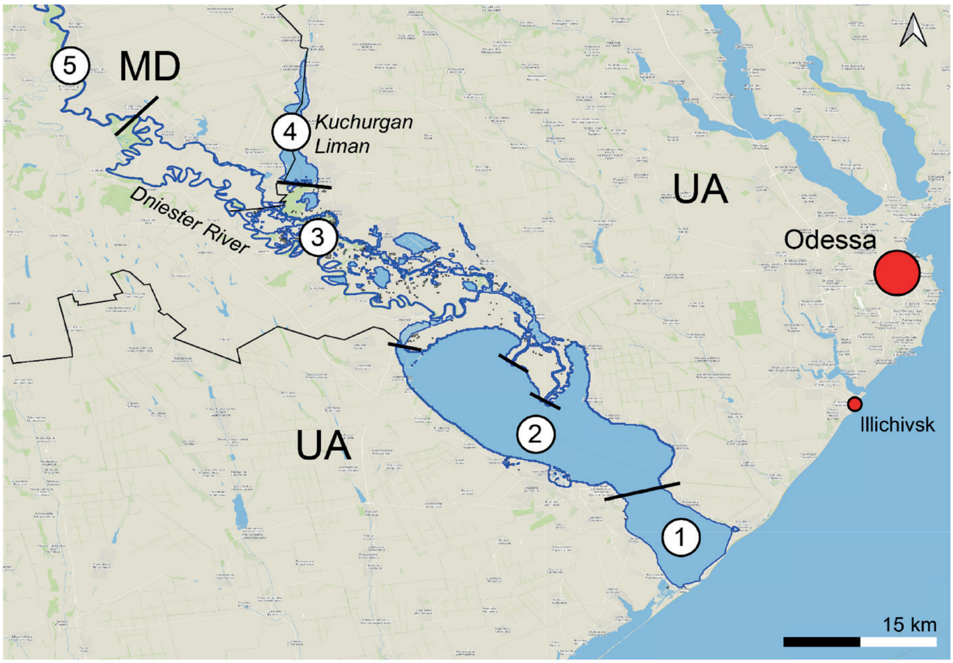


Figure A2.2.2. Dniester Liman. See IDs of the sub-areas in Table A2.2.1. Map is projected in EPSG Projection 4326 - WGS 84.

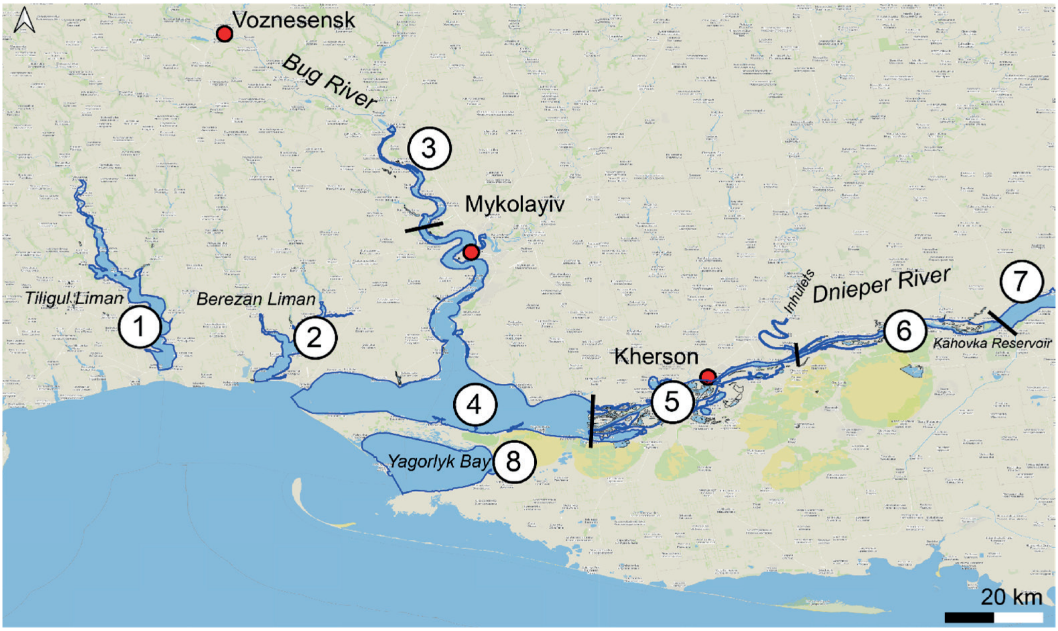


Figure A2.2.3. Dnieper-Bug Estuary. See IDs of the sub-areas in Table A2.2.1. Map is projected in EPSG Projection 4326 - WGS 84.

Figure A2.2.4. Taganrog Bay-Don Delta and SE Azov Sea coast. See IDs of the sub-areas in Table A2.2.1. Map is projected in EPSG Projection 4326 - WGS 84.

Appendix 2.3. Pontocaspian habitat polygon shapefiles

Available at https://datadryad.org/stash/share/cMhMU-zTUUULuZM1XjtQKZNwN5M-L6cwKiKP4kaf6go.

3

Legal framework for Pontocaspian biodiversity conservation in the Danube delta (Romania and Ukraine)

In preparation:
Gogaladze, A., Biesmeijer, J.C., Son, M.O., Marushchak, O., Wesselingh, F.P., Lattuada, M., Sandu, C., Albrtecht, C., Mihailescu, S., Raes, N. Legal framework for Pontocaspian biodiversity conservation in the Danube Delta (Romania and Ukraine).

Abstract
Legal arrangements play an important role in biodiversity conservation planning, implementation and coordination of actions. These arrangements are complex and operate on different levels of governance (from supranational to national), which means that the status of single species or populations may be governed by a set of interacting or even conflicting regulations, with increasing complexity for species that occur across national borders. Romania (EU member state) and Ukraine (non-EU member state) exemplify neighboring countries with different governance systems, which share the same endemic aquatic community that inhabits the transitional zones between freshwater and marine ecosystems, known as Pontocaspian (PC) biota. This community includes surrogate species such as sturgeons, and lesser-known crustaceans and mollusks and is severely threatened as a result of human activities. We assessed the legal basis for the protection of PC biota in the Danube Delta and the effectiveness of current conservation approaches based on a review of legal documents and literature, expert opinion, and practitioner reflections regarding PC biodiversity conservation. We found that PC invertebrate species are not adequately addressed in the current legal documents and that the surrogate approach (where protection of umbrella species results in protection of background species) does not work as there is little overlap between the habitats of sturgeons and PC invertebrate communities. Furthermore, the habitat definitions currently used in legal documents lack the level of detail needed to protect PC habitats that are characterized by specific salinity (brackish) conditions. We finish by sketching out recommendations towards improved legal and political frameworks for effective and efficient conservation of PC invertebrate biota.

3.1 Introduction

Biodiversity conservation benefits from a clear and transparent legal and political framework (De Klemm and Shine 1993; Díaz et al. 2019). International Environmental Regimes (IERs) set conservation goals and provide guidance on how to achieve these goals, whereas the national legislation provides a framework for the actions and restrictions at the national level to meet international obligations. A prominent example of an IER is the Convention on Biological Diversity (CBD 1992), which defines the global biodiversity goals and provides the policies for its parties (individual contracting countries) to implement. The European Union (EU), while establishing environmental policy for its member states (see e.g. Delreux and Happaerts 2016), is conceptually broader than an IER (Skjærseth and Wettestad 2002), because "EU member states have transferred national sovereignty to a supranational institution. Accordingly, EU laws are directly binding on the member states rather than requiring member states to ratify joint commitments, as is the case within international regimes" (Skjærseth and Wettestad 2002, p. 103).

Legal arrangements to address biodiversity conservation operate on different levels of governance from supranational (e.g., UN or EU) to national and sub-national. This means that rules and policies inevitably influence each other, whether they target the same or different environmental challenges (Visseren-Hamakers 2018). As a result, often the same species and single populations are governed by an interacting, combined set of regulations, more so if their distribution crosses national borders (Iwanski 2011; Singh 1999). Regulations may support each other, have no effect, or may counteract. Few studies have investigated the relationships and the combined performance of different rules and governance systems in the context of biodiversity conservation (Gomar et al. 2014; Visseren-Hamakers 2018). However, understanding the mutual effects of different legal instruments , and how these instruments deal jointly with conservation needs, is imperative for effective conservation outcomes (Visseren-Hamakers 2015). In this paper, we will assess the level of coherence among the regulations governing biodiversity conservation in one of Europe's largest deltas, the Danube Delta, which is under shared responsibility of Ukraine and Romania and that hosts a unique aquatic fauna.

Romania and Ukraine exemplify countries with different governance systems, which share the responsibility for effective conservation and governance of species and ecosystems within the Danube Delta (ICPDR 2015, 2020). Romania is an EU member state since 2007, while Ukraine is signatory to an EU-association agreement. Consequently, Romania is legally bound to EU Directives, including the Habitats Directive (EU 1992) and Birds Directive (EU 2009), respecting at the same time the national conservation legislation, while Ukraine is currently in the process of approximation to the EU acquis. The Danube Delta is internationally recognized as Europe's largest water purification system and important wildlife habitat and its management is regulated by a number of different rules and regulations (Baboianu 2016; Teampău 2020; The World Bank study team 2015). For example, as a 'Waterflow Habitat' it is a designated Ramsar site in Romania and Ukraine. Additionally, within the UNESCO Man and Biosphere Program, it is declared as a

"Danube Delta transboundary Biosphere Reserve Ukraine and Romania". Furthermore, the Danube Delta is protected and managed through the Danube River Protection Convention (1994) and the Bern Convention (1979). From all these treaties and policy instruments, the latter is the most significant for biodiversity conservation as it builds a network of protected areas such as Natura 2000 and Emerald sites in Romania and Ukraine respectively, to provide protection to threatened species and habitats (Díaz 2010; Evans 2012).

The Danube Delta shelters a unique, aquatic ecological community, known as the Pontocaspian (PC) biodiversity (Popa et al. 2009; Velde et al. 2019; Wesselingh et al. 2019), which is characterized by charismatic vertebrate species such as sturgeons, lesser-known invertebrate groups, such as mollusks and crustaceans, as well as diatoms and dinoflagellates (Grigorovich et al. 2003; Marret et al. 2004). PC habitats comprise transitional zones between the freshwater, and salt water bodies on coastal plains of the Black Sea and the Sea of Azov, such as lower stretches of rivers, lagoons, delta areas, estuaries, brackish lakes and bays, as well as the entire Caspian Sea (Gogaladze et al. Submitted; Zenkevitch 1963). However, many PC species also inhabit fresh waters in lower reaches of large rivers. The PC biota is threatened and rapidly declining due to direct anthropogenic drivers, such as damming of rivers, modification of marine and freshwater influx in coastal areas and invasive species among others (Son 2007a, b; Velde et al. 2019); as well as indirect drivers, such as limited knowledge on PC species and suboptimal institutional alignment of stakeholders (Gogaladze et al. 2020a; Gogaladze et al. 2020b; Wesselingh et al. 2019). The legal basis to address the decline of PC biodiversity, has not been studied, with the exception of sturgeon species (Munteanu et al. 2013; Reinartz et al. 2012).

Conservation of species can be achieved through ecosystem-based measures (also known as the coarse-filter approach) and/or species-based measures (also known as fine-filter approaches) (Glowka et al. 1998). Ecosystem-based conservation targets biotic communities, instead of individual species, and potentially benefits many species simultaneously. Biotic communities are often defined by surrogate taxa (Groves et al. 2000), which involve keystone, indicator, umbrella and flagship species (Favreau et al. 2006). Flagship species are primarily used to promote public awareness and to raise funds for conservation (Verissimo et al. 2011), while the protection of umbrella species is expected to benefit a wide range of co-occurring species (Caro 2010; Roberge and Angelstam 2004). Consequently, the flagship species selection is based on sociocultural considerations, whereas umbrella species are selected based on ecological criteria (Caro 2010; Verissimo et al. 2011). PC sturgeon species are both flagship and umbrella species of the Black Sea and Danube Delta region according to the International Commission for the Protection of the Danube River (ICPDR 2018, 2020). Whether sturgeons can be seen as surrogates for the other PC biota remains unclear. For example, studies on benefits to the invertebrate PC communities from sturgeon conservation are lacking. This may be, partly, explained by the fact that PC invertebrate species have disputed taxonomy, include multiple synonymies and misidentifications, and are mostly data deficient in IUCN assessments (see e.g. Wesselingh et al. 2019 for PC mollusk species).

Consequently, it might be the case that PC invertebrate species fall through the 'coarse filters' of area-based conservation approaches (and thus do not benefit from sturgeon conservation measures) and may require the 'fine-filter' of species or community-based approaches.
We use the Danube Delta case to assess whether the legal bases in Romania and Ukraine are sufficient to support the conservation of PC biodiversity, and study the impact of regulations from the supranational institutions, such as the EU. First, we analyze whether PC invertebrate species and flagship sturgeon species or their habitats are represented in the current legal documents. Second, we assess whether the different regulations are coherent among each other and whether regulations for sturgeons are likely to be relevant for other PC species and habitats. Following Gomar et al. (2014), we define coherence as the complementarity of action (mutual reinforcement) and not as post-accession compliance with EU environmental legislation, or consistency or compatibility of action (absence of contradiction). Third, we assess the degree to which the conservation of PC species and habitats is implemented, through examining the current conservation programs and plans and the extent to which PC habitats are covered by the network of protected areas (PAs) as well as the representation of PC species in the PA management plans..

3.2 Methods

PC habitats encompass several habitats from the European Nature Information System (EUNIS) classification (https://eunis.eea.europa.eu/). These are:

1. A2: Littoral sediment
2. C1.2: Permanent mesotrophic lakes, ponds and pools
3. C2.32: Metapotamal and hypopotamal streams
4. C2.41: Brackish water tidal rivers
5. C2.42: Freshwater tidal rivers (within low reaches of large rivers and estuaries in Ukrainian and Romanian sectors of Black and Azov seas)
6. X01: Estuaries
7. X03: Brackish coastal lagoons

In the Danube Delta (Fig. 3.1) all except 'C2.41: Brackish water tidal rivers' are present so we exclude it from the analysis. There are no tides in the BSB (Giosan et al. 1999), but the regular wind surges that occur in the open estuaries of the BSB, e.g., in the Danube and Don Deltas cause the upstream movement of the sea water into the deltas creating conditions that are similar to the 'tidal rivers' in the other sea basins. Therefore, we include the C2.42: Freshwater tidal rivers in our analysis. We adopt the definition of the Danube Delta area from WWF (2007) and The World Bank study team (2014, 2015), who include lower stretch of the Danube River – from Braila to the Black Sea; its 3 branches – Chilia, Sulina and Sf. Gheorghe and the floodplain lakes around these branches; Razim-Sinoe Lake complex in Romania to the south and a number of large lakes on the Ukrainian northern side of the delta (Fig. 3.1).

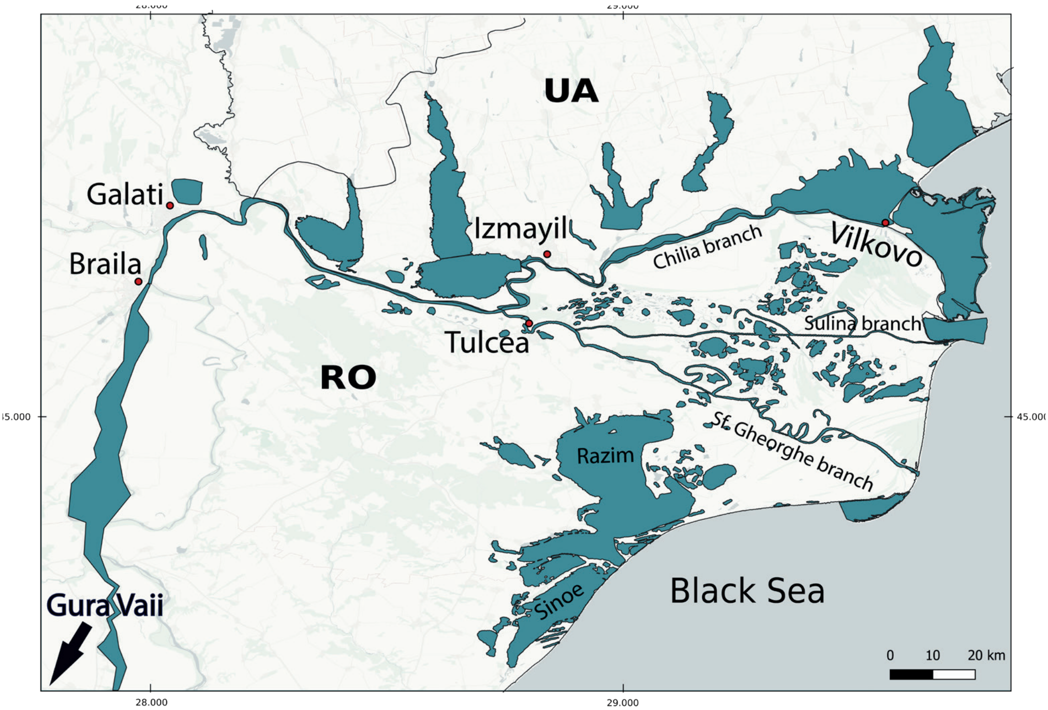


Figure 3.1. Pontocaspian Habitats in the Danube Delta are shown in blue. According to Gogaladze et al. (Submitted) PC habitats extend upstream the Danube River from Bralia up till Gura Vaii commune in Romania. This study, however, focuses on Danube Delta so the Danube River upstream from Braila is not included in the analyses.

3.2.1 Identifying relevant legal documents

We define Pontocaspian (PC) biodiversity related legal documents as those which directly promote the conservation of PC species and/or PC habitats. Legal documents for the analysis were selected on a global, regional (EU and the Black Sea) and national levels. Globally, all five biodiversity-related conventions (Koester 2002) plus the Convention on Environmental Impact Assessment in a Transboundary Context, also known as Espoo Convention (UNECE 1991) were included. The five global biodiversity-related conventions are: 1) Convention on Biological Diversity (CBD 1992); 2) Convention on the International Trade in Endangered Species of Wild Fauna and Flora (CITES 1973), also known as the Washington Convention; 3) Convention on the Conservation of Migratory Species of Wild Animals (CMS 1979) also known as the Bonn Convention; 4) Convention on Wetlands of International Importance Especially as Waterfowl Habitat (UNESCO 1971), also known as the Ramsar Convention; and 5) Convention for the Protection of the World Cultural and Natural Heritage (UNESCO 1972), commonly known and World Heritage Convention (WHC).

At regional level (EU and the Black Sea) we selected conventions based on two criteria. First, they had to list the species, ecological communities and habitat types, or any of these as a cornerstone for conservation efforts. Second, they had to be operational in Ukraine and/or in Romania. Most prominent example of such convention is the Bern Convention on the Conservation of European Wildlife and Natural Habitats (Council of Europe 1979). Additionally, we considered Convention on the Protection of the Black Sea against Pollution (Black Sea Commission 1992), also known as 'Bucharest Convention', which did not directly list the species and habitat types but whose implementation required listing of species and habitats on national and/or regional levels. Furthermore, we included in the analysis the Convention on cooperation for the protection and sustainable use of the river Danube (DRPC 1994), which ensures sustainability and effective nature conservation of the Danube River. At the EU level, all biodiversity-related Directives, such as: 1) The Birds Directive (EU 2009); 2) the Habitats Directive (EU 1992); 3) Water Framework Directive (EU 2000); and 4) Marine Strategy Framework Directive (EU 2008) were included. Additionally, we included the EU Wildlife Trade Regulations (EU 1996), which is the EU-Level implementation mechanism of CITES.

National Romanian laws were retrieved from the national biodiversity strategy and action plan of Romania (The Government of Romania 2014) and the fifth national report to the CBD (Ministry of Environment and Climate Change of Romania 2014). The list of Ukrainian national laws was built from the fifth and sixth national reports on implementation of the Convention on Biological Diversity (Ministry of Ecology and Natural Resources of Ukraine 2015, 2018). The official texts of national laws and their amendments, appendices and annexes were retrieved from the official legislative portals of Romania (http://legislatie.just.ro/) and Ukraine (https://zakon.rada.gov.ua/laws/main/index). Provisions of national laws were only available in official languages of the issuing countries so they were Google translated in English for analysis. All the legal documents and their amendments were read and carefully examined and only those were selected which a) provided lists of species and/or habitats; and/or b) which did not list species and/or habitats in their provisions but regulated public relations with regard to the listed species and habitats from the provisions of other laws.

Additionally, we examined IUCN Red Lists of species and habitats at EU level. For PC species presence, we analyzed the 'Red List of Non-Marine Mollusks' (Cuttelod et al. 2011), and the European Red List of Freshwater Fishes (Freyhof and Brooks 2011), and for PC habitat representation in IUCN assessments we examined the European red list of habitats, part 1: marine habitats (Gubbay et al. 2016), and European red list of habitats, part 2: terrestrial and freshwater habitats (Janssen et al. 2016).

3.2.2 Analysis

We applied a mix of quantitative and qualitative research approaches and methods to analyze the identified legal documents (Landman 2002). Quantitatively, we assessed firstly the extent to which the identified legal documents mention PC species and habitats in their formulations, using key word search (see Appendix 3.1), and secondly, the degree to which PC habitats are covered by the existing network of protected areas (see below). Qualitatively, we thoroughly read all the identified legal documents to understand the PC biodiversity conservation context and framing (see below).

3.2.1.1 Quantitative analysis

To search for presence of PC species names in legal documents, we used all the recorded genus names known from the Danube Delta, within each PC group (see below), as search terms and scanned all the identified legal documents for presence of these terms (Appendix 3.1). We accounted for taxonomic synonymy and misidentification by selecting both currently accepted and synonymous genus names, which have been used by different authors in the last decade. In total we retrieved 70 invertebrate genus names belonging to mollusks - gastropods and bivalves (Wesselingh et al. 2019), crustaceans - amphipods, cumaceans, copepods (Monchenko 2003) and decapods (Policar et al. 2018), and mysidae (Audzijonyte et al. 2008). Finally, we searched cnidaria and hirudinea (Mordukhay-Boltovskoy 1960) as well as 2 vertebrate genus names of sturgeons (Appendix 3.1).

Spatial data on Important Bird Areas was retrieved from Birdlife Data Zone, (http://datazone.birdlife.org/site/search) and the Ramsar dataset from the Ramsar website (https://rsis.ramsar.org/). Data on Emerald network and Natura 2000 datasets were retrieved from the European Environment Agency (EEA, http://emerald.eea.europa.eu/, and https://natura2000.eea.europa.eu/ respectively). Spatial data on national protected areas was retrieved from IUCN World Database on Protected Areas (WDPA, https://www.iucn.org/theme/protected-areas/our-work/world-database-protected-areas). Data on PC habitats were retrieved from earlier work that defined, documented and mapped the PC habitats based on literature review and expert opinions (Gogaladze et al. Submitted). We calculated the area of PC habitats and its percentage covered by protected areas with a geometric overlying between the PC habitats and the protected area polygons in R package 'sf' (Pebesma 2018). For each PC habitat polygon, we calculated the surface area and the area percentage that is protected by the protected areas on three administrative levels: global (UNESCO, Ramsar Convention and Important Bird Areas), European (Natura 2000 network for Romania and Emerald network for Ukraine) and national (all types of national protected areas).

3.2.1.2 Qualitative analysis

Provisions of identified legal documents (Fig. 3.2, Appendix 3.2) were further read to understand how PC species and habitats were defined in the global, European and national legal arrangements and to examine whether PC biodiversity decline was addressed and how conservation measures and restrictions were framed. Additionally, we searched for and read the management plans of national protected areas, Natura 2000 and Emerald Network sites that covered the PC habitats to examine whether PC biodiversity was adequately addressed in the management plans.

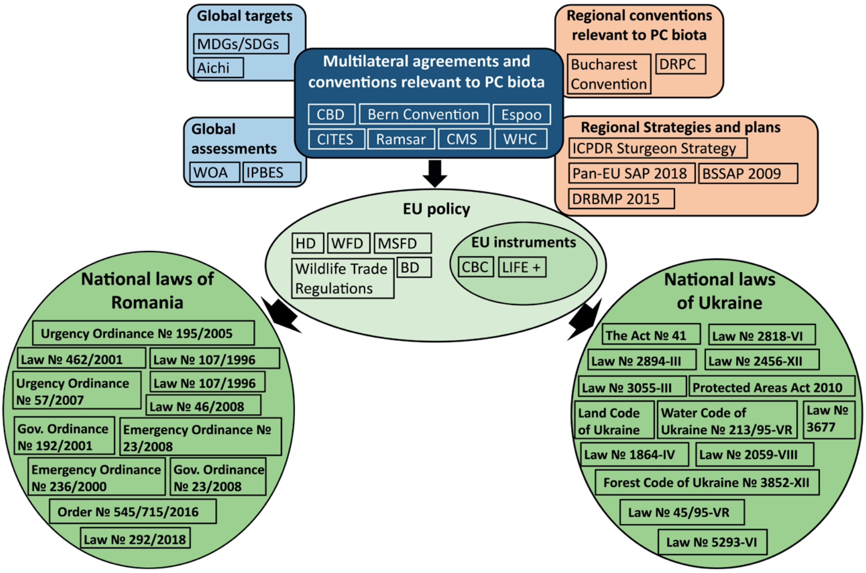


Figure 3.2. PC biodiversity conservation policy landscape. International Environmental Regimes (IERs) set the conservation goals and guidance on how to achieve these goals, which then shape EU policy. National legislation provides a framework for the actions and restrictions at the national level to meet the international obligations. See a full list and description of legal documents, as well as abbreviation definitions in Appendix 3.2.

3.3 Results

3.3.1 Pontocaspian biodiversity conservation legal landscape

We identified a complex legal and political framework within which PC biodiversity conservation is embedded (Fig. 3.2). For readability, we provide a full list and description of legal documents on global, regional and national levels, as well as their abbreviations in Appendix 3.2.

3.3.2 PC Species-based conservation

PC species were poorly represented in legal documents at all levels (Table 3.1 and Table A3.3.1). The Annexes of CITES and the Bern Convention did not list any PC invertebrate species. On EU level, the WFD did not list any PC species in its annexes. While the EU Wildlife Trade Regulations listed one sturgeon species, all six sturgeon species were listed in EU Habitats Directive. The MSFD listed the priority habitats and taxonomic groups, which encompassed benthic and pelagic habitats and habitats of special regional interest. Listed taxa included marine planktonic groups, benthic invertebrates, fishes, marine mammals and reptiles among others. PC groups, however, were not listed in MSFD.

Table 3.1. Pontocaspian genera represented in those identified legal documents that list the species names (Fig. 3.2, Appendix 3.2). LR: Low Risk, corresponds to IUCN's non-threatened categories 'least concern' and 'near threatened'. HR: High Risk, encompasses categories 'vulnerable', 'endangered' and 'critically endangered'. DD stands for 'Data Deficient'. Values in parentheses represent the number of species under the corresponding conservation category (see the PC species list in Appendix 3.3).

	UN Conventions (global and regional)			EU		Romania		Ukraine	Other	
PC groups	Bern Convention	CITES	CMS	Habitats Directive	EU Wildlife Trade Regulations	Emergency ordinance no 57/2007	Law. No. 192/2001	Law No. 3055-III	IUCN (EU)	Bucharest Convention
Amphipoda	-	-	-	-	-	-	-	HR (5)	-	HR (3) LR (1)
Bivalvia	-	-	-	-	-	3	-	HR (2)	LR (1)	-
Cnidaria	-	-	-	-	-	-	-	HR (1)	-	-
Decapoda	-	-	-	-	-	1	1	-	-	-
Gastropoda	-	-	-	1	-	-	-	LR (1)	HR (1) LR (4) DD (2)	-
Hirudinea	-	-	-	-	-	-	-	HR (1)	-	-
Mysida	-	-	-	-	-	-	-	HR (2)	-	HR (2)
Sturgeons	4	1	6	4	1	6	6	HR (6)	HR (6)	HR (2)

We identified 11 Romanian national legislative documents and 13 Ukrainian legislative documents that listed species and/or habitats, or regulated public relations with regard to the species and habitats listed in the provisions of other laws (Fig. 3.2, Appendix 3.2). National legal documents of Romania and Ukraine listed all six sturgeon species. As for the PC invertebrate species, Annex 4B on species of national interest of the Romanian Government Emergency Order no. 57/2007 listed all three limnocardiine bivalve species and one PC decapod species (Table 3.1 and Table A3.3.1). Other PC groups, however, were absent from Romanian national laws. As for Ukraine, the Red Data Book of Ukraine (RDBU), regulated by the Law No. 3055-III, listed few invertebrate species from different PC groups. Decapods were not listed in RDBU.

IUCN species assessments relevant to PC biodiversity on EU level were conducted for fish and mollusk species only. For other PC invertebrate species IUCN assessments were lacking. All but one species of sturgeon were listed as critically endangered in IUCN assessments (Table 3.1 and Table A3.3.1). As for PC mollusks, seven gastropod species were data deficient, and four gastropod species were least concern. Furthermore, the bivalve subfamily Lymnocardiinae (and the Cardiidae family to which it belongs) were completely absent. The Black Sea Red Data Book (BSRDB), which was created in response to the regional Bucharest Convention (Dumont et al. 1999), automatically included all species that were at that time in RDBU and Romanian laws, and supplemented those with two additional amphipod species, such as *Echinogammarus trichiatus* Martynov, 1932 (as *Chaetogammarus ischnus major*) and *Dikerogammarus villosus* (Sowinskii, 1894).

Table 3.2. PC habitat coverage by legal documents.

Zones	EUNIS Habitats types covering PC habitats	PC regional varieties in EUNIS Habitat Classification	Annex I of Resolution 4 (1996) of the Bern Convention (Emerald Network)	EU Habitats Directive Annex I (Natura 2000)	IUCN assessments (Gubbay et al. 2016; Janssen et al. 2016)	Covered PC biota	PC Invertebrate species presence
Freshened part of the Black Sea, mouths of branches of the Danube Delta	A2 Littoral sediment	A2.262 Pontogammarus maeoticus in fine mediolittoral sands	A2.2 Littoral sand and muddy sand	1140 Mudflats and sandflats not covered by seawater at low tide	Absent	Specific mid-littoral community widespread in the Black and Azov seas	RO, UA
		A2.326 Pontic polychaete dominated littoral muds; A2.327 Pontic oligochaete and chironomid dominated littoral muds; A2.328 Pontic "camca" habitat of River Danube mouths	A2.3 Littoral mud			Poor communities with Pontocaspian (Gammaridae, Polychaeta) and marine species	RO, UA
		A2.4 Littoral mixed sediment	A2.4 Littoral mixed sediment				
		A5.224 Pontic mobile sands of the Danube mouths	A5 Sublittoral sediment				
Estuarine transitional zones	X01 Estuaries	NA	X01 Estuaries	1130 Estuaries	Absent	Most of the communities of the PC invertebrates	UA
	X03 Brackish coastal lagoons	NA	X03 Brackish coastal lagoons	1150 Coastal lagoons	Absent	Cardiidae species	RO
Freshwater zones of the limans and deltas	C1.2 Permanent mesotrophic lakes, ponds and pools C2.32 Metapotamal and hypopotamal streams C2.42 Freshwater tidal rivers	NA	C1.222 Floating Hydrocharis morsus-ranae rafts; C1.223 Floating Stratiotes aloides rafts; C1.225 Floating Salvinia natans mats; C2.33 Mesotrophic vegetation of slow-flowing rivers	3150 Natural eutrophic lakes with Magnopotamion or Hydrocharition-type vegetation	C1.2a Permanent oligotrophic to mesotrophic waterbody with Characeae (VU); C1.2b Mesotrophic to eutrophic waterbody with vascular plants (NT); C2.3 Permanent non-tidal, smooth-flowing watercourse (LC); C2.4 Tidal river, upstream from the estuary (EN)	Different vegetation can be used as habitat by different PC crustaceans and dreissenid bivalves	RO, UA

Table 3.3. Coverage of PC habitats by the network of protected areas across different administrative levels. Values are the percentages of PC habitats that are within protected areas. HD, SCI stands for Habitats Directive, Site of Community Importance and BD, SPA stands for Birds Directive, Special Protection Area (see Appendix 3.2. for details).

Protection type	Romania	Ukraine
UNESCO Man and Biosphere Programme	74%	32%
Ramsar sites	89%	57%
IBA	96%	45%
Natura 2000 (HD)	95%	NA
Natura 2000 (BD)	99%	NA
Emerald Sites	NA	96%
National protected areas	7%	32%

3.3.3 Area-based conservation

Important PC habitats such as the estuarine habitats of non-tidal seas (X01) and brackish coastal lagoons (X03) were poorly classified in the EUNIS habitat classification and absent as separate codes in Annex I of Resolution 4 (1996) of the Bern Convention and Annex I of Habitats Directive (Table 3.2; present only as complexes without distinction between littoral, benthic and pelagic zones). Regional varieties of PC habitats in freshened parts of the Black Sea and branches of the Danube Delta were used neither by the Bern Convention and EU Habitats Directive to structure the Natura 2000 and Emerald networks. Instead, higher level broad habitat types were used. For example, specific habitat in the Danube Delta such as 'A5.224 Pontic mobile sands of the Danube mouths' was represented by a higher level 'A5 Sublittoral sediment' habitat type. This higher-level habitat type failed to account for sublittoral sand in specific, variable salinity (estuarine) conditions (EUNIS habitat type A5.22). Furthermore, 'C1.2 Permanent mesotrophic lakes', 'C2.32 Metapotamal and hypopotamal streams, ponds and pools', and 'C2.42 Freshwater tidal rivers' were missing from the Annex I of Resolution 4 (1996) of the Bern Convention and Annex I of the Habitats Directive (Table 3.2). Within 'C1.2 Permanent mesotrophic lakes, ponds and pools' several types of vegetation (e.g., 'C1.222 Floating *Hydrocharis morsus-ranae* rafts' among others, see Table 3.2) are included in Annex I of Resolution 4 (1996) of the Bern Convention. However, these habitats are not valuable for PC species (Mordukhay-Boltovskoy 1960). The Ramsar Convention (1971), did not list habitats or species that need protection, but on the 9th Meeting of the Conference of the Parties (COP) Resolution IX.1 Annex E identified coastal tidal flats, rivers and streams, which form part of the PC habitats, as priority areas that shall receive more attention to improve integrated wetland inventory, assessment and monitoring. PC habitats were poorly represented in IUCN assessments (Table 3.2).

Most of the PC habitats in the Danube Delta were covered by the sites of international importance, such as IBAs, Danube Delta Biosphere Reserve and Ramsar sites (Table 3.3, Fig. 3.3). On European level, Natura 2000 sites and Emerald Network provided almost an absolute coverage of the PC habitats (Table 3.3). National protected areas partially covered the stretches of Danube River and few PC lakes in Romania and Ukraine, but ignored most of the important estuaries, which contain important PC invertebrate communities. Management plans were not in place for most of the protected areas (see Table A3.4.1 in Appendix 3.4). In the protected area management plans that were in place PC invertebrate species were not mentioned, placing no restrictions on interventions that endanger them. Management plans were non-existent for Emerald Sites in Ukraine which encompassed PC habitats, because the Law "On the Territories of the Emerald Network" of Ukraine was not yet into force.

Relevant Romanian and Ukrainian national legislations were not coherent (mutually reinforcing): neither vertically coherent, i.e., coherent with global treaties and the EU directives, nor horizontally coherent, i.e., coherent with each other. Reviewed reports and legal documents suggested that even though the national Romanian biodiversity legislation was in line with the provisions of CBD, most of the strategies and action plans for biodiversity conservation were not executed, because they were not adopted by normative acts and therefore had no legal power for enforcement (The Government of Romania 2014). Furthermore, Romania faced considerable administrative, governance and financial challenges in the implementation of EU Nature Directives (European Commission 2019). In general, biodiversity conservation-related Romanian legislation was characterized by frequent amendments due to compliance to the EU Directives, resulting in a very complex landscape of conservation laws, secondary laws and emergency amendments to the laws (Appendix 3.2, Table A3.2.1). According to the fifth National Biodiversity Strategy and Action Plan (NBSAP) of Romania, the frequent emergency amendments resulted in a situation in which, "a series of sanctions are omitted for the non – compliance with some legal provisions already established (The Government of Romania 2014, p. 39)". Biodiversity conservation related Ukrainian laws lacked the adequate subordinate legislation (regulations and guidelines). As part of European integration, many new Emerald sites were identified for designation and the Law of Ukraine "On the Territories of the Emerald Network" was presented for a public hearing by the Ministry of Ecology and Natural Resources of Ukraine (2018). However, this law is not yet into force resulting in the absence of management plans for Emerald sites and obstruction of coherence in the implementation of the Natura 2000/Emerald site protection in Romania and Ukraine respectively. Additionally, a previous study on stakeholder network functioning involved in PC biodiversity conservation identified incoherence within the Ukrainian environmental legislation, which resulted in a situation where some national laws were contradictory, which complicated PC biodiversity conservation planning (Gogaladze et al. 2020b).

Sturgeons were well protected by law as were their habitats. However, PC habitat range was larger (Fig. 3.1) than the sturgeon habitats which comprised only the Danube River and its three branches (Schmutz and Sendzimir 2018), therefore a large part of the PC habitats fell outside the regulatory scope of sturgeon related laws. Whether the co-occurring part of the PC invertebrate biodiversity benefited from sturgeon related laws was unclear. Sturgeon related laws provided protection to sturgeons by prohibiting the use of certain types of fishing gear, regulating and limiting the number of fishing gears, craft, and the power of vessels as well as building special

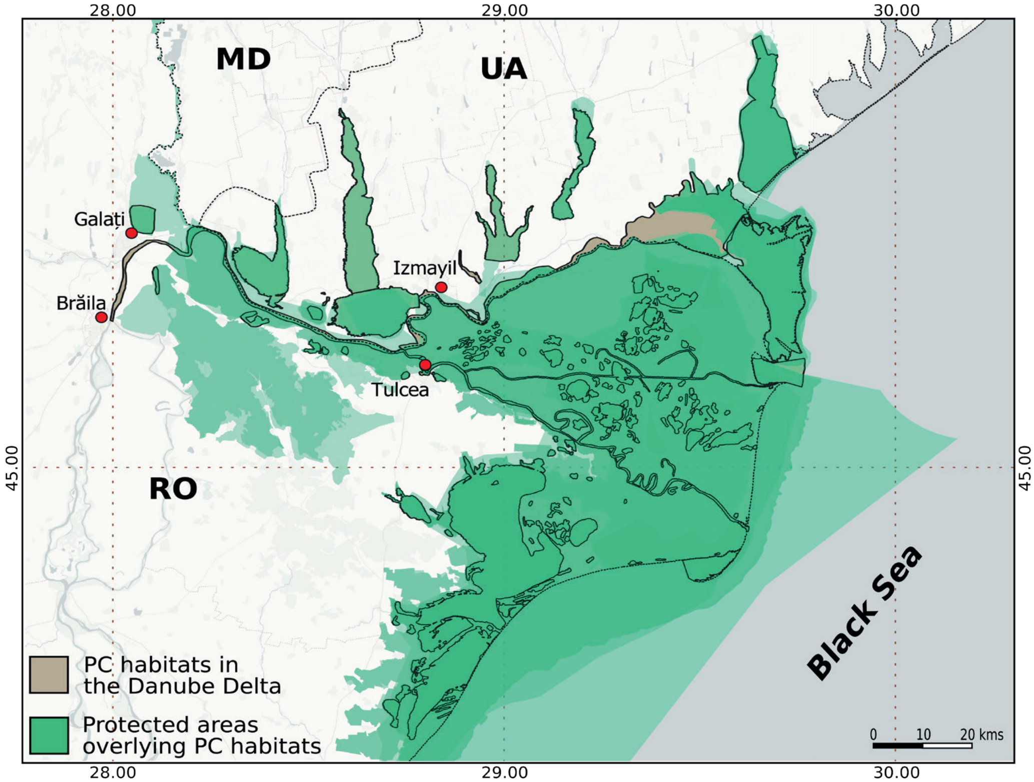


Figure 3.3. PC habitat coverage by protected areas, overlayed by Ramsar sites, UNESCO Biosphere Reserve and World Heritage Sites, Important Bird Areas, Emerald and Natura 2000 network sites and the national protected areas. Multiple overlays are indicated by darker green shades.

installations on dams that would allow the migration of sturgeons in the Danube River (e.g., Romanian Law. No. 192/2001 and Ukrainian Law №3677 in Appendix 3.2). Additionally, sturgeon-related laws regulated the restocking of sturgeon species in Romania and Ukraine (e.g., Order No. 84/2012 of Romania and Law № 5293-VI of Ukraine). Dam construction had been identified as one of the major threats to PC invertebrate biodiversity (Gogaladze et al. Submitted) and therefore dam removal could be expected to have positive impact on the PC invertebrate fauna.

3.4 Discussion

PC biodiversity conservation is embedded within a complex legal and political framework (Fig. 3.2). Some of the PC species and parts of PC habitats are included in the identified legal documents on global, regional and national levels, however, the majority of the PC invertebrate species and the specific conditions of the brackish PC habitats, such as the salinity gradients are not adequately addressed and defined. This results in the omission of PC invertebrate species from conservation management plans and implementation, as well as the environmental impact assessment studies, leading to suboptimal conservation actions. Furthermore, we do not see legal coherence across relevant Ukrainian and Romanian legislations and across the PC species groups covered by different legal documents, which further hampers effective conservation planning.

3.4.1 Recommendations for improved laws and regulations

Laws and regulations that list the PC species and/or habitats need to be updated and amended according to the best available scientific knowledge. On EU-level, the Annexes of the Bern Convention list very few species of aquatic invertebrates, and endemic PC species are absent (Table 3.1 and Table A3.3.1). Inclusion of threatened PC invertebrate species in the appendices of Bern Convention, following the Recommendation No. 56 (1997) concerning guidelines to be taken into account while making proposals for amendment of Appendices I and II of the Convention and while adopting amendments, is important. The same applies to amendments of the EU Habitats Directive and Water Framework Directive. Listing PC invertebrate species in appendices of CITES is perhaps less urgent due to the low commercial and economic value of the PC invertebrate species resulting in low pressure on these taxa from international trade. Similarly, Convention on Migratory Species shall require no inclusion of PC invertebrate species in its appendices due to limited migration of these taxa. On Black Sea regional level, the Black Sea Red Data Book (Dumont et al. 1999) is outdated, and an update is urgent. It is also necessary to update the Red Data Book of Ukraine (Akimov 2009) and amend the species list in the Romanian Emergency ordinance no 57/2007 to adequately and consistently incorporate the missing PC invertebrate species in national legal documents.

Revision of Annex I of Resolution 4 (1996) of the Bern Convention (last revised in 2018), to account for the specific salinity conditions of PC habitats, can greatly benefit PC biodiversity conservation. Such a revision shall ideally aim to achieve two major goals, firstly to fully integrate the lower-level Danube Delta-specific habitat types from the EUNIS habitat classification into the Bern convention; and secondly to adequately classify the estuarine habitats of non-tidal seas (X01) and brackish coastal lagoons (X03), which are currently not classified in the EUNIS habitat classification and are absent as separate codes in Resolution 4 (1996) of the Bern Convention and Annex I of Habitats Directive. Estuarine habitats of non-tidal seas (X01) and brackish coastal lagoons (X03) are present only as higher-level habitat complexes without distinction between littoral, benthic and pelagic zones (see Table 3.2). Providing such detailed classification in the Bern Convention can be expected to result in an updated EUNIS habitat classification and Annex I of the Habitats Directive. The current poor classification of estuarine and lagoonal habitats in the Bern Convention could be understood as a holistic, umbrella approach, which leads to the coverage of all components of the habitat e.g., entire benthic and planktonic communities. However, covering only the large estuarine habitat complex without further detail, the Bern Convention fails to separate the brackish characteristics of PC habitats from "marine" conditions of the estuarine mouth districts.

This is consequential for PC invertebrate community conservation, since changes in salinity regime resulting in a decline of PC species (Son 2007b; Trichkova 2007; Varbanov 2002; Velde et al. 2019), will not formally be considered as destruction of the biotope. Indicating salinity regimes in estuarine habitats in ecological management programs is paramount, since all large rivers in the region have a controlled artificial regime of flooding and water use, that negatively affects PC biodiversity (Gogaladze et al. Submitted). Freshwater habitats are classified better in the Bern Convention but there is room for improvement. Specifically, only the thickets of aquatic plants are covered, but bottom and plankton communities are missing, whereas most of the PC communities inhabit mostly bottom substrates.

Different groups of PC animals (e.g., Cnidaria, Mollusca, Crustacea) are unevenly represented in different lists, and can benefit from consistency in conservation regulations. For example, in the Red Data Book of Ukraine, Cnidaria, Bivalvia and Crustacea are well embodied, but most of the endangered gastropods as well as the Europe's most endangered crayfish such as Pontastacus pachypus (Bláha et al. 2017; Policar et al. 2018) are absent (Table 3.1 and Table A3.3.1). Romanian Government Emergency Ordinance no. 57/2007 lists all 3 PC limnocardiine bivalve species, but all PC gastropods and other invertebrate PC groups are missing. IUCN assessments do not include most of the PC invertebrate groups, but only mollusks and crayfish are included in the European-level assessments (Cuttelod et al. 2011). Furthermore, most of the legal documents dealing with PC biodiversity conservation are outdated and in need of an update. One of the additional reasons for the non-inclusion of PC invertebrate taxa in legal documents may be the lack of a consistent taxonomy, which has made the production of a list of PC invertebrate species virtually impossible till now. Clearly, the taxonomy of PC biota needs to be updated, i.e. fix the taxonomic synonymy (see Appendix 3.3, but also Gogaladze et al. (Submitted), and Wesselingh et al. (2019)), before policymakers can be expected to include them in the legal documents.

Selection criteria for inclusion of species in national policy documents and assessments shall also be based on best scientific knowledge and transparent criteria in Romania and Ukraine. Unlike the broad-sweep, largely unbiased IUCN approach, evaluation of species for conservation purposes at the national level often depends on the availability and interests of experts and conservation organizations (Martín-López et al. 2007; Martín-López et al. 2009). For example, the selection process of taxa for evaluation in the Red Data Book of Ukraine (RDBU) is voluntary, thus depending on the willingness of the members of the RDBU commission as well as the state representatives, rather than on any transparent criteria (MOS, pers. comm). The same applies to Romania (Gogaladze et al. 2020a). Consequently, there is often a bias towards the 'preferred species' (species that are well known or have specialists working on them) resulting in omission of other species from evaluations. This automatically translates to the decisions made on choices of species for inclusion in the regional Black Sea Red Data Book (BSRDB). As a result, some common widespread species are given the status of "vulnerable" or even "endangered" in RDBU and BSRDB (MOS, pers. comm).

Revisions and amendments in the current legal documents, that shall be based on best scientific knowledge and transparent criteria, can be expected to improve the legal coherence on both horizontal (between Romania and Ukraine) and vertical (between Romania and EU as well as Ukraine and EU) levels. Legal coherence is an important requirement for effective implementation of conservation policy (Gomar et al. 2014) and an urgent priority in the cross-border conservation context of the Danube Delta. Many species and habitats, including PC biodiversity, cannot be maintained in single and/or isolated protected areas due to their dependence on specific interrelationships within their environment. Therefore, the Habitats Directive encourages EU member states, as well as the countries of the Eastern European partnership to ensure the ecological coherence of the Natura 2000 and Emerald Networks. Currently, effective management of Natura 2000 sites in Romania and the Emerald sites in Ukraine is hampered due to administrative challenges in the former (European Commission 2019) and absence of adequate legislation in the latter (Ministry of Ecology and Natural Resources of Ukraine 2018). However, teams of national and international experts are working hard on addressing these challenges and significant progress has already been made in preparing the Natura 2000 management plans in Romania and drafting new environmental laws and amending the existing laws in Ukraine to improve the biodiversity conservation framework. Such legal framework can be expected to benefit PC biodiversity conservation, as long as PC biodiversity is adequately integrated in legal documents and conservation plans.

3.4.2 How can PC biota be better protected?

PC invertebrate biodiversity conservation requires PC invertebrate community-tailored conservation approaches. Literature suggests that Romania and Ukraine meet most of the objectives of conserving globally important biological diversity within the Danube Delta, e.g. the wetlands and bird populations (The World Bank study team 2014). The endemic PC biodiversity, however, is declining and the legal basis to remedy this decline is weak in case of sturgeons (see e.g. ECODIT LLC 2017; ICPDR 2018, 2020), or non-existent in case of most invertebrate PC groups. The demise of PC sturgeon populations is recognized by the EU, the International Commission for the Protection of Danube River (ICPDR), and individual country authorities (ECODIT LLC 2017; ICPDR 2018). However, the majority of the associated invertebrate species are not part of the biodiversity conservation agenda. We argue that insufficient legal recognition of invertebrate PC biodiversity is an important driver of their demise, which, in turn, could be due to poor knowledge on PC species identities (Wesselingh et al. 2019) and their distributions (Gogaladze et al. Submitted), resulting into low conservation priority and the incentive for stakeholders to act (Gogaladze et al. 2020a; Gogaladze et al. 2020b). Improving the knowledge base on different aspects of PC biodiversity and informing the conservation practitioners and decision makers on the urgent need of PC biodiversity conservation is required to adequately address this biota.

PC invertebrate species shall be integrated in the protected area management plans. National protected areas do not cover most of the PC habitats in the Danube Delta (Table 3.3). Although Natura 2000 and Emerald sites cover most of the PC habitats, these networks only provide protection to species that are listed in the Annexes of Habitats and Birds Directives and the Appendices of the Bern Convention. PC invertebrate species are absent from relevant Annexes and Appendices (see Table 3.1 and Table A3.3.1), which means that they are automatically absent from site evaluations and environmental impact assessment studies. Unlike the national protected areas, on Natura 2000 and Emerald sites practically all types of activities are permitted, provided that they do not cause adverse impact on the species and habitats for which the given site was created. Therefore, PC invertebrate species cannot be adequately protected through the Natura 2000 and Emerald Network sites. Poor classification of PC habitats in Bern Convention (Table 3.2) could further limit the adequate assessments and site evaluations within the PC habitats. Additionally, the Emerald Network is relatively new and not yet fully integrated in Ukrainian legislation.

3.4.3 Does the flagship approach work here?

We did not find any studies or reports demonstrating the effectiveness of the conservation of sturgeons as surrogate species for wider PC taxa conservation. Furthermore, we argue that sturgeon species may not be considered as umbrella species for the PC invertebrate biodiversity. As mentioned in the introduction, flagship species are mostly used to promote public awareness and to raise funds for conservation (Verissimo et al. 2011), while the protection of umbrella species is expected to benefit a wide range of co-occurring species (Caro 2010; Roberge and Angelstam 2004). Sturgeons are indeed well-known by the general public, scientific community and policy makers and sturgeon conservation has received considerable funding from different sources, most notably from the EU LIFE program (https://ec.europa.eu/easme/en/life). However, sturgeon conservation cannot be expected to fully support the protection of PC invertebrate communities because sturgeon habitats make up only a small fraction of the entire PC range within Danube Delta. Danube sturgeons have been reported to inhabit the Danube River and its three branches (Schmutz and Sendzimir 2018). Many invertebrate PC species, however have been reported from isolated and/or semi-isolated lakes in and around the Danube Delta (Fig. 3.1), where Sturgeons have not been found. Therefore, sturgeon-related conservation measures and approaches can theoretically only benefit the co-occurring invertebrate communities. Future studies are needed to fully understand the ecological relationships between sturgeons and other PC taxa and showcase the benefits of sturgeon conservation for PC invertebrate biota in the Black Sea region.

Even if sturgeons cannot provide adequate protection to wider PC biodiversity through surrogacy, the sturgeon conservation networks create an excellent platform for the integration of lesser-known PC invertebrate biodiversity in the conservation programs. For example the Program "Sturgeon 2020" aims at halting sturgeon loss and improving their population sizes through 1) Acquiring political support for sturgeon conservation; 2) Capacity building and law enforcement;

3) In-situ sturgeon conservation; 4) Ex-situ sturgeon conservation; 5) Socio-economic measures in support of sturgeon conservation; and 6) Raising public awareness (ICPDR 2018, 2020). These measures, coupled with capacity building for conservation practitioners are urgently required also for the invertebrate PC communities and the sturgeon conservation networks can greatly help achieve it if financially supported and incentivized.

3.5 Conclusion

This study examined the current legal basis for addressing the decline of endemic aquatic biodiversity in Romania and Ukraine, known as Pontocaspian biota. The study showed that PC habitats and invertebrate species are poorly represented in international and national legal documents, even though they urgently require protection. Although the protected area network covers large parts of PC habitats, management plans are either not in place or fail to address the PC biodiversity conservation, providing incidental and therefore sub-optimal protection to the PC biodiversity. Furthermore, current PC biodiversity related legal landscape is incoherent on both horizontal (between Romania and Ukraine) and vertical (between Romania and EU as well as Ukraine and EU) levels. PC flagship species such as the sturgeon species are recognized to be under great threat and are well represented in legal documents. They can, however, not be considered as effective umbrella species for the conservation of wider PC taxa due to habitat mismatches. We recommend updating of laws and regulations that list the PC species and/or habitats and amendments according to the best available scientific knowledge. PC invertebrate biodiversity conservation requires integration of this biota in the protected area management plans and the development of PC invertebrate community-tailored conservation approaches.

Appendices

Appendix 3.1. Key search terms used for PC species and habitat presence in legal documents.
Appendix 3.2. PC biodiversity legal landscape
Appendix 3.3. PC species presence in the analyzed legal documents.
Appendix 3.4. Protected areas overlaying the PC habitats in the Danube Delta.

Appendix 3.1. Key search terms used for PC species and habitat presence in legal documents.

PC species

Table A3.1.1. Pontocaspian (PC) invertebrate groups, approximate number of PC species within each group (depending on author interpretations) and list of the parent genus names. Genus names listed here are used as key terms for the analysis to search for the PC species presence in the identified legal documents (Appendix 3.2). These names are known for Danube Delta and include both, currently accepted but also unaccepted terms, which have been used by different authors in the last decade.

	PC groups †	Number of species	Reference	PC genus names
Invertebrate	Cnidaria	2-4	(Mordukhay-Boltovskoy 1960)	*Cordylophora, Moerisia, Odessia, Polypodium*
	Hyrudinea	1	(Mordukhay-Boltovskoy 1960)	*Archaeobdella*
	Polychaeta	3	(Mordukhay-Boltovskoy 1960)	*Hypania, Hypaniola, Manajunkia*
	Gastropoda	12	(Wesselingh et al. 2019)	*Theodoxus, Neritina, Caspia, Clathrocaspia, Laevicaspia, Pyrgula, Euxinipyrgula, Turricaspia, Clessiniola*
	Bivalvia	6	(Wesselingh et al. 2019)	*Adacna, Monodacna, Hypanis, Dreissena*
	Amphipoda	40-45	(Mordukhay-Boltovskoy 1960)	*Gammarus, Dikerogammarus, Pontogammarus, Echinogammarus, Obessogammarus, Stenogammarus, Niphargoides, Niphargogammarus, Chaetogammarus, Iphigenella, Cardiophilus, Gmelina, Amathilina, Gmelinopsis, Turkogammarus, Corophium, Chelicorophium*
	Mysidae	10	(Audzijonyte et al. 2008)	*Paramysis, Katamysis, Limnomysis, Hemimysis*
	Decapoda	2	(Policar et al. 2018)	*Astacus, Pontastacus*
	Isopoda	1	(Mordukhay-Boltovskoy 1960)	*Jaera*
	Copepoda	12	(Monchenko 2003)	*Halicyclops, Schyzopera*
	Cladocera	4-5	(Mordukhay-Boltovskoy 1960)	*Cercopagis, Evadne*
	Cumacea	11	(Mordukhay-Boltovskoy 1960)	*Pterocuma, Stenocuma, Pseudocuma, Schizorhynchus*
	Acari	1	(Mordukhay-Boltovskoy 1960)	*Caspiahalacarus*
Vertebrate	Sturgeons	5-6	(Eschmeyer and Bailey 1990)	*Acipenser, Huso*

† We exclude Turbellaria, parasitic worms, Ostracoda, Bryozoa and Oligochaeta, because there is no common agreed understanding among specialists which species in these groups are Pontocaspian relics.

PC habitats

Optimum PC habitats, defined by Gogaladze et al. (Submitted) contain following habitat types from the EUNIS habitat classification (https://eunis.eea.europa.eu/):

1. A2: Littoral sediment
2. C1.2: Permanent mesotrophic lakes, ponds and pools
3. C2.32: Metapotamal and hypopotamal streams
4. C2.41: Brackish water tidal rivers
5. C2.42: Freshwater tidal rivers (within low reaches of large rivers and estuaries in Ukrainian and Romanian sectors of Black and Azov seas)
6. X01: Estuaries
7. X03: Brackish coastal lagoons

We searched for these habitat types in identified legal documents to check for presence of PC habitats. Additionally, we searched in the identified legal documents for the following key words: “Pontocaspian”, “Ponto-caspian”, “Ponto”, “Pontic”, “lagoon”, “liman”, “estuary”, “stream”, “lake”, “river”, “coastal”, “transitional”, “brackish”, “anomalohaline” and “freshwater”.

Appendix 3.2. PC biodiversity legal landscape

Global targets and assessments

MDGs/SDGs - Millennium Development Goals (MDGs), started a global effort in 2000 to tackle poverty and hunger, which was in 2012 replaced by the Sustainable Development Goals (SDGs), whose objective was to "produce a set of universal goals that meet the urgent environmental, political and economic challenges facing our world". Aichi Biodiversity targets are a set of 20 global targets under the Strategic Plan for Biodiversity 2011-2020. World Ocean Assessments (WOA) is a report on the state of the planet's oceans, which includes the Black Sea and the Danube Delta (UN group of experts 2016). Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) performs regular and timely assessments of knowledge on biodiversity and ecosystem services and their interlinkages at the global level (Díaz et al. 2019). Full names and descriptions of biodiversity conventions, EU Directives and the national laws of Romania and Ukraine are provided below.

Biodiversity conventions

Bern Convention - Convention on the Conservation of European Wildlife and Natural Habitats (1979) aims to preserve the wild flora and fauna in Europe. It provides the lists of threatened species under two categories: 'Strictly Protected' (Annex I for plants and Annex II for animals) and 'Protected' (Annex III). Habitats, which shall be protected are listed in Annex I of the Resolution No. 4 (1996) of the Convention. Habitat list was initially based on the Palaearctic Classification (Devilliers and Devilliers-Terschuren 1996), but this classification is no longer supported so, in 2019 a revised Annex I was adopted based on the EUNIS classification (Evans and Roekaerts 2015). Annex I is periodically updated, last time being December 2019 (https://rm.coe.int/16807469e7).

Bucharest Convention - Convention on the Protection of the Black Sea against Pollution (1992), addresses biodiversity conservation in its provisions, among other environmental concerns, in response to which the Black Sea Red Data Book was developed listing the endangered species and their habitats.

CBD - Convention on Biological Diversity (1992) is a global agreement of nations to achieve effective biodiversity conservation, sustainable use of the components of biodiversity and equitable sharing of the benefits arising from the genetic resources (article 1). The convention defines the overall biodiversity goals and provides the policies for its parties (individual contracting countries) to implement. The local context of every party is different, so the countries determine the course of action for implementing the provisions of the convention in their own unique way through the preparation and implementation of National Biodiversity Strategies and Action Plans (NBSAPs).

CITES - Convention on the International Trade in Endangered Species of Wild Fauna and Flora (1973) is an international agreement that prevents species from becoming or remaining object of unsustainable exploitation by international trade (https://www.cites.org/). Within the EU, provisions of CITES are implemented through the Wildlife Trade Regulations. EU Council Regulation (EC) No 338/97 covers the species listed in the Appendices I-III of CITES, in its Annexes A-C respectively. Annexes A and B also include some of the non-CITES species, and Annex D includes mostly no-CITES species to protect the native European species, which are under the Habitats Directive (https://ec.europa.eu/environment/cites/legislation_en.htm).

CMS - Convention on the Conservation of Migratory Species of Wild Animals (1979) is an international treaty of the United Nations for the conservation and sustainable use of migratory animals and their habitats (https://www.cms.int/en/legalinstrument/cms). The convention lists threatened species in Appendix I, and species that require international agreement to conserve in Appendix II.

DRPC - Danube River Protection Convention (1994) forms an overall legal instrument aiming to ensure that the surface and ground waters of the Danube River Basin are sustainably and equitably managed. DRPC is implemented by the International Commission for the Protection of the Danube River (ICPDR). The ICPDR consists of delegates from all Contracting Parties to the DRPC, but also developed a framework allowing other organizations to join. Biodiversity conservation is one of the key priorities for the ICPDR. As a result, ICPDR monitors Danube River biodiversity and develops and implements conservation programs and strategies.

Espoo convention - Convention on Environmental Impact Assessment in a Transboundary Context (1991) aims at preventing, reducing and controlling negative transboundary environmental impacts from proposed development interventions at an early stage of planning. Convention does this by institutionalizing a standardized process of transboundary environmental impact assessment (EIA). In considering proposed activities the concerned Parties may consider whether the activity is likely to have a significant adverse transboundary
impact on the national protected areas, Ramsar sites, sites of special scientific interest or cultural heritage sites (Appendix III). According to the convention the effects of human activities on 'valued' biological species and organisms shall also be considered.

Ramsar Convention - Convention on Wetlands of International Importance Especially as Waterfowl Habitat (1971) is an international treaty on the protection of the wetlands of international importance (Matthews 1993). This convention does not list species or habitats that shall be protected. However, on the 9th Meeting of the Conference of the Parties (COP), Resolution IX.1 Annex E identified coastal tidal flats and rivers and streams as priority areas that shall receive more attention to improve integrated wetland inventory, assessment and monitoring.

WHC - Convention for the Protection of the World Cultural and Natural Heritage (1972) aims to identify and protect the world's natural and cultural heritage by establishing a list of properties that have outstanding universal value, which is referred to as the World Heritage List. Such properties represent the part of the cultural and natural heritage of states that are Parties to the WHC.

EU Directives

European Union's implementation of the commitments outlined in CBD and Bern Convention is achieved through four directives: 1) The Council Directive 79/409/EEC on the protection of wild birds, adopted in 1979 (Birds Directive); 2) the Habitats Directive (EU 1992); 3) Water Framework Directive (WFD); and 4) Marine Strategy Framework Directive (MSFD). The Birds Directive is about protecting wild bird species, which naturally occur within the EU. The Habitats Directive complements the Birds Directive by including additional animal and plant species and their habitats. The Directive lists natural habitat types of community interest in its Annex I. Animal and plant species of community importance are listed in three different annexes. Annex II lists the species whose conservation requires designation of special areas of conservation (SAC). Annex IV lists those species, which are strictly protected beyond the SACs; and Annex V lists the species whose taking from the wild and exploitation may be subject to management measures. Central to the Habitats Directive is the creation of 'Natura 2000', an EU-wide ecological network comprising all areas that are protected under the Birds Directive (Special Protection Areas, SPAs) and the Habitats Directives (SACs composed of sites hosting the natural habitat types listed in Annex I and habitats of the species listed in Annex II). Equivalent to Natura 2000 in non-EU European countries, such as Ukraine, is the Emerald Network, which is based on the Bern Convention. WFD aims to maintain and/or improve the ecological conditions of water bodies within the EU. This Directive is not focused on biodiversity conservation and lists the taxonomic groups only as indicators for monitoring the water quality. Marine Strategy Framework Directive (MSFD) extends the WFD to the marine realm. Similar to the WFD, the MSFD obliges the EU member states to monitor the water quality based on biological, chemical and physical indicators (Annex III). MSFD lists the priority habitats and taxonomic groups. Listed habitats encompass benthic and pelagic habitats, habitats that are listed in the Habitats Directive that belong to the marine realm, and habitats of special regional interest. Listed taxa include marine planktonic groups, benthic invertebrates, fishes, marine mammals and reptiles among others.

Cross Border Cooperation (CBC) is a key element of the European Neighbourhood Policy (ENP), which promotes cooperation between EU countries and neighbourhood countries sharing a land border or sea crossing. CBC supports and encourages cross-border cooperation among Romania, Ukraine and Moldova (https://www.ro-ua.net/en/). LIFE program is a funding instrument of EU for environment and climate action, that supports biodiversity conservation programs in the Danube Delta, e.g., LIFE for Danube Sturgeons Project (https://danube-sturgeons.org/the-project/).

Table A3.2.1. National laws and resolutions of Romania and Ukraine related to Pontocaspian biodiversity conservation.

Romania (RO)		Ukraine (UA)	
Laws and regulations	**Description**	**Laws and Regulations**	**Description**
Government Urgency Ordinance No. 195/2005 on environmental protection, approved by Law no. 265/2006 and last updated on 22/12/2007 https://lege5.ro/Gratuit/hazdinrs/ordonanta-de-urgenta-nr-195-2005-privind-protectia-mediului?d=2020-08-24	This normative act was adopted as a matter of urgency to fulfill the requirements of the EU in the process of integration and regulates environmental protection in Romania. This emergency ordinance is the basis of subsequent environmental legislation.	The Act of Ukraine on the protection of environment (1991, No. 41). https://zakon.rada.gov.ua/laws/show/1264-12	The act defines the overall legal environmental framework and is very important for all the environmental activities. It briefly discusses biodiversity conservation in general terms (including aquatic living resources) through the prevention of economic activities from nature reserves and objects which are subject to special protection, such as those listed in the Red Book of Ukraine.
NA	NA	Law of Ukraine on the Main Principles (Strategy) of the State Environmental Policy of Ukraine for the period up to 2020 (2010, No. 2818-VI). https://zakon.rada.gov.ua/laws/show/2818-17#Text	The law aims to stabilize and improve the ecological conditions in Ukraine through the integration of environmental values and concerns into the development strategies of different sectors. Target 5 of the law, specifically addresses the loss of biological and landscape diversity and aims at conserving rare and endemic biological species in compliance with the EU regulations.
NA	NA	Law on the Red Book of Ukraine (2002, No. 3055-III). https://zakon.rada.gov.ua/laws/show/3055-14#Text	The objective of the law is to regulate public relations regarding the conservation, utilization and reproduction of rare and endangered species of flora and fauna listed in the Red Book of Ukraine, with the purpose of preventing the extinction of such species from nature and ensuring the preservation of species and genetic diversity. This law itself does not list species.
NA	NA	Law on Fauna (2001, No. 2894-III). https://zakon.rada.gov.ua/laws/show/2894-14#Text	The law ensures the protection of wildlife by the establishment of the rules and standards for protection and rational use of wildlife objects; the creation of ecological network and state reserves as well as the identification of new areas (which are subject to special protection); development and implementation of conservation programs and action plans for the species included in the Red Book of Ukraine.
Government Emergency Ordinance No. 236/2000 on the regime of protected natural areas, conservation of natural habitats, wild flora and fauna (http://legislatie.just.ro/Public/DetaliiDocument/25339), approved with modifications and completions by Law no. 462/2001 (http://legislatie.just.ro/Public/DetaliiDocument/29936), and its Annexes No. 2, 3, 4 and 5 updated by Order No. 1198 of the 25th of November 2005.	This emergency ordinance aims to guarantee the conservation and sustainable use of the natural heritage by regulating the conservation of biological diversity by conserving natural habitats; national protected area categories, natural habitat types and establishment and management of national protected areas, among others. The Emergency Ordinance lists natural habitats whose conservation require the declaration of special conservation areas in Annex 2, Annex 3 is a continuation of Annex 2 for the establishment of the network of special conservation areas and lists the plants and animals whose conservation requires the designation of special areas of conservation. Furthermore, Annexes 4 and 5 list the species of community importance that require strict protection.	Law on the Ukraine Nature Reserve Fund (1992, No. 2456-XII; amended in January 2010) https://zakon.rada.gov.ua/laws/show/2456-12#Text	The law defines the legal basis for the organization, protection and effective use of the nature reserve fund of Ukraine, which includes the biosphere reserves and national nature and landscape parks, among others.

(continuation Table A3.2.1.)

Romania (RO)		Ukraine (UA)	
Laws and regulations	**Description**	**Laws and Regulations**	**Description**
NA	NA	Law on Ecological Network of Ukraine (2004, No. 1864-IV). https://zakon.rada.gov.ua/laws/show/1864-15#Text	Ecological network is built on the foundations provided by the existing protected areas including the Emerald Network. Among others, the ecological networks include the territories that are habitats of species of fauna and flora listed in the Red Data Book of Ukraine. The law provides the framework for formation and management of ecological networks. The legal basis for the formation of the national ecological network are the laws of Ukraine "On the protection of the environment" (1264-12), "On the nature reserve fund of Ukraine" (2456-12), "On the animal world" (3041-12), "On flora world "(591-14), Land Code of Ukraine (561-12), Forest Code of Ukraine (3852-12) and Water Code of Ukraine (213/95-BP).
Urgency Ordinance No. 57/2007 regarding the management of protected areas and the conservation of natural habitats and wild flora and fauna (http://legislatie.just.ro/Public/DetaliiDocument/83289) approved by Law No. 49 of April 7, 2011 (http://legislatie.just.ro/Public/DetaliiDocumentAfis/127715)	This Urgency Ordinance transposes the Habitats Directive into the national Romanian laws and shapes the policies concerning the protected areas. On the date of entry into force of this Emergency Ordinance the Government Emergency Ordinance no. 236/2000 shall be repeated. The Emergency Ordinance lists the priority habitats in Annex 2 and propriety species in Annexes 3, 4A, 4B, 5A, 5B, 5C, 5D and 5E as a cornerstone for conservation.	Protected Areas Act (last amended December 2010): The main framework for the governance, conservation, and effective use of protected areas in Ukraine	The Act provides a legal base for establishing and managing protected areas. Also, it establishes a classification of protected areas in Ukraine.
Forest Code - Law no. 46/2008 (updated in 2016) http://legislatie.just.ro/Public/DetaliiDocumentAfis/227177.	The Forest Code regulates not only forested lands, but also water bodies within the forests and the associated biodiversity	Forest Code of Ukraine (1994, No 3852-XII. Last amended in December 2010). https://zakon.rada.gov.ua/laws/show/3852-12#Text	The Forest Code covers not only forested lands, but all lands supervised by the State Agency of Forest Resources, which include many wetlands and certain agricultural lands.
Water Law No. 107/1996	The Law regulates the use, conservation and protection of water resources, including the coastal ecosystems of the Black Sea and Danube Delta.	Water Code (1995, No. 213/95-VR. last amended in December 2010) https://zakon.rada.gov.ua/laws/show/213/95-%D0%B2%D1%80#Text	The Water Code defines roles and responsibilities of state institutions in water management, briefly mentioning that waters found within protected areas are thereby protected.
NA	NA	Land Code of Ukraine (2002, №2768-III). https://zakon.rada.gov.ua/laws/show/2768-14#Text	The Land Code ensures rational land use and protection of lands. It divides all the land into nine categories, including a category "water lands" which is relevant to PC biodiversity

(continuation Table A3.2.1.)

Romania (RO)		Ukraine (UA)	
Laws and regulations	**Description**	**Laws and Regulations**	**Description**
Law No. 292 of December 3, 2018 on assessing the impact of certain public and private projects on the environment. http://legislatie.just.ro/Public/DetaliiDocumentAfis/208590	This law regulates the environmental impact assessment of public and private projects that may have significant effects on the environment. Namely, on biodiversity, paying special attention to protected species and habitats in accordance with the provisions of Government Emergency Ordinance no. 57/2007, approved with amendments and completions by Law no. 49/2011, with subsequent amendments and completions.	Law of Ukraine on environmental impact assessment (No. 2059-VIII, 2017) https://zakon.rada.gov.ua/laws/show/2059-19#Text	The law provides framework for environmental impact assessments (EIAs) that apply to new projects that may have adverse impacts on the environment.
Governmental Emergency Ordinance No. 23/2008 on the fisheries and aquaculture. http://legislatie.just.ro/Public/DetaliiDocument/90207	This Emergency Ordinance is a general regulatory framework under which a secondary legislation is issued related to the fisheries sector. It regulates the conservation and exploitation of living water resources in the Black Sea and Danube Delta by laying down measures concerning the organizational and administrative responsibilities related to fishing, control and observance of legislation, responsibilities and sanctions and scientific research in the field. This Emergency Ordinance was issued for swift adoption of the EU legal framework in accordance to the Community Fisheries Policy.	NA	NA
Law No. 192 of 19 April 2001 on fish stocks, fisheries and aquaculture. http://legislatie.just.ro/Public/DetaliiDocumentAfis/46009	Regulates fishing periods and duration in different areas in Romania, including Danube Delta and Razim-Sione complex. In Annex 2 the law lists species which are prohibited to catch. Annex 4 lists the minimum dimensions of the fish, mollusk, amphibian (e.g., frogs) and crustacean species that can be fished in Romanian waters.	Law №3677 of 2011 on Fishery, Industrial Fishery and Protection of Water Biological Resources. https://zakon.rada.gov.ua/laws/show/3677-17#Text	This Law defines the basic principles of activity and state regulation in the field of fisheries, conservation and rational use of aquatic bioresources, the order of relations between public authorities, local governments and economic entities engaged in fishery activities in inland water bodies of Ukraine, inland marine waters and territorial sea.
Order no. 545/715/2016 on measures to restore and conserve sturgeon populations in natural fish habitats https://lege5.ro/Gratuit/geydknrvgm2a/ordinul-nr-545-715-2016-privind-masurile-de-refacere-si-conservare-a-populatiilor-de-sturioni-din-habitatele-piscicole-naturale	This order aims to conserve sturgeon populations in natural waters from threats and to develop sturgeon aquaculture.	Law № 5293-VI of 2013 about aquaculture. https://zakon.rada.gov.ua/laws/show/5293-17#Text	This Law defines the basic principles of development and functioning of aquaculture and provides the legal basis for the activities of executive authorities and local governments in the field of aquaculture. Sturgeons are briefly mentioned in the law.

Appendix 3.3. PC species presence in the analyzed legal documents.

Table 3.3.1. PC species presence in the analyzed legal documents.

		UN Conventions		EU		Romania		Ukraine	Other	
	Species	**Bern convention**	**CITES and CMS**	**Habitats Directive**	**EU Wildlife Trade regulation**	**Emergency Ordinance no 57/2007**	**Law. No. 192/2001**	**Law No. 3055-III**	**IUCN (EU)**	**Bucharest Convention (RO; UA)**
Amphipoda	Dikerogammarus villosus	-	-	-	-	-	-	-	-	VU (VU; VU)
	Niphargogammarus intermedius (as Niphargoides intermedius in RBDU)	-	-	-	-	-	-	VU	-	-
	Gmelina pussila	-	-	-	-	-	-	VU	-	-
	Iphigenella acanthopoda	-	-	-	-	-	-	EN	-	VU (-; VU)
	Lanceogammarus andrussovi (as Iphigenella andrussovi in BSRDB and RDBU)	-	-	-	-	-	-	VU	-	LR (NE; LR)
	Shablogammarus chablensis (as Iphigenella shablensis in BSRDB and RDBU)	-	-	-	-	-	-	VU	-	VU (-;-)
Bivalvia	Adacna fragilis (as Hypanis laeviuscula (Milachevitch, 1916) in RBDU)	-	-	-	-	Present	-	VU	-	-
	Dreissena bugensis	-	-	-	-	-	-	-	LC	-
	Dreissena polymorpha	-	-	-	-	-	-	-	NA¥	-
	Monodacna colorata	-	-	-	-	Present	-	-	-	-
	Hypanis plicata	-	-	-	-	Present	-	VU	-	-
Cnidaria	Odessia maeotica (as Moerisia maeotica in BSRDB and RDBU)	-	-	-	-	-	EN	-	VU (EN; VU)	
Decapoda	Astacus astacus	-	-	Present	-	Present	Astacus sp.	-	-	-
Gastropoda	Clathrocaspia knipowitchii (as Caspia knipowitchii in EURL)	-	-	-	-	-	-	-	LC	-
	Laevicaspia ismailensis (as Turricaspia ismailensis in EURL)	-	-	-	-	-	-	-	VU B1ab(iii)	-
	Theodoxus danubialis (as Theodoxus prevostianus in EU Habitats Directive and Emergency Ordinance no 57/2007)	-	-	Present	-	Present	-	-	LC	-
	Theodoxus fluviatilis	-	-	-	-	-	-	-	LC	-
	Turricaspia dimidiata	-	-	-	-	-	-	-	DD	-

(continuation Table A3.3.1.)

		UN Conventions		EU		Romania		Ukraine	Other	
	Species	Bern convention	CITES and CMS	Habitats Directive	EU Wildlife Trade regulation	Emergency Ordinance no 57/2007	Law. No. 192/2001	Law No. 3055-III	IUCN (EU)	Bucharest Convention (RO; UA)
	Clessinola variabilis (as Turricaspia variabilis in EURL)	-	-	-	-	-	-	-	DD	-
	Laevicaspia lincta (as Turricaspia lincta in EURL)	-	-	-	-	-	-	Rare	LC	-
Hirudinea	Archaeobdella esmonti	-	-	-	-	-	-	VU	-	-
Mysida	Katamysis warpachowskyi	-	-	-	-	-	-	EN	-	EN (NE; EN)
	Hemimysis anomala	-	-	-	-	-	-	EN	-	EN (NE; EN)
Sturgeons	Acipenser nudiventris	-	Present in CMS	Present	-	Present	Present	EX	CR	-
	Acipenser ruthenus	Present	Present in CMS	Present	-	Present	Present	EN	VU	-
	Acipenser sturio	Present	Present in CMS and CITES	Present	Present	Present	Present	EX	CR	-
	Acipenser gueldenstaedtii	-	Present in CMS	Present	-	Present	Present	VU	CR	VU (VU; VU)
	Acipenser stellatus	Present	Present in CMS	Present	-	Present	Present	VU	CR	VU (VU; VU)
	Huso huso	Present	Present in CMS	Present	-	Present	Present	EN	CR	

¥ According to EU IUCN list of non-marine mollusks "species were considered to be Not Applicable (NA) if they were judged to be of marginal occurrence in the region. Species were regarded as of marginal occurrence if it was estimated that less than 1% of their global range lies within Europe and if the European populations are not disjunct of the main species range".

Appendix 3.4. Protected areas overlaying the PC habitats in the Danube Delta.

Table A3.4.1. International regional and national protected areas that cover parts of the PC habitats in the Danube Delta. Percentages of PC habitats that are within protected areas are reported in Table 3.3.

Administrative level	Designation type	Site name	Site ID	Area (km^2)	PC habitats covered (Gogaladze et al. Submitted)	Management Plan	Country
Global	World Heritage Site (natural or mixed)	Danube Delta	67728	3124.4	Most of the PC habitats in Romania	Not Reported	RO
Global	Ramsar Site	Danube Delta	68147	6470	Most of the PC habitats in Romania	Management plan is implented and available	RO
Global	IBA	Lake Beibugeac (Plopu)	RO084	2.4	Floodplain lakes south to Sf. Gheorghe branch	NA	RO
Global	IBA	Black Sea	RO082	1429.55	Sakhalin area and Musura Bay	NA	RO
Global	IBA	Danube Delta	RO081	5155.8	Most of the PC habitats in Romania	NA	RO
Global	IBA	Beştepe - Mahmudia	RO083	42.9	Floodplain lakes south to Sf. Gheorghe branch	NA	RO
Global	Ramsar Site	Kartal Lake	166896	5	Northern floodplain lakes west of Izmail	Management plan is not implented and not available	UA
Global	Ramsar Site	Kugurlui Lake	166898	65	Kugurlui Lake	Management plan is not implented and not available	UA
Global	Ramsar Site	Kyliiske Mouth	166899	328	Chilia branch and outer delta lakes downstream from Vilkovo	Management plan is not implented but is available	UA
Global	Ramsar Site	Sasyk Lake	166904	210	Sasyk Lake	Management plan is not implented and not available	UA
Global	UNESCO-MAB Biosphere Reserve	Dunaisky	220032	464.03	Chilia branch and outer delta lakes downstream from Vilkovo and Chilia branch of Danube River, upstream from Vilkovo	Not Reported	UA
Global	IBA	Sasyk lake	UA085	228	Sasyk lake	NA	UA
Global	IBA	River Danube	UA082	25	A stretch of the River Danube, Chilia branch, near Kiliya town	NA	UA
Global	IBA	Stentsivs'ko-Zhebriyanivs'ki plavni	UA084	420	Chilia branch of Danube River, upstream from Vilkovo	NA	UA
Global	IBA	Kugurluj and Kartal lakes	UA081	192	Kugurluj and Kartal lakes	NA	UA
Global	IBA	Kytaj lake	UA083	50	Kytaj lake	NA	UA
Global	IBA	Kagul lake	UA080	105	Kagul lake	NA	UA
European	Site of Community Importance (Habitats Directive)	Delta Dunării	ROSCI0065	4532.0526	Most of the PC habitats in Romanian part of the Danube Delta	Present	RO

(Continuation Table A3.4.1.)

Administrative level	Designation type	Site name	Site ID	Area (km2)	PC habitats covered (Gogaladze et al. Submitted)	Management Plan	Country
European	Site of Community Importance (Habitats Directive)	Delta Dunării - zona marină	ROSCI0066	3357.2249	Sakhalin area and Musura Bay	Present	RO
European	Special Protection Area (Birds Directive)	Beştepe - Mahmudia	ROSPA0009	36.5133	Floodplain lakes south to Sf. Gheorghe branch	Present	RO
European	Special Protection Area (Birds Directive)	Delta Dunării și Complexul Razim - Sinoie	ROSPA0031	5078.2463	Most of the PC habitats in Romanian part of the Danube Delta	Present	RO
European	Special Protection Area (Birds Directive)	Lacul Beibugeac	ROSPA0052	4.6861	Floodplain lakes south to Sf. Gheorghe branch	Present	RO
European	Special Protection Area (Birds Directive)	Marea Neagră	ROSPA0076	1489.7589	Sakhalin area and Musura Bay	Present	RO
European	Special Protection Area (Birds Directive)	Lacul Brateş	ROSPA0121	158.7484	Lake Brates	Absent	RO
European	Emerald Network	Danube Biosphere Reserve	UA0000018	501.27	Bistroe Channel of the Danube Delta and upper tip of Lake Sasyk	Absent	UA
European	Emerald Network	Izmailski Ostrovy	UA0000182	35.43	Kiliya Branch of Danube River and lake Lung located near town Izmail	Absent	UA
European	Emerald Network	Systema Dunaiskykh Ozer	UA0000142	526.58	Lakes Kagul, Kugurlui, Yalpug, Katlabukh and Kitai.	Absent	UA
European	Emerald Network	Sasyk Lyman	UA0000151	189.51	Lake Sasyk		UA
National	Nature Reserve	Ostrovul Prut	183971	0.82	Danube River Braila-Tulcea (small part close to Galati)	Not reported	RO
National	Nature Reserve	Călugăru - Iancina	193264	1.37	Lake Razim-Golovita (small coastall part)	Not reported	RO
National	Nature Reserve	Dealurile Beştepe	193266	3.48	Floodplain lakes south to Sf. Gheorghe branch	Not reported	RO
National	Nature Reserve	Enisala	193267	0.62	Floodplain lakes south to Sf. Gheorghe branch	Not reported	RO
National	Natural Park	Parcul Natural Lunca Joasă A Prutului Inferior	196473	81.08	Lake Brates; small part of the Danube River (close to Galati)	Not reported	RO
National	Scientific Reserve	Insulele Prundu Cu Păsări	392158	1.86	Part of Lake Razim-Golovita	Not reported	RO
National	Scientific Reserve	Insula Ceaplace	392159	1.18	Part of Lake Razim-Golovita	Not reported	RO
National	Nature Reserve	Corbu - Nuntași - Histria	9388	18.03	Coastal lakes near Lake Sinoe	Not reported	RO
National	Nature Reserve	Complexul Sacalin Zătoane	11184	190.54	Sakhalin area	Not reported	RO

(Continuation Table A3.4.1.)

Administrative level	Designation type	Site name	Site ID	Area (km2)	PC habitats covered (Gogaladze et al. Submitted)	Management Plan	Country
National	Nature Reserve	Roşca - Buhaiova	31702	92.99	Floodplain lakes between Chilia and Sulina branches	Not reported	RO
National	Nature Reserve	Pădurea Letea	31703	24.47	Floodplain lakes between Chilia and Sulina branches	Not reported	RO
National	Nature Reserve	Grindul Şi Lacul Răducu	31704	27.12	Floodplain lakes between Chilia and Sulina branches	Not reported	RO
National	Nature Reserve	Lacul Nebunu	31705	1.36	Floodplain lakes between Chilia and Sulina branches	Not reported	RO
National	Nature Reserve	Pădurea Caraorman	31706	22.57	Floodplain lakes between Sulina and Sf. Gheorghe branches	Not reported	RO
National	Nature Reserve	Complexul Vătafu - Lunguleţ	31707	15.68	Floodplain lakes between Sulina and Sf. Gheorghe branches	Not reported	RO
National	Nature Reserve	Complexul Periteaşca - Leahova	31708	41.55	Lake Leahova	Not reported	RO
National	Nature Reserve	Sărăturile Murighiol	31709	1.01	Floodplain lakes south to Sf. Gheorghe branch	Not reported	RO
National	Nature Reserve	Arinişul Erenciuc	31710	0.3	Small coastal part of Sf. Gheorghe branch of Danube River	Not reported	RO
National	Nature Reserve	Insula Popina	31711	0.89	Small part of Lake Razim	Not reported	RO
National	Nature Reserve	Capul Doloşman	31713	1.03	Small coastal part of Lake Razim	Not reported	RO
National	Nature Reserve	Grindul Lupilor	31714	21.45	Part of Lake Razim-Golovita	Not reported	RO
National	Nature Reserve	Grindul Chituc	31717	24.94	Coastal lakes near Sinoe	Not reported	RO
National	Nature Reserve	Lacul Potcoava	183474	7.28	Floodplain lakes between Sulina and Sf. Gheorghe branches	Not reported	RO
National	Nature Reserve	Lacul Belciug	183475	1.12	Floodplain lakes south to Sf. Gheorghe branch	Not reported	RO
National	Nature Reserve	Cetatea Histria	183476	4.33	Part of Lake Sinoe	Not reported	RO
National	National Biosphere Zapovednik	Dunaiskiy / Danube Delta	160873	464.02	Chilia branch and outer delta lakes downstream from Vilkovo and Chilia branch of Danube River, upstream from Vilkovo	Not reported	UA


Supreme

4

Using social network analysis to assess the Pontocaspian biodiversity conservation capacity in Ukraine

Published as:
Gogaladze, A., Wesselingh, F.P., Biesmeijer, K., Anistratenko, V.V., Gozak, N., Son, M.O., Raes, N., 2020. Using social network analysis to assess the Pontocaspian biodiversity conservation capacity in Ukraine. *Ecology and Society* 25(2):25. https://doi.org/10.5751/ES-11575-250225

Abstract
Social networks, defined as sets of relationships between stakeholder organizations, are important determinants of constructive actions for biodiversity conservation. Such actions are achieved through cooperation between various stakeholders, exchange of information, and joint planning and implementation. Here we used a mix of qualitative and quantitative social network analysis methods to investigate the inter-organizational network of stakeholders in Ukraine, and the implications of network properties for the conservation of Pontocaspian biodiversity. Pontocaspian biota contains unique and endemic fauna, which are threatened by anthropogenic impacts, making effective conservation measures an urgent priority. We identified a well-connected, centralized network in Ukraine. However, the strong network has not resulted in effective conservation of Pontocaspian biodiversity. Suboptimal conservation action stems from the subordinate role of Pontocaspian species in the inter-organizational interactions, likely due to lack of knowledge regarding Pontocaspian taxa. Social variables, such as funding scarcity and legal constraints, further limit the effectiveness of biodiversity conservation actions. We conclude that the current landscape of stakeholders in Ukraine is well placed to rapidly improve conservation actions if supplied with improved information and recognition of conservation needs of Pontocaspian taxa, combined with improved financial and legal conditions.

4.1 Introduction

Pontocaspian biota comprises endemic flora and fauna which evolved in the isolated anomalohaline (brackish) lake systems in and around the Black and Caspian Sea basins over the past two million years (Kostianoy and Kosarev 2005; Krijgsman et al. 2019). This biota includes mollusks, crustaceans, and fish, as well as planktonic groups such as dinoflagellates and diatoms (Grigorovich et al. 2003; Marret et al. 2004). Within their native range, the diversity and abundance of Pontocaspian species are subject to anthropogenic pressures, such as habitat destruction, introduction of invasive alien species and pollution (Grinevetsky et al. 2016; Lattuada et al. 2019; Velde et al. 2019). The Ukrainian territory covers an important part of Pontocaspian habitats (Fig. 4.1). In Ukraine, Pontocaspian species richness and abundance are in decline and require effective conservation actions (Anistratenko and Anistratenko 2018; Bloesch et al. 2006; Wesselingh et al. 2019). Legal instruments for the conservation of Pontocaspian biota are confined to few taxa (Anistratenko 2009; Dumont et al. 1999; Munasypova-Motyash 2009a, b) and scientific information regarding the majority of Pontocaspian species is scarce and restricted to individual stakeholder organizations (ECODIT LLC 2017).

This study is part of the Horizon 2020 'Pontocaspian Biodiversity Rise and Demise' (PRIDE) program. The PRIDE program (http://www.pontocaspian.eu/) was designed to generate scientific knowledge on Pontocaspian biodiversity, inform decision-making, and guide effective conservation policy. Effective collaboration between stakeholder organizations, defined as high levels of information exchange and coordination of joint actions is essential for adequate implementation of biodiversity conservation measures (Binning et al. 1999; Briggs 2001; Durham et al. 2014). Different types of stakeholders such as academic organizations, policy makers, non-governmental organizations, public sector and conservation managers need to be involved and act at different levels of biodiversity conservation. This involvement ranges from the delivery of scientific information, to the enforcement of rules and regulations and actual implementation of conservation measures (Durham et al. 2014). Scientific information, knowledge and management experiences are at the heart of these processes (Lee 1999; Salafsky et al. 2002). Therefore, effective collaboration to address environmental issues largely depends on knowledge sharing and implementation in conservation policy (Cash et al. 2003; Francis and Goodman 2010; Pullin and Knight 2001). Recent studies indicate that defining and understanding the different types and roles of stakeholders and their professional relationships - including the exchange of information – are a requirement for optimal conservation planning and the protection of biological diversity (Isaac 2012; Mills et al. 2014; Paletto et al. 2015).

A commonly used tool to analyze and visualize relationships between stakeholders is a Social Network Analysis (SNA), which models the statistical properties of a social network (Wasserman and Faust 1994). Social networks define the relationships between stakeholder organizations, capturing the scale of information and knowledge sharing, as well as joint actions and decision making between network members (Barnes et al. 2016; Ernoul and Wardell-Johnson 2013). Social networks are therefore critical to facilitate biodiversity conservation and effective management of natural resources (Bodin et al. 2006; Bodin and Crona 2009). Empirical studies on the relationships between the structural characteristics of a network and the outcomes for biodiversity conservation identify which properties of a network are beneficial for conservation. For example, well-connected networks allow for the effective exchange of information and facilitate the definition and prioritization of biodiversity conservation challenges (Abrahamson and Rosenkopf 1997; Sandström and Carlsson 2008; Weimann 1982). Decision making is facilitated when one or few institutions take a central position in a network (Leavitt 1951). Furthermore, bi-directional knowledge and information exchange between producers and users is positively correlated with increased social and environmental impacts of scientific research (Fazey et al. 2013). Similarly, strong connections and frequent interactions among stakeholders are indicative of high levels of trust, and are necessary to communicate complex biodiversity related information (Crona and Bodin 2006; Newman and Dale 2005). In summary, a structurally strong network that enables effective exchange of information between different types of stakeholders has the potential to enhance collaboration and achieve optimal conservation of biodiversity.

High levels of information sharing alone, however, may not suffice because networks may exist in which not all actors hold shared ideas and goals, making its functioning less effective (Ernstson et al. 2008; Mizruchi and Galaskiewicz 1993). Additionally, power relations among stakeholder organizations are important determinants of network outcomes (Markovsky et al. 1988). Different stakeholders have different interests and power, potentially resulting in more powerful actors using their favorable positions to their own advantage (Adger et al. 2005). Moreover, social variables such as funding schemes and funding availability, governance arrangements, stability and functioning of organizations, personal attitudes and willingness to collaborate further influence the functioning of the network (Cowling and Wilhelm-Rechmann 2007; Fuhse and Mützel 2011; Knoke and Kuklinski 1991). The extent to which the exchanged information in an existing network influences conservation policy depends on its content, relevance and legitimacy (Reed et al. 2014; Stringer and Dougill 2013). Often, the information and scientific knowledge shared with policy-makers is difficult to interpret, or may be contested depending on how knowledge is produced, translated or transformed as it is shared (Reed et al. 2013; Stringer and Dougill 2013). According to Reed et al. (2009), Prell et al. (2009) and Hauck et al. (2015) the combination of SNA methods and the qualitative analysis of stakeholders' knowledge, referred to as the mixed-methods approach, allows for triangulation between the network structure, social variables, and their outcomes for conservation action. The mixed-method is an adequate approach to link the structure of the social relationships expressed in the network to individual stakeholders, and the context in which the relations exist (Fuhse and Mützel 2011; Herz et al. 2015).

Here, we combine the results of SNA with qualitative analysis of stakeholder knowledge to understand the structure and functioning of the network, and the outcomes of network properties for the conservation of Pontocaspian biota. We aim to a) quantify the Pontocaspian biodiversity related information sharing network using SNA; b) examine the content of the network interactions using a qualitative approach; c) identify social variables that influence collaboration; and d) outline areas for improvement for effective conservation of Pontocaspian biodiversity in Ukraine.

Table 4.1. Stakeholders included in the study and their respective stakeholder categories. "Acad" represents academic institutions, "Gov" - governmental, "NGO" – non-governmental and "Pa" – protected areas, under 'Category'.

ID	Abbreviation	Category	Organization name	Department/Service
1	IZAN	Acad	I.I. Schmalhausen Institute of Zoology of the National Academy of Sciences of Ukraine (NASU)	Department of Invertebrate Fauna and Systematics
2	IHB	Acad	Institute of Hydrobiology of the NASU	
3	IMB	Acad	Institute of Marine Biology of the NASU	
4	KHS	Acad	Kherson Hydrobiology Station of the NASU	
5	KSU	Acad	Kherson State University	Faculty of Biology, Geography and Ecology
6	ONU	Acad	Odessa National University	Faculty of Biology
7	YN	Acad	Southern Scientific Research Institute of Marine Fisheries and Oceanography	
8	KNU	Acad	Taras Shevchenko National University of Kiev	Department of Ecology and Zoology
9	US	Acad	Ukrainian Scientific Center of Ecology of the Sea	
10	KSRA	Gov	Kherson State Regional Administration	Department of Ecology
11	MAPF	Gov	Ministry of Agrarian Policy and Food	Department of Agriculture
12	MENR	Gov	Ministry of Ecology and Natural Resources of Ukraine	Department for Protection of Natural Resources
13	MSRA	Gov	Mykolaiv State Regional Administration	Department of Ecology
14	OSRA	Gov	Odessa State Regional Administration	Department of Ecology
15	CRS	NGO	Centre for Regional Studies	
16	NECU	NGO	National Ecological Centre of Ukraine	
17	WWF	NGO	World Wide Fund for Nature in Ukraine	
18	BSBR	Pa	Black Sea Biosphere Reserve of the NASU	
19	DBR	Pa	Danube Biosphere Reserve of the NASU	
20	KSRP	Pa	Kinburn Spit Regional Landscape Park	
21	LDNP	Pa	Lower Dnieper National Nature Park	
22	NPBS	Pa	National Park "Biloberezhia Sviatoslava"	

4.2 Methods

4.2.1 Stakeholder identification and prioritization

Twenty-nine stakeholder institutions directly or indirectly involved in Pontocaspian biodiversity research and conservation were identified through online research and exploratory consultations with PRIDE partner institutions in Ukraine for inclusion in the study. We define a stakeholder as a person or group who influences or is influenced by the Pontocaspian biodiversity related research, following Durham et al. (2014). Stakeholder roles were assessed through online inquiries of their activities and subsequent interviews. Stakeholders that lacked any activities or interest in Pontocaspian biodiversity were subsequently omitted from the study, resulting in a final list of 22 institutions (Table 4.1, Fig. 4.1). These institutions were assigned to four stakeholder categories based on their function and responsibilities: Academic (Acad), governmental (Gov), non-governmental (NGO), and protected areas (Pa).

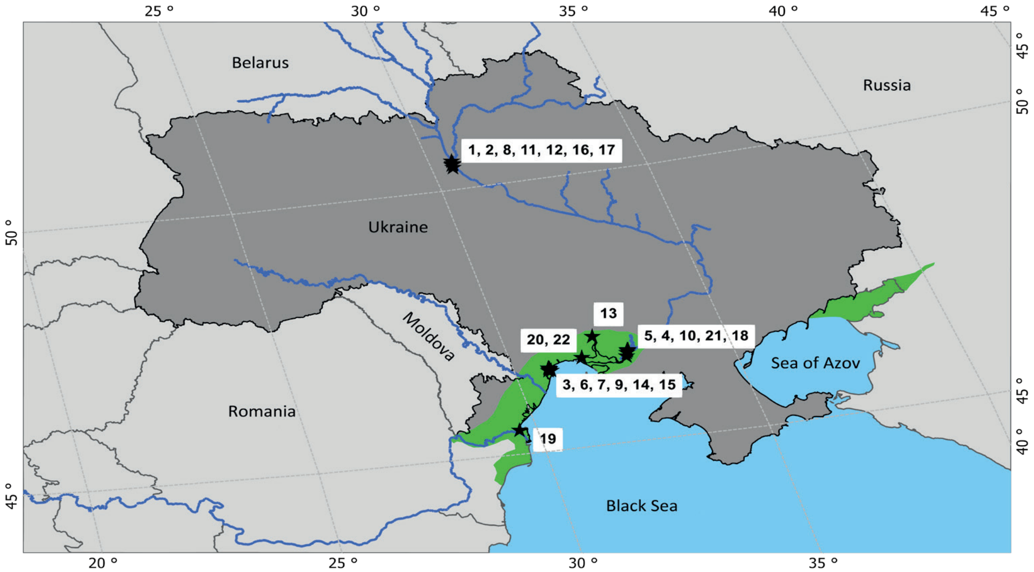


Figure 4.1. Map of the study area. The black stars on the map represent the stakeholder institutions (IDs in Table 1). Green areas indicate major Pontocaspian habitats.

4.2.2 Data collection

Quantitative and qualitative network data were acquired through semi-structured, in-depth interviews with the heads or vice-heads of institutions using a questionnaire (Appendix 4.1). Interviews of 1-3 hours in length were conducted between May and July 2017. A 'whole network analysis' approach was employed, in which each stakeholder was questioned about each of the other 21 stakeholders using a standardized questionnaire. All interviews were audio recorded.

Qualitative data

Data on the content of interactions among stakeholder organizations was collected using two qualitative questions, first asking the interviewees to describe their professional relationships with the other stakeholders, and second specifically asking whether the interaction involved Pontocaspian biodiversity (See Appendix 4.1 for the full interview protocol). If the interaction did not involve Pontocaspian biodiversity, the protocol was to move on asking about the next stakeholder from the list of stakeholders (Table 4.1). If the interaction involved Pontocaspian biodiversity related topics, the interviewees were asked to rank the strength of reported interaction using a table of strength definitions developed as part of the questionnaire (Table A4.1.1). Once a Pontocaspian biodiversity related link was established, stakeholders were asked to report if the interaction was perceived to be sufficient or insufficient to achieve the desired level of collaboration and information exchange. Not all stakeholder institutions were easily reached or willing to answer the interview questions, resulting in some missing data. We used the imputation-by-reconstruction method (Stork and Richards 1992) to deal with missing data (see Appendix 4.1 for details).

Quantitative data

We used the frequency of contact as a measure of strength (weight) of relational links following Prell et al. (2009), Paletto et al. (2015) and Giurca and Metz (2017). Five weight categories (0 to 4) were used ranging from no contact (0) to very frequent contact (4). We defined strong relationships as the weights higher than or equal to 3. Only formal connections were considered in the network because the informal, personal contacts could not be confirmed. The values given to the strength of confirmed relationships between pairs of stakeholders did not always match. In the cases of bi-directional information exchange, tie values were left as reported by the stakeholders. In the case of unidirectional information transfer, however, the lowest tie value was selected. Answers to this question allowed for the generation of a weighted, directed, information and knowledge transfer network.

4.2.3 Analysis

Qualitative analysis

For qualitative data analysis we used the established methods of Ryan and Bernard (2003) and Bradley et al. (2007), and applied an inductive approach. This means that the themes of interaction were determined based on acquired data and not on theoretical knowledge or assumptions. Transcribed interviews were carefully examined and read multiple times to understand the context of the network. The themes in the transcribed text were identified based on repetitions (Bogdan and Taylor 1975). A 'constant comparison' method was used to refine the dimensions of determined themes and to identify new themes (Glaser et al. 1967). The identified themes for both the content of confirmed relational links and perceived sufficiency of relationships were counted, and their relative importance was determined based on the order of frequency. Identified themes of interaction were grouped in three categories based on similarity: 'communication relations' – linkages between actors primarily used for transmitting information; 'collaboration relations' – the ties between actors consisting of joint action; and 'authority/power relations' – relational links, which indicate the rights of organizations to issue commands and obligations of other organizations to obey.

Social network analysis

For readability, we provide all SNA term definitions in Appendix 4.3. Basic network characteristics, such as number of actors and relational ties, graph density, and network centralization index were calculated using the CRAN R package 'igraph' (Csardi and Nepusz 2006), which was also used to visualize the sociogram. Mean shortest distance, a measure for average distance between actors in the network, was calculated using the CRAN R package 'tnet' (Opsahl 2009) because the 'igraph' package does not take edge weights into account when measuring the shortest distance. The network centralization index was calculated based on degree centrality scores of individual nodes. Measurements of density and centralization were converted to percentages for visual representation.

Centrality of individual nodes was measured through the degree centrality and betweenness centrality measures (Freeman 1978). We regarded the central stakeholders as those with centrality scores higher than or equal to the third quartile threshold, following the methods of Grilli et al. (2015), Paletto et al. (2015), and Yamaki (2017).

Brokers were identified based on the combination of quantitative and qualitative data. Quantitatively, we regarded brokers to be the stakeholders with high betweenness scores, which also accounted for low Burt's constraint values. Qualitatively, we searched for evidence of brokerage from the network narratives following the definition of Fazey et al. (2013), whereby brokerage implies involvement in the mobilization of information, deliberation between different types of stakeholders and potentially the mediation through working groups to address conservation issues. We used only strong ties (≥ 3) to identify brokers as they reflect regular contact.

Finally, we used a null-model approach to examine the degree of 'homophily' in the network (Newman 2003). We tested whether densities within and between stakeholder groups (defined by the stakeholder category) were significantly higher or lower than random expectation. We randomly assigned nodes to the stakeholders proportional to the true network and subsequently assessed the stakeholders within and between group densities. This was replicated 1000 times, and the resulting 1000 stakeholder group density values were ranked from low to high. Observed within and between group densities were then compared to the randomized results. If the actual density values were outside the 95% confidence interval of the random distribution, we regarded the true within or between group densities to be significantly higher (top 2.5%) or lower (lower 2.5%) than expected by random chance.

4.3 Results

In total 82% of the network data was gathered, with 18 out of 22 institutions interviewed (16 face-to-face and 2 through an electronic questionnaire). Three out of the four remaining institutions were formally contacted, but did not respond and did not complete the electronic questionnaire. One institution could not be reached during the fieldwork period

4.3.1 Network structure

The quantitative results revealed a well-connected information-sharing network with a total number of 191 confirmed, directed relational ties out of 462 potential ties, resulting in a network edge density of 41% (Table 4.2). The Pontocaspian biodiversity conservation network was centralized on few central stakeholders (degree of centralization 38 %), and none of the stakeholders occupied an isolated position in the network (Fig. 4.2). On average, each organization had 17 relational ties (including both incoming and outgoing ties). The majority of the information sharing links were strong (61%; weight ≥ 3) reflecting regular contacts (Table 4.2). The mean distance between any

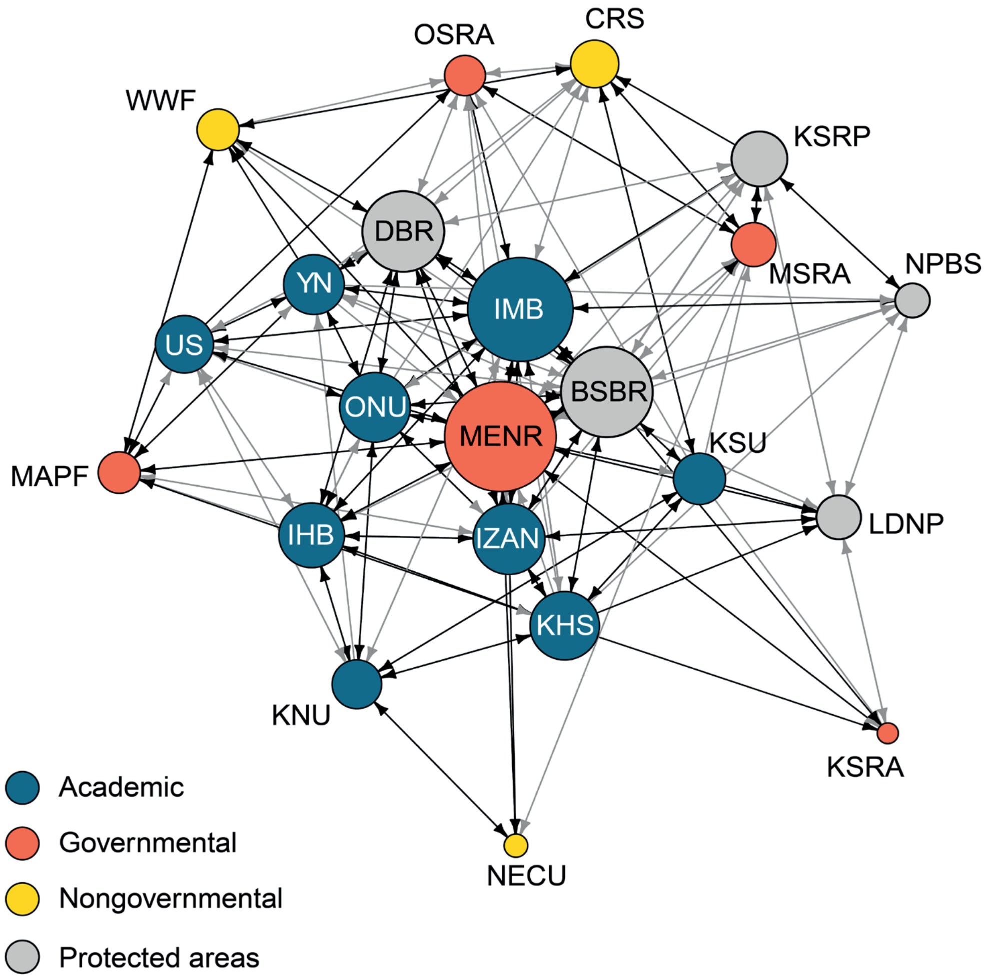


Figure 4.2. Sociogram of the information transferring network of stakeholder organizations involved in Pontocaspian biodiversity conservation and planning. Nodes represent organizations (see Table 4.1 for full names). The size of the nodes corresponds to the node strength. Arrows represent relationships between the nodes and show the direction of relevant information transfer. Black arrows (ties with value ≥ 3) represent strong relationships and gray arrows (ties with value < 3) represent weak relationships.

two actors was 1.5. In-degree and out-degree were very closely correlated (rho = 0.78), so the exchange of information was reciprocated, with stakeholders sending information to many institutions also receiving information from multiple sources.

Table 4.2. Network statistics.

Network data	Values
Total No. actors	22
Total No. ties	191
Mean degree	17
Density (%)	41
Degree of centralization (%)	38
Tie Reciprocity (rho)	0.78
Strong/weak ties (%)	61/39
Mean shortest distance	1.5

4.3.2 Relational content

From the network narratives, we identified 13 themes of stakeholder interactions (Fig. 4.3, Table A4.2.1). These interactions included 'communication relations', e.g., exchange of data and management experiences; 'collaboration relations', e.g., joint research and conservation planning; and 'power relations' e.g., directing action and scientific supervision. Most stakeholders indicated to have multiple kinds of interactions with other stakeholders (Table A4.2.2). For example, organizations collaborating in joint conservation projects also exchanged ecological and environmental information, as well as opinions. Similarly, organizations involved in commercial fishing exchanged information regarding living water resources, and shared management experiences (Table A4.2.2). Few stakeholders only engaged in the exchange of information and did not collaborate with each other. For example, Kherson Hydrobiology Station regularly reported to the Ministry of Ecology and to the regional administrations on study results, but did not engage with them in joint actions. Similarly, protected areas exchanged information and opinions among each other, but hardly collaborated with each other. Out of the identified 191 relational links, 67 links had a single theme of interaction, 72 links had 2 themes of interaction, 43 links had 3 themes of interaction, 8 links had 4 themes of interaction and remaining 1 link had 5 themes of interaction. The links with more relational content were significantly stronger than links with less relational content ($p < 0.001$, Fig. A4.2.1).

Only one theme, namely 'Sturgeon conservation' was identified to directly target the Pontocaspian species. Interviewees mentioned this theme 3 times (Fig. 4.3, Table A4.2.1). The other themes did not directly address Pontocaspian biodiversity, but Pontocaspian species were incidental to the interactions. For example, shared data on ecosystem functioning and dynamics (theme 'Ecological data'), assessments of water parameters (theme 'Environmental data'), advice on restoration projects (theme 'conservation planning'), and joint fieldwork and research (theme 'Research'), were reported by the interviewees to occasionally involve Pontocaspian habitats and/or species. We did not include a standard question on the definition of Pontocaspian species in our questionnaire, but the network narratives indicated that stakeholders had slightly different ideas on what Pontocaspian species and habitats comprise. In some cases, interviewees avoided specifying in

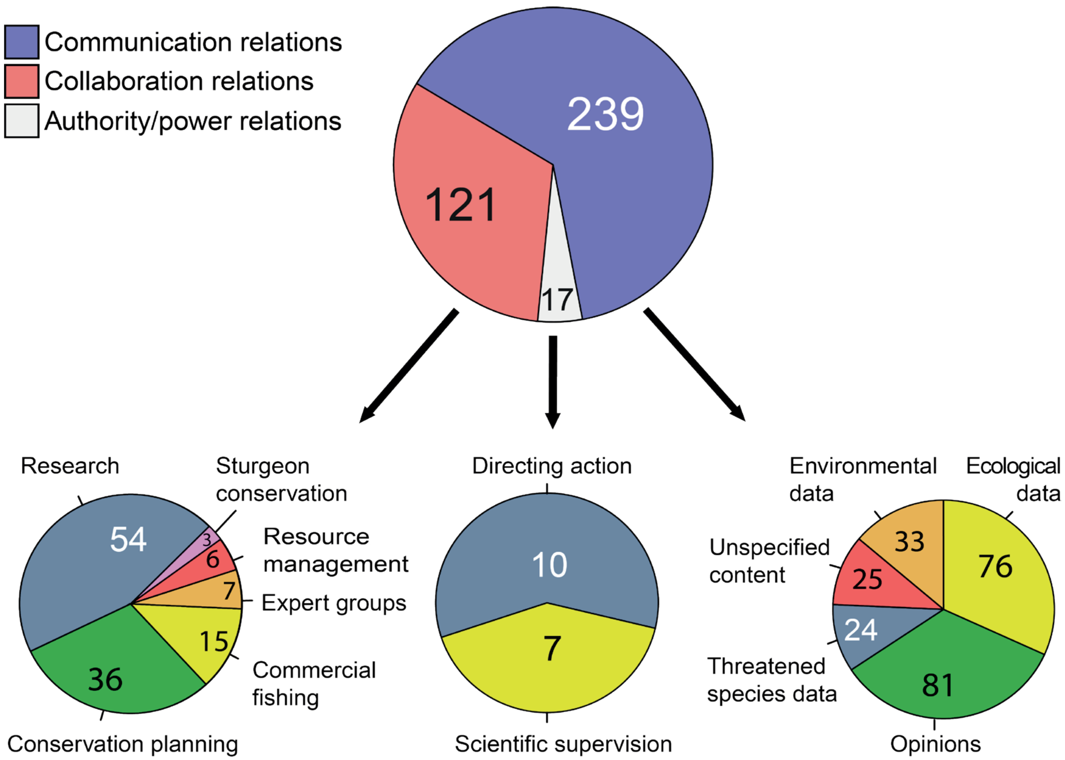


Figure 4.3. Categories and themes of stakeholder interactions. Values in pie charts represent absolute numbers. See definition of themes in Table A4.2.1.

which context Pontocaspian biodiversity related data was exchanged (Fig. 4.3, Table A4.2.1, collated within the theme 'Unspecified content')

4.3.3 Perceived sufficiency of interactions

A total of 42 relational links (31% of 137 links for which the sufficiency was indicated by interviewees) were reported to be insufficient, i.e. below the desired intensity of collaboration and information exchange (Table A4.2.3). Insufficient collaboration was mostly attributed to 'budget constraints' (18 times) and 'legal limitations' (15 times). 'Budget constraints' referred to either a general lack of funding or unfavorable funding schemes, which restricted the participation of stakeholders in a project. 'Legal limitations' referred to inconsistency in conservation policy, which resulted from contradictions in national laws. 'Lack of interconnection' and 'Employee turnover' were minor factors limiting the collaboration (Table A4.2.3). Interestingly, most of the 'insufficient' relational links were strong links ('budget constraints' – 13 strong vs. 5 weak, and 'legal limitations' – 8 strong vs. 7 weak links), suggesting that regular stakeholder contacts within the network were not necessarily indicative of sufficient collaboration.

Table 4.3. Node-specific measures. Values between brackets under 'Degree centrality' represent the in-degree and out-degree measures respectively. In bold are values higher than, or equal to the third quartile threshold (lower or equal to the first quartile threshold in case of 'Burt's constraint'). Numbers between brackets under 'Qualitative data' represent the frequency of respective themes characterizing the incoming and outgoing ties.

	Quantitative data				Qualitative data		
Abbr.	**Degree centrality**	**No. ties strong/ weak**	**Betweenness centrality**	**Burt's constraint**	**Communication relations**	**Collaboration relations**	**Authority/ power relations**
MENR	**32 (17, 15)**	20/12	**110**	**16**	47 (30, 17)	18 (12, 6)	6 (0, 6)
IMB	**28 (14, 14)**	23/5	**108**	**21**	48 (20, 28)	16 (8, 8)	4 (0, 4)
BSBR	**28 (13, 15)**	17/11	**46**	**25**	38 (18, 20)	14 (7, 7)	2 (2, 0)
DBR †	**24 (12, 12)**	16/8	16	28	31 (13, 18)	20 (9, 11)	3 (3, 0)
IZAN	**21 (9, 12)**	14/7	12	28	21 (10, 11)	13 (5, 8)	1 (0, 1)
ONU	**21 (10, 11)**	14/7	12	28	21 (9, 12)	15 (10, 5)	0
IHB	19 (9, 10)	14/5	7	29	28 (9, 19)	15 (6, 9)	1 (0, 1)
KHS	19 (7, 12)	14/5	**20**	**26**	24 (7, 17)	13 (6, 7)	1 (1, 0)
YN	19 (8, 11)	10/9	5	34	33 (11, 22)	18 (8, 10)	1 (1, 0)
US	19 (9, 10)	9/10	7	36	20 (7, 13)	13 (6, 7)	2 (2, 0)
KSRP	18 (9, 9)	7/11	12	42	23 (9, 14)	7 (3, 4)	3 (3, 0)
KNU †	15 (7, 8)	10/5	10	29	15 (7, 8)	8 (4, 4)	0
CRS †	15 (9, 6)	7/8	18	33	22 (14, 8)	6 (3, 3)	0
KSU	14 (5, 9)	10/4	**20**	28	6 (5, 1)	11 (3, 8)	1 (0, 1)
OSRA †	14 (9, 5)	5/9	1	42	16 (14, 2)	9 (5, 4)	1 (0, 1)
LDNP	14 (8, 6)	6/8	3	33	13 (8, 5)	8 (4, 4)	2 (2, 0)
MAPF	13 (7, 6)	7/6	4	36	12 (8, 4)	10 (7, 3)	1 (0, 1)
MSRA	13 (7, 6)	8/5	15	**27**	19 (12, 7)	6 (3, 3)	2 (1, 1)
NPBS	12 (7, 5)	4/8	0	69	17 (10, 7)	4 (2, 2)	2 (2, 0)
WWF	11 (6, 5)	9/2	**20**	31	9 (6, 3)	12 (5, 7)	0
KSRA	7 (5, 2)	3/4	0	44	8 (7, 1)	3 (3, 0)	1 (0, 1)
NECU	6 (4, 2)	5/1	7	38	7 (5, 2)	3 (2, 1)	0

† Institutions that could not be interviewed for which relationships were imputed.

4.3.4 Stakeholder centrality and brokerage

Node level statistics identified central stakeholders (Table 4.3). Three out of nine academic institutions had a very high number of relational ties ('degree centrality' score higher than or equal to the third quartile threshold ≥20). The Ministry of Ecology had the most connections in the network and was the only governmental organization with a high degree centrality score. None of the NGOs accounted for high degree centrality values. The Black Sea Biosphere Reserve and the Danube Biosphere Reserve represented two out of the five protected areas with high connectivity. The ratio of strong to weak ties (for individual stakeholders) was diverse throughout the network. All central stakeholders had more strong ties than weak ties.

We identified four organizations with structurally favorable positions to act as brokers in the network, displayed through their high betweenness centrality (higher than or equal to the third quartile threshold ≥20) and low Burt's constraint values (lower than or equal to the first quartile threshold ≤27). These organizations were the Ministry of Ecology, the Institute of Marine Biology, the Black Sea Biosphere Reserve and the Kherson Hydrobiology Station (Table 4.3). However, qualitative data showed that only the Ministry of Ecology and the Institute of Marine Biology were actually involved in brokering behavior, such as mobilization of information and resources, deliberation between different types of stakeholders, and coordination of research and conservation action (Table A4.2.2, themes 'Expert groups', 'Scientific supervision', and 'Directing action'). For example, the Ministry of Ecology was reported to form expert groups composed of representatives of various stakeholder categories to discuss progress towards the implementation of the national conservation agenda and to facilitate strategic planning (theme 'Expert groups'). Furthermore, the Ministry of Ecology was involved in directing and coordinating the actions of several scientific institutions (e.g. the Ukrainian Scientific Center of Ecology of the Sea) and all the protected areas (theme 'Directing action'). The Institute of Marine Biology was a scientific supervisor for several protected areas (e.g. the Danube Biosphere Reserve, the Kinburn Spit Regional Landscape Park, and the National Park "Biloberezhia Sviatoslava") and acted as a bridge between them which were otherwise disconnected or weakly connected (Table A4.2.4, 'Pa-Pa' – 10 weak links).

Black Sea Biosphere Reserve and Kherson Hydrobiology Station, although structurally well positioned, did not take advantage of this to initiate Pontocaspian biodiversity related conservation action. These organizations were hosting academic institutions and protected area representatives to do research on their territories, and reported the study results to the Regional Administrations (Table A4.2.2), resulting in their many, and potentially bridging ties (Table 4.3). However, no evidence was found that these organizations initiate any collective action with regard to Pontocaspian biodiversity conservation to utilize their favorable positions, perhaps due to the low priority for Pontocaspian species conservation and lack of funding.

4.3.5 Stakeholder group connectivity

Academic institutions had significantly higher within group density value than expected by random chance (Table A4.2.4). They were also strongly connected to each other (35 strong vs. 12 weak connections) indicative of regular contact. When in contact, the academic organizations exchanged data and experiences, and engaged in face-to-face interactions such as joint research and conservation planning. Links among academic organizations were mostly constrained by lack of funding necessary for research and collaboration (Table A4.2.4). This latter also limited cooperation between academic sector and protected areas as the academic institutions could not afford regular fieldwork within protected areas. Academic institutions and non-governmental organizations were significantly less connected with each other than expected by chance, reflecting comparatively little exchange of information and collaboration between these groups. When in contact, academic institutions and NGOs rarely met face-to-face and mostly interacted via the 'communication relations' (Table A4.2.4). For example, Centre for Regional Studies (CRS) was found to be requesting and receiving scientific information from the Institute of Marine Biology, Odessa

National University, Kherson State University, and Southern Scientific Research Institute of Marine Fisheries and Oceanography on yearly or biannual bases, but no collaborative relation was found between them. CRS used the requested information for preparing reports on state of environment and for providing consultancy to the central, regional and local authorities (http://www.crs.org.ua/en/about.html). Besides the lack of funding, unfavorable policy regulations impeded the desired levels of collaboration between academic organizations and other stakeholder categories. For example, Odessa National University and Southern Scientific Research Institute of Marine Fisheries and Oceanography reported having difficulty conducting an inventory of aquatic species within the protected areas due to a disagreement between the Ministry of Agrarian Policy and the Ministry of Ecology on common study methodology. Policy regulations also obstructed collaboration efforts between NGOs and the protected areas, and among governmental organizations (Table A4.2.4).

Most stakeholder groups had considerably more 'Communication relations' than 'Collaboration relations' (Table A4.2.4), which may indicate that the exchanged information did not always result in conservation action in Ukraine. Governmental organizations were the only ones with equal amount of information exchange and collaborative action. However, governmental organizations were collaborating among themselves only on topics related to commercial fishing and management of aquatic resources; but not on topics related to joint conservation planning (Table A4.2.4). Some stakeholders were involved in specific interactions. For example, WWF in Ukraine was a beneficiary in the project 'Life for Danube Sturgeons' focusing on saving the sturgeon species (https://danube-sturgeons.org/). To implement the project, WWF collaborated with the governmental organizations, such as the Ministry of Ecology, and the Ministry of Agrarian Policy; and a single protected area, namely the Danube Delta Biosphere Reserve (Table A4.2.2).

4.4 Discussion

Pontocaspian biodiversity is in need of effective conservation action, which requires the coordinated involvement of institutions including governmental organizations, NGOs, the academic sector and protected areas. In our analysis, we found that the Pontocaspian conservation network in Ukraine has structural properties capable of allowing optimal conservation action. Institutions within the network are well connected (high network density) and tend to have strong connections to many partners, with whom they collaborate and regularly exchange information (Tables 4.2 and 4.3, Fig. 4.2). The two most central stakeholders in the network, such as the Ministry of Ecology and the Institute of Marine Biology exploit their structurally favorable positions and act as brokers, by mobilizing information and resources and deliberating between different types of stakeholders (Tables 4.3 and A4.2.2). These are, according to network theory, characteristics of a well-functioning network (Crona and Bodin 2006; Fazey et al. 2013; Leavitt 1951). Yet, from our interview results and recently published studies, it is evident that the conservation status of Pontocaspian biota in Ukraine is sub-optimal (Anistratenko and Anistratenko 2018; Dumont et al. 1999; Wesselingh et al. 2019). This is primarily caused by the fact that Pontocaspian biodiversity does not drive the inter-organizational interactions in Ukraine (Fig. 4.3, Table A4.2.1). Instead, the primary focus is on the conservation of the flagship species, notably sturgeons, leaving the majority of Pontocaspian taxa absent from the conservation agenda. The general lack of knowledge on Pontocaspian species identities and ecology (with the exception of sturgeons) is a likely cause of their observed subordinate role in the organizational interactions. Furthermore, the optimal functioning of the structurally adequate network for biodiversity conservation is challenged by social variables such as limited funding availability and lack of consistency in conservation policy.

4.4.1 Network relations and challenges to optimal Pontocaspian biodiversity conservation

Stakeholder organizations in Ukraine are in close contact, but rarely discuss or act on issues related to Pontocaspian species (Fig. 4.3, Table A4.2.1). Typically, stakeholder interactions target Pontocaspian flagship species, such as sturgeons; commercially important species, including few Pontocaspian species such as the gobies; and alien invasive species (Fig. 4.3, Table A4.2.1, themes - 'Sturgeon conservation', 'Commercial fishing' and 'Ecological data'). Few other Pontocaspian species, such as some bivalve species, were mentioned as part of the theme 'Threatened species data' (Fig. 4.3, Table A4.2.1). Themes listed under the 'Collaboration relations' category mostly exclude Pontocaspian species with the exception of sturgeons. However, these themes do target the Pontocaspian habitats, including coastal areas and the lower stretches of the rivers (Fig. 4.1), indirectly affecting biological communities occupying these habitats. The minor role of Pontocaspian species in organizational interactions is likely a result of low level of knowledge regarding Pontocaspian species, including a lack of clarity on species identities. Recent research on Pontocaspian mollusk taxonomy and autecology supports this observation by showing that many of the Pontocaspian mollusk species have disputed identities, multiple synonymies and are data deficient in the IUCN Red List Databases (Wesselingh et al. 2019).

In addition to knowledge gaps, utilization of exchanged information in conservation planning is suboptimal and needs to be studied further. From the interviews, we learned that information exchange between the academic sector and governmental organizations and between protected areas and governmental organizations occurs on mandatory bases. However, the advice and recommendations that are exchanged, are not always taken into consideration and do not always translate in conservation action, even when stakeholders are strongly interlinked (Table A4.2.4). Additionally, we found that regional administrations, central governmental bodies, the academic sector and NGOs operate at a variety of scales and sometimes independently, complicating conservation efforts. For example, the regional administrations involved in biodiversity conservation were separated from the Ministry of Ecology in 2010. As a result, the actions of the regional administrations are no longer centrally coordinated and controlled, reported as 'Legal limitations' among 'Gov-Gov' interactions (Table A4.2.4). Regional administrations are not decision makers, but execute with disparate views on biodiversity conservation targets. Effective biodiversity management and species conservation requires coordinated actions from different institutions to be based on the best available knowledge and recommendations (Binning et al. 1999; Briggs 2001).

Optimal functioning of the studied network is restricted by funding availability (Tables A4.2.3 and A4.2.4). Project-based collaboration on conservation of Pontocaspian biodiversity is limited in Ukraine (Fig. 4.3, Table A4.2.1) and the exchange of information mostly occurs due to organizational mandates or voluntary actions and supporting attitudes of organizations. Academic institutions suffer most from the lack of funding, which often translates into weak connections (Table A4.2.4). From the stakeholder narratives, we learned that weak connections rarely result from conflicting views or lack of acquaintance, but rather from lack of funding. For example, few academic organizations can financially afford to carry out fieldwork within protected areas more than once a year. Limited available funding to study the Pontocaspian species and their absence from the global biodiversity databases such as the IUCN Red List of Threatened Species reduces the interest of NGOs to collaborate on topics related to these taxa. Consequently, NGOs focus on obtaining funding on the flagship species conservation and have a relatively marginal position in the network (Tables 4.3 and A4.2.4).

In some cases, the criteria for grant applications further limit access to funding for Pontocaspian biodiversity projects. For example, Universities are excluded from projects funded by the National Academy of Sciences of Ukraine (NASU), and organizations under NASU are not eligible to take part in projects funded by the Ministry of Education and Science. Similarly, grants from regional administrations are mostly aimed at organizations within the region. International small grants are mostly available to NGOs, or NGOs plus a regional administration. The European Union 'LIFE Program' projects (https://ec.europa.eu/easme/en/life) are aimed at organizations registered in EU and usually involve one, or few institutions from Ukraine as associated beneficiaries, e.g. involvement of WWF in Ukraine in a sturgeon conservation project (Table A4.2.2). Cross-Border Cooperation (CBC) projects (https://www.euneighbours.eu/en) are the only ones, which frequently combine different types of stakeholder organizations, such as academic institutions, NGOs and protected areas. While the term 'Pontocaspian' is largely absent in the formulations of CBC projects, these projects target Pontocaspian habitats such as the lower Danube river and the Black Sea coastline. CBC grants, however, limit stakeholder participation to local or regional parties. For example, the programs on Black Sea conservation allow participation of only those organizations, which are located in the Odessa, Kherson and Mykolaiv regions. Similarly, grants on the conservation of the Danube Delta target only organizations from the Odessa region. In summary, available funding schemes in Ukraine limit the participation of multiple stakeholders from different administrative regions with unparalleled ecological knowledge and experiences to collaborate and act together, which is a necessary precondition for optimal conservation. This has previously been recognized as a challenge for research and conservation action in Ukraine by an independent panel of experts and national peers, and recommendations have been developed for improvement through increased availability of grants to all types of stakeholder organizations from a centralized state fund (Chang et al. 2017).

The lack of consistency in biodiversity conservation policy ('Legal limitations') is another factor that hampers adequate collaboration and Pontocaspian conservation action (Tables A4.2.3 and A4.2.4). 'Legal limitations' refer to uncoordinated action of regional administrations, and to some of the national laws in Ukraine which are contradictory and create confusion among conservation organizations. For example, fish, mollusks, as well as water resources in general are under the control of the Ministry of Agrarian Policy and Food (MAPF), whereas protected areas are under governance of the Ministry of Ecology (MENR). Laws made by MAPF that regulate research methodologies and set standards to assess commercial fish and mollusk species richness and population densities are not implemented by the Ministry of Ecology. Therefore, academic institutions contracted by the MAPF face restrictions in conducting research within protected areas (Table A4.2.4). Interviewed stakeholders are aware of the contradicting national laws and MENR is taking a leading role in resolving the legal inconsistencies and coordinating the efforts to reach better alignment of laws and regulations.

4.4.2 A strong social network is in place to improve Pontocaspian conservation

We argue that the key structural characteristics of the studied network, such as high number of connections and reciprocated ties, high network centralization, and clearly defined broker institutions, are favorable for effective biodiversity conservation actions (Tables 4.2 and 4.3). The content of interactions (Fig. 4.3, Table A4.2.1) and the social variables, such as the funding and policy frameworks (Table A4.2.3), seem to be more consequential for biodiversity conservation outcomes than the network structure itself. According to network theory, centralized networks are highly beneficial in the initial phase of the conservation process to disseminate information, mobilize and coordinate resources, and to make simple decisions (Leavitt 1951; Olsson et al. 2004). Decentralized networks with multiple stakeholders holding many relational ties are more suitable to solve complex long-term conservation challenges (Crona and Bodin 2006; Leavitt 1951). In Ukraine, our results together with the reviewed literature suggest that there is a long tradition of research on Pontocaspian biodiversity but the translation of research outputs into effective biodiversity conservation actions is relatively novel (Anistratenko 2009; Cuttelod et al. 2011; Munasypova-Motyash 2009a, b). A 'centralized network' such as we find in the current phase is well placed to overcome this hurdle, making the existing network structurally suited to implement an improvement in Pontocaspian biodiversity conservation actions.

The two identified broker organizations in the studied network (Table 4.3) are very important stakeholders, considerably influencing the functioning of the network, and need to be involved in long-term Pontocaspian biodiversity conservation and planning in Ukraine. Furthermore, the qualitative data indicates that WWF in Ukraine is involved in the conservation of Pontocaspian flagship species, such as the sturgeons, through the enforcement of conservation laws and awareness raising activities (Table A4.2.2). Besides the identified interactions in the studied network, WWF in Ukraine operates a large network of young volunteers and students, and closely collaborates with different entities such as fishery patrol inspectors and state border guards in Odessa. Therefore, WWF in Ukraine has the potential to rapidly spread new knowledge throughout the network and beyond, if supplied with information. WWF in Ukraine, together with two identified broker institutions, which are the Ministry of Ecology and Institute of Marine Biology, can play a critical role in the initial phase of Pontocaspian biodiversity conservation action, through organizational capacity building, and awareness raising to expand the current scope of conservation initiatives beyond flagship species. However, the factors hampering conservation efforts must be addressed to create conditions in Ukraine, which can support collective actions. In summary, the observed structural properties of the network suggest that improving the content of interactions through resolving taxonomic uncertainties and raising awareness of non-flagship species, combined with addressing the limiting social variables, such as funding scarcity and contradicting laws will enable a rapid improvement in effectiveness of Pontocaspian biodiversity conservation actions.

4.5 Conclusion

We identified a strong stakeholder network for Pontocaspian biodiversity conservation in Ukraine. Yet, indications of Pontocaspian biodiversity decline have not resulted in strong, concerted conservation actions. Overall, it emerged that Pontocaspian taxa play a minor role in inter-organizational interactions. Academic institutions and the protected areas study specific aspects of Pontocaspian biodiversity, but research outputs are not always related to, or translated into, environmental policy and biodiversity conservation planning priorities. Funding scarcity, legal limitations and taxonomic uncertainty of Pontocaspian biota emerged as key contributing factors leading to the observed sub-optimal conservation outcomes. With the current stakeholder landscape in Ukraine, it can be expected that improved taxonomic definitions of Pontocaspian species and better understanding/awareness, combined with increased research funding and more consistent conservation policy will quickly translate into increased conservation actions. The maintenance of the existing network in Ukraine is, however, a critically important pre-condition for such actions.

Acknowledgements

We would like to thank the EU Innovative Training Network (ITN) Pontocaspian Biodiversity Rise and Demise (PRIDE) Program (grant agreement number: 642973 – PRIDE – H2020-MSCA-ITN-2014) for funding this research. We also thank the entire WWF in Ukraine Team for their invaluable assistance and support. Furthermore, we thank Prof. Ivan Moysiyenko, from Kherson State University, and Sergei Ovechko, from NASU Kherson Hydrobiology Station for helping to arrange meetings with stakeholders. We also thank all the interviewed stakeholders for finding time to meet and for providing honest and thorough answers to the survey questions. We would like to also acknowledge our colleagues from Naturalis Biodiversity Center: Nieke Knoben, for assistance in developing the questionnaire; Leon Marshall and Matteo Lattuada, for statistical advice and support; Thomas Edward Roberts and Martina de Freitas Prazeres, for the proofreading and for their helpful comments on earlier drafts of this paper; and Caroline van Impelen, for organizational support. Finally, we thank our reviewers who gave us invaluable comments that improved our work considerably.

Appendices

Appendix 4.1. Interview protocol, survey questions and missing SNA data.
Appendix 4.2. Network findings.
Appendix 4.3. SNA term definitions.

Appendix 4.1. Interview protocol, survey questions and missing SNA data.

Interview protocol

Network data was acquired through semi-structured, in-depth interviews with the heads or vice-heads of institutions using a questionnaire (see survey questions below). Qualitative data regarding the overall, tie-focused descriptions was collected using a general question: "Do you have professional acquaintance/links with [stakeholder organization named here from table 4.1]?" If the answer was positive, follow-up questions were asked, allowing interviewees to narrate the content of the interaction: "How would you describe your interaction with this stakeholder? What matters/topics do you discuss when you are in touch?" These questions were asked in general terms, without referring to Pontocaspian biodiversity. After the narrative, a specific question was asked addressing Pontocaspian biodiversity related information exchange: "Do you exchange scientific data, information, knowledge, opinion or advice regarding Pontocaspian biodiversity with this stakeholder organization?" In cases of short or unclear answers, the interviewees were asked to explain the link in more detail and provide examples of interaction. We were particularly interested in Pontocaspian biodiversity, so if the answer to this question was negative, we stopped asking regarding this particular stakeholder, and moved on asking about the next stakeholder organization from the list of identified 22 organizations. Subsequently, the interviewees were asked to rank the strength of the reported Pontocaspian biodiversity related interactions using a table of strength definitions developed as part of the questionnaire (Table A4.1.1). Once the Pontocaspian biodiversity related relational link was established, its perceived sufficiency was addressed through the question: "Do you consider your contact with this stakeholder sufficient or insufficient to achieve effective collaboration and information exchange?" In case of insufficiency, a follow-up question was asked: "If the contact is insufficient what is the reason you are not in contact more often?" Not all stakeholder institutions were easily reached or willing to answer the interview questions, resulting in some missing data. We used the imputation-by-reconstruction method (Stork and Richards 1992) to deal with missing data (see 'missing SNA data' section below for details).

Survey questions

Background

1. Organization name?
2. Name of the person interviewed ?
3. Position of the person interviewed?
4. Location?
5. Date?

Relationships for social network analysis (SNA)

6. Do you have Professional acquaintance/links with [stakeholder organization named here from the list of selected 22 organizations]?
7. How would you describe your interaction with this stakeholder? What matters/topics do you discuss when you are in touch?
8. Do you exchange scientific data, information, knowledge, opinions or advice regarding the Pontocaspian biodiversity with this stakeholder organization?
9. From the table below, how strong would you classify your professional acquaintance/links with this stakeholder?

Table A4.1.1. Tie strength definitions.

Weight	Strength	Definition
0	Absent	We are never in contact with each other.
1	Very weak	We have been in contact at some point in the past and foresee contact in the future.
2	Weak	We are in contact incidentally, e.g. if we have joint projects or if we need specific knowledge, services, support or expertize from each other. However, the rate of interaction is low and irregular.
3	Strong	We are in contact regularly, on a monthly or quarterly basis.
4	Very Strong	We are in contact very often, on a daily or weekly basis.

10. Do you consider your contact with this stakeholder sufficient or insufficient to achieve effective collaboration and information exchange?

10a. If the contact is insufficient what is the reason you are not in contact more often?

Missing SNA data

Missing interview data complicates the social network analysis (Barnes et al. 2016; Dean Jr and Brass 1985; Monge et al. 1983; Prell et al. 2009). Ignoring missing values was demonstrated to have considerable negative effects on the structure of the network leading to significant loss of information (Huisman 2009). Huisman (2009) showed that in directed networks with small amounts of missing data (20-30%), reconstruction provides more representative results than ignoring missing values. The reconstruction method assumes the link between a respondent and a non-respondent to be as reported by the respondent (Stork and Richards 1992). Two preconditions have to be met when using the imputation-by-reconstruction method. Firstly, respondents shall be similar to non-respondents. Secondly, the description of the relational links provided by the respondents shall be reliable. The similarity of respondents and non-respondents shall be verified in two ways: in terms of individual level traits (e.g. legal status) and in terms of the number and strength of links they receive (Stork and Richards 1992). The reliability of the responses can be measured through the confirmation rate. Confirmation rate is the proportion of links described similarly by both stakeholders involved. If respondents and non-respondents are similar and the confirmation rate is high, it can be assumed that the respondent's description of the link accurately characterizes the relationship between respondent and non-respondent (Stork and Richards 1992). In this study, 82% of the links was gathered and 18% was missing, therefore below the 20% threshold. Out of the four institutions that could not be interviewed one is academic, one governmental, one non-governmental and one a protected area; therefore non-responding institutions are similar to responding institutions in terms of individual level traits. The confirmation rate was 88% and Chi-squared test revealed no significant differences in the distribution of the weights of received relationships between the respondents and non-respondents (p-value = 0.78). Therefore, the imputation-by-reconstruction method was adopted.

Appendix 4.2. Network findings.

Table A4.2.1. Identified themes of stakeholder interactions and their descriptions. 'Frequency' reports the number of mentioning of identified themes by the interviewees. The numbers in brackets reflect how many times the theme was associated to strong vs. weak relational links.

Category	Theme name	Theme description	Frequency (strong/ weak)
Communication relations	Opinions	Exchange of opinions, consultations and recommendations on current work, plans and initiatives; exchange of project management experiences.	81 (50/31)
	Ecological data	Exchange of data and knowledge directly or indirectly related to Pontocaspian communities. For example, data on ecosystem functioning and dynamics to which Pontocaspian species are incidental; data on invasive species, which potentially harm Pontocaspian species; data on species distribution and population genetics, which sometimes involve Pontocaspian species; assistance with species identification.	76 (49/27
	Environmental data	Exchange of information on the state of environment. For example, exchange of study results on the sea and fresh water parameters, pollutants and water resources.	33 (22/11)
	Unspecified content	Exchange of Pontocaspian biodiversity related information reported by an interviewee without specifying the context or the content of interaction. For example, 'if we need specific data we are in touch', 'sometimes our interests overlap'.	25 (11/14)
	Threatened species data	Exchange of information on the state of threatened species, including the red list species; providing consultations.	24 (12/12)
Collaboration relations	Research	Joint fieldwork, lab work and publications, which sometimes involve Pontocaspian species and habitats. Hosting the fieldworks and lab works, providing the necessary equipment and/or space for work and receiving the generated results.	54 (47/7)
	Conservation planning	Collaboration and joint conservation planning, e.g. agreeing on actions; developing and working in joint nature restoration projects; providing scientific support for different conservation activities.	36 (22/14)
	Commercial fishing	Joint planning and regulation of matters related to commercial fishing. For example, rules, methods, mode of fishing, limits, and quotes.	15 (9/6)
	Expert groups	Participation of experts in working group meetings and discussions, which are facilitated by the Ministry of Ecology to solve the coastal lake, river and Black Sea related problems, which sometimes concern Pontocaspian habitats.	7 (4/3)
	Resource management	Joint planning and agreeing on the procedures, limits and standards of use of different biological resources.	6 (2/4)
	Sturgeon conservation	Collaboration, planning and data exchange through the projects on charismatic Pontocaspian species, such as the sturgeons. For example, 'Life for Danube Sturgeons' (https://danube-sturgeons.org/).	3 (3/0)
Authority/power relations	Directing action	Giving directions of work and research, and asking for the generated study results or reports on outcomes, which sometimes involve Pontocaspian species and habitats.	10 (5/5)
	Scientific supervision	Developing and providing research standards and methodology.	7 (6/1)

Table A4.2.2. Number of mentioning of interaction themes by individual stakeholders. Values between brackets represent No. times the theme characterized the incoming ties and No. times the theme characterized the outgoing ties.

	Communication relations					Collaboration relations						Authority/power relations	
Abbr.	**Opinions**	**Ecol. data**	**Environ-mental data**	**Unspec. content**	**Threat. species data**	**Research**	**Conserv. planning**	**Commerc. fishing**	**Sturgeon conserv.**	**Expert groups**	**Resource managem.**	**Directing action**	**Scientific supervision**
MENR	22(11,11)	8(7,1)	7(6,1)	2(1,1)	8(5,3)	1(1,0)	7(6,1)	3(2,1)	1(1,0)	2(1,1)	4(1,3)	6(0,6)	0
IMB	20(7,13)	21(8,13)	1(1,0)	2(2,0)	4(2,2)	10(3,7)	6(5,1)	0	0	0	0	0	4(0,4)
BSBR	9(5,4)	15(6,9)	6(3,3)	6(3,3)	2(1,1)	9(5,4)	3(1,2)	2(1,1)	0	0	0	1(1,0)	1(1,0)
DBR	13(5,8)	12(4,8)	2(1,1)	2(2,0)	2(1,1)	7(3,4)	10(4,6)	2(1,1)	1(1,0)	0	0	2(2,0)	1(1,0)
IZAN	6(3,3)	11(5,6)	0	1(1,0)	3(1,2)	10(4,6)	3(1,2)	0	0	0	0	0	1(0,1)
ONU	6(3,3)	14(5,9)	0	1(1,0)	0	13(9,4)	0	0	0	2(1,1)	0	0	0
IHB	13(4,9)	4(4,0)	0	11(1,10)	0	12(5,7)	2(0,2)	0	0	1(1,0)	0	0	1(0,1)
KHS	4(2,2)	11(3,8)	5(1,4)	1(1,0)	3(0,3)	9(4,5)	2(1,1)	2(1,1)	0	0	0	0	1(1,0)
YN	4(2,2)	7(3,4)	12(3,9)	1(1,0)	9(2,7)	6(5,1)	1(0,1)	11(3,8)	0	0	0	1(1,0)	0
US	6(3,3)	5(1,4)	4(1,3)	3(2,1)	2(0,2)	3(2,1)	3(1,2)	2(1,1)	0	5(2,3)	0	1(1,0)	1(1,0)
KSRP	9(4,5)	8(3,5)	4(0,4)	2(2,0)	0	5(2,3)	2(1,1)	0	0	0	0	2(2,0)	1(1,0)
KNU	7(3,4)	3(2,1)	1(0,1)	4(2,2)	0	8(4,4)	0	0	0	0	0	0	0
CRS	5(2,3)	8(6,2)	4(3,1)	3(1,2)	2(2,0)	0	6(3,3)	0	0	0	0	0	0
KSU	2(2,0)	2(2,0)	0	2(1,1)	0	8(3,5)	3(0,3)	0	0	0	0	0	1(0,1)
OSRA	8(6,2)	4(4,0)	1(1,0)	0	3(3,0)	0	5(3,2)	0	0	0	4(2,2)	1(0,1)	0
LDNP	3(3,0)	3(1,2)	3(2,1)	3(1,2)	1(1,0)	4(2,2)	3(1,2)	1(1,0)	0	0	0	2(2,0)	0
MAPF	1(1,0)	3(2,1)	5(3,2)	1(1,0)	2(1,1)	1(1,0)	1(1,0)	5(3,2)	1(1,0)	2(1,1)	0	1(0,1)	0
MSRA	5(4,1)	7(4,3)	6(3,3)	0	1(1,0)	0	3(1,2)	0	0	0	3(2,1)	1(0,1)	1(1,0)
NPBS	8(3,5)	2(2,0)	2(2,0)	4(2,2)	1(1,0)	2(1,1)	1(0,1)	1(1,0)	0	0	0	1(1,0)	1(1,0)
WWF	3(2,1)	1(1,0)	1(1,0)	0	4(2,2)	0	8(4,4)	1(1,0)	3(0,3)	0	0	0	0
KSRA	3(2,1)	3(3,0)	1(1,0)	0	1(1,0)	0	2(2,0)	0	0	0	1(1,0)	1(0,1)	0
NECU	5(4,1)	0	1(1,0)	1(0,1)	0	0	1(1,0)	0	0	2(1,1)	0	0	0

Table A4.2.3. Identified themes of insufficient interactions and their descriptions. 'Frequency' reports the number of times a theme was mentioned, with strength of representing links in parentheses.

Name	Description	Frequency (strong/weak)
Budget constraints	Organizations cannot achieve the desired levels of interaction due to the general lack of funding for research and conservation initiatives; and/or due to the unfavourable funding schemes, which restrict the participation of different types of stakeholder organizations in a project.	18 (13/5)
Legal limitations	The desired levels of interaction cannot be achieved due to the lack of consistency in conservation policy, which results from the contradicting national laws and complicates collaboration and exchange of information.	15 (8/7)
Lack of interconnection	The desired levels of interaction cannot be achieved because one of the stakeholders abstains from having more contact.	6 (1/5)
Employee turnover	The desired levels of interaction cannot be achieved because of the staff turnover and the loss of established contacts.	3 (2/1)

Table A4.2.4. Stakeholder group relations. Values in brackets under 'Category' report the number of ties within or between stakeholder groups. An * indicates significant difference from random expectation at 5% level according to the null-model test.

Category (No. ties)	Density (%)	No. ties strong / weak	Reasons for insufficient interaction (No. mentioning)	Themes of interaction (No. mentioning)
Pa-Pa (14)	70	4/10	Budget constraints (1)	Communication relations (Total 19) Opinion (7) Unspecified content (7) Pontocaspian species data (4) Environmental data (1) Collaboration relations (Total 3) Research (3)
Acad-Acad (47)	65*	35/12	Budget constraints (11)	Communication relations (Total 55) Pontocaspian species data (22) Opinion (21) Unspecified content (8) Environmental data (3) Threatened species data (1) Collaboration relations (Total 36) Research (28) Conservation planning (3) Expert groups (3) Commercial fishing (2) Authority/power relations (Total 2) Scientific supervision (2)
Gov-Gov (10)	50	6/4	Legal limitations (5) Lack of interconnection (1)	Communication relations (Total 8) Opinion (4) Environmental data (3) Pontocaspian species data (1) Collaboration relations (Total 8) Resource management (6) Commercial fishing (2)
NGO-NGO (2)	33	2/0	NA	Communication relations (Total 1) Opinion (1) Collaboration relations (Total 2) Conservation planning (2)

Category (No. ties)	Density (%)	No. ties strong / weak	Reasons for insufficient interaction (No. mentioning)	Themes of interaction (No. mentioning)
Acad-Pa (43)	24	29/14	Budget constraints (5) Legal limitations (4) Lack of interconnection (2)	Communication relations (Total 48) Pontocaspian species data (19) Opinion (12) Environmental data (8) Threatened species data (6) Unspecified content (3) Collaboration relations (Total 34) Joint research (21) Conservation planning (7) Commercial fishing (6) Authority/power relations (Total 4) Scientific supervision (4)
Gov-NGO (12)	21	8/4	Employee turnover (2)	Communication relations (Total 14) Opinion (6) Threatened species data (4) Environmental data (2) Pontocaspian species data (2) Collaboration relations (Total 9) Conservation planning (5) Expert groups (2) Sturgeon conservation (2)
Gov-Pa (19)	21	10/9	Lack of interconnection (3)	Communication relations (Total 28) Opinion (13) Pontocaspian species data (9) Environmental data (6) Collaboration relations (Total 8) Conservation planning (8) Authority/power relations (Total 8) Directing action (8)
Acad-Gov (28)	15	13/15	Legal limitations (2) Budget constraints (1) Employee turnover (1)	Communication relations (Total 44) Opinion (12) Pontocaspian species data (12) Threatened species data (11) Environmental data (6) Unspecified content (3) Collaboration relations (Total 13) Conservation planning (5) Commercial fishing (4) Joint research (2) Expert groups (2) Authority/power relations (Total 3) Directing action (2) Scientific supervision (1)

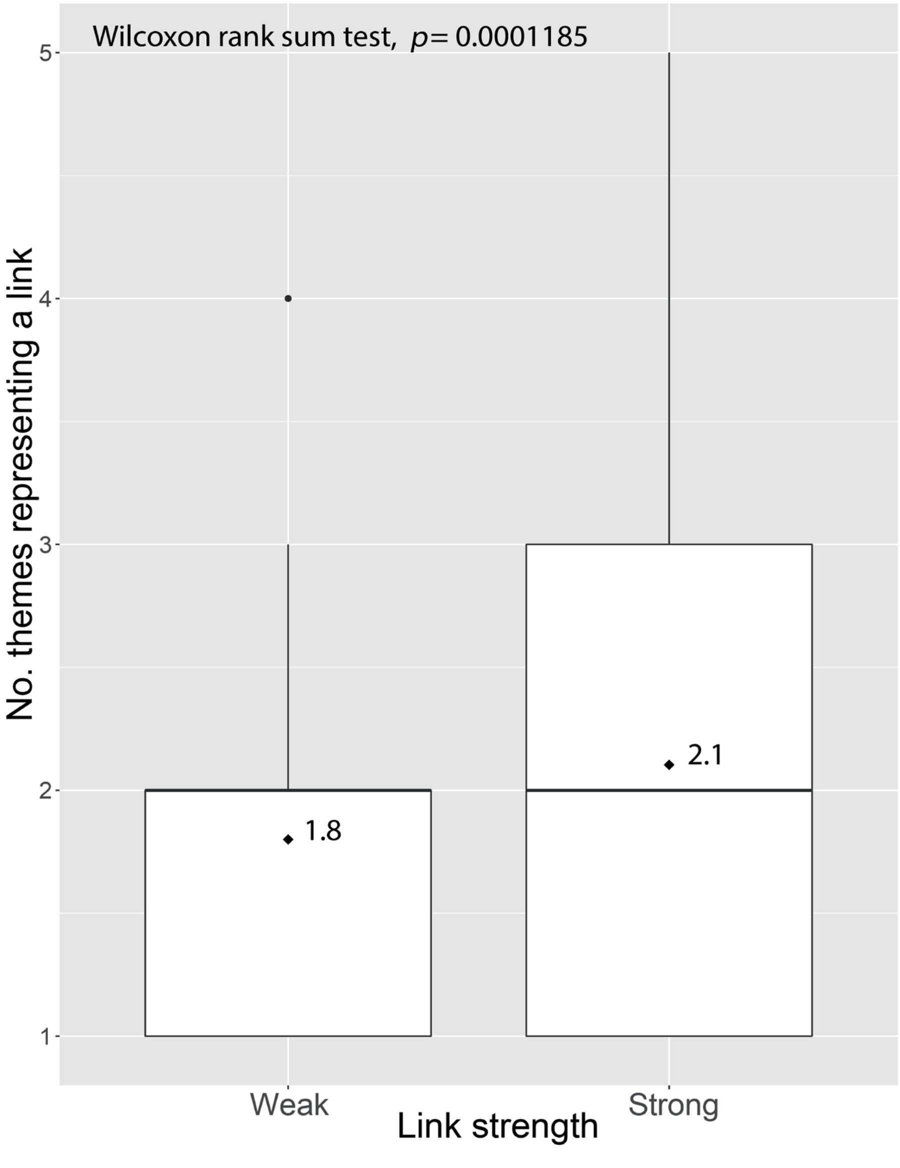


Figure A4.2.1. Boxplot on number of themes representing a link and the strength of the link. Horizontal lines in the boxes represent the median values. Diamonds represent the mean number of the themes.

Appendix 4.3. SNA term definitions.

Betweenness centrality - a measure, developed to assess the extent to which a node is among other nodes in a network i.e. how many times a certain node connects the other two nodes that are not directly connected (Freeman 1978). Betweenness centrality takes the intermediary nodes into consideration and is calculated based on the shortest path among the nodes (Opsahl et al. 2010).

Broker - a node with high betweenness centrality (Freeman 1977) and/or low Burt's constraint score (Burt 1992; Lee 1999; Therriault et al. 2004), which both, receives but also sends many relational ties out to the other stakeholders (Wasserman and Faust 1994) and serves as a bridge between the disconnected or weakly connected stakeholders. Betweenness centrality locates the brokers with respect to all the other actors in the network. Burt's constraint however, is a local measure of brokerage based on the triadic closure principle. A triad is any three nodes in the network with any type of relationship (Davis and Leinhardt 1967). If the tie is absent between two neighboring nodes in a triad, then the triad is incomplete and has a structural hole in it (Burt 1992). A node connecting two disconnected nodes in an incomplete triad has a power to broker. Brokers have low Burt's constraint score, meaning that their behavior is not constrained by the other disconnected nodes in a triad (Burt 1992). High constraint on the actor means that it is involved in many complete triads and is constrained to act as broker.

Burt's constraint - a measure, developed to assess the extent to which an actor's behavior is constrained by the other actors in a network, based on a triadic closure principle. Actor can have a Burt's constraint value ranging from 0, if it is involved in many incomplete triads, to 1, if it is involved in many complete triads (Burt 1992). Lower the actor's Burt's constraint score, lesser its behavior is constrained by other nodes in the network.

Confirmation rate - proportion of relational links described similarly by both nodes involved (Stork and Richards 1992).

Degree centrality - the number of connections that a particular node has with all the other actors in a network (Freeman 1978). In a directed network, the degree of a node is measured through a combination of in-degree and out-degree values. The in-degree value of a node is the number of the actors that have an incoming link to it, and the out-degree value is the number of outgoing links from the node (Kleinberg 1998). In weighted networks node strength represents an extension of degree centrality to the sum of tie weights and integrates information about connectivity and the weights of links (Barrat et al. 2004; Newman 2004; Opsahl et al. 2008).

Directed network - a network, in which the edges have a direction, as such a message or resources are sent from a sender to a receiver (Shannon and Weaver 1949).

Edge - a relational link between actors, also known as arc or tie (Wasserman and Faust 1994).

Network centralization - a measure of the extent to which certain actors are more connected in the network than the others (Freeman et al. 1979; Wasserman and Faust 1994). A centralized network is one in which only one or few actors are having the majority of ties. Such a network has a high overall centralization score. If actors are not very different from each other in their degree of connectedness, the overall centralization score is low, so the network is decentralized. The network centralization index can be calculated based on 'degree centrality' scores of individual nodes, and indicates the relative dominance of single actors in the network (Freeman et al. 1979).

Network density - also referred to as the graph density, is a measure of the proportion of the relational ties that are actually present in a network. It is calculated by dividing the number of existing ties by all the possible ties in a network (Scott 1991). Density can have a value ranging from 0, if all the ties are absent, to 1, if all the possible ties are present (Scott 1991; Wasserman and Faust 1994).

Network homophily - a selective linking between actors based on specific attributes, such as the category of institution (Newman 2003). Stakeholders are more likely to form strong connections with similar stakeholders than with stakeholders from other categories as they have higher mutual understanding (Prell et al. 2009).

Node - representation of actor in a network, also referred to as a vertex or point (Wasserman and Faust 1994).

Node centrality - a measure of a particular actor's involvement in the network, represented through the degree and betweenness centralities. The more relational ties an actor has, and more times it connects the other nodes that are not directly connected, the more central it is.

Shortest distance - a minimum number of steps that the nodes are away from each other in a network. In weighted networks the tie weights shall be taken under consideration (Opsahl et al. 2010).

Sociogram - a two-dimensional picture showing relationships between the actors where the actors are represented by the nodes and the relationships between them are represented by the edges (Moreno 1953).

Theme - a recurrent unifying concept or a statement about the content/subject of the inquiry (Bradley et al. 2007).

Triad - any three nodes in a network with any type of relationship (Davis and Leinhardt 1967). A triad is complete if all three actors in it are connected to each other, and incomplete if a tie is absent between two neighboring nodes in it (Burt 1992).

Weighted network - a network in which the edges carry values that can be used as a measure of the strength of the relationship (Wasserman and Faust 1994).


YAMAHA
02852-TL

5

Social network analysis and the implications for Pontocaspian biodiversity conservation in Romania and Ukraine: A comparative study

Published as:
Gogaladze, A., Raes, N., Biesmeijer, K., Ionescu, C., Pavel, A.B., Son, M.A., Gozak, N., Anistratenko, V.V., Wesselingh, F.P., 2020. Social network analysis and the implications for Pontocaspian biodiversity conservation in Romania and Ukraine: A comparative study. PLoS ONE 15:740084. https://doi.org/10.1371/journal.pone.0221833

Abstract
Romania and Ukraine share the Black Sea coastline, the Danube Delta and associated habitats, which harbor the endemic, aquatic Pontocaspian biota. Currently, this biota is diminishing both in numbers of species and their abundance because of human activities, and its future persistence strongly depends on the adequacy of conservation measures. Romania and Ukraine have a common responsibility to address the conservation of Pontocaspian biodiversity. The two countries, however have different socio-political and legal conservation frameworks, which may result in differences in the social network structure of stakeholder institutions with different implications for Pontocaspian biodiversity conservation. Here, we study the social network structure of stakeholder organizations involved in conservation of Pontocaspian biodiversity in Romania and the implications of network structure for conservation outcomes. Then we compare the findings from Romania to an earlier similar study from Ukraine. We apply a mix of qualitative and quantitative social network analysis methods to combine the content and context of the interactions with relational measures. We show that Pontocaspian biodiversity plays a minor and mostly incidental role in the inter-organizational interactions in Romania. Furthermore, there is room for improvement in the network structure through e.g., more involvement of governmental and nongovernmental organizations and increased motivation of central stakeholders to initiate conservation actions. Social variables, such as lack of funding, hierarchical, non-inclusive system of conservation governance and continuous institutional reforms in the public sector are consequential for the network relations and structure. Social network of stakeholders in Ukraine is more connected and central stakeholders utilize their favorable positions. However, neither in Ukraine is the Pontocaspian biodiversity a driver of organizational interactions. Consequently, both networks translate into sub-optimal conservation

actions and the roads to optimal conservation are different. We end with sketching out conservation implications and recommendations for improved national and cross-border conservation efforts.

5.1 Introduction

Romania and Ukraine hold an important part of the Pontocaspian (PC) habitats in the Northern part of the Black Sea Basin, which harbor aquatic PC community (Grigorovich et al. 2003; Kostianoy and Kosarev 2005; Krijgsman et al. 2019). The PC biota comprises endemic flora and fauna including mollusks, crustaceans, planktonic groups (e.g., dinoflagellates and diatoms) and fish species (Grigorovich et al. 2003; Marret et al. 2004; Wesselingh et al. 2019). Currently, PC species numbers and abundances are in decline as a result of human activities and their future persistence strongly depends on the adequacy of conservation measures (Grigorovich et al. 2003; Grinevetsky et al. 2016; Therriault et al. 2004). The distribution of PC species in Romania is limited to the Razim-Sinoe-Babadag lake complex (Popa et al. 2009; Velde et al. 2019), the area along the Danube River and the Black Sea coastal zone, which together form the Danube Delta and have the status of Biosphere Reserve. In Ukraine, PC communities occur in the coastal lakes, deltas and estuaries from the Danube Delta in the south to the Dnieper estuary in the north and in the north-eastern part of the Sea of Azov (Anistratenko 2009, 2013; Anistratenko and Anistratenko 2018). The two countries share the responsibility of conserving the PC habitats and the associated threatened biota (Anistratenko 2009; Munasypova-Motyash 2009a, b; Velde et al. 2019). However, they have different socio-political settings and histories. Romania is a member of the European Union (EU) since 2007, thus complying with the EU environmental policy, whereas Ukraine is an EU-associated country since 2017. Being part of the EU, Romania experiences continuous adjustments in the institutional alignment (Vasile 2013) and a transformation of governance systems from authoritative state, to democratic and inclusive, multi-stakeholder systems (Stringer and Paavola 2013). This may result in different social environment in Romania to deal with biodiversity conservation issues compared to Ukraine (Gogaladze et al. 2020b).

In both countries Pontocaspian species are threatened and conservation measures are urgently required. In the past 30 years, the number, abundance and distribution ranges of PC species have decreased dramatically in Romania as a result of human influence (Popa et al. 2009; Velde et al. 2019). In Ukraine, PC species are declining as a result of habitat fragmentation caused by river damming and deep sea shipping lane constructions (Semenchenko et al. 2015; Zhulidov et al. 2018). Some of the PC species (e.g., some mollusk and sturgeon species) are of national concerns in both countries - they are recognized to be threatened and in need of conservation (Anistratenko 2009; Munasypova-Motyash 2009a, b; Popa et al. 2009). Yet, indications exist that strong conservation measures are not in place to preserve these species and populations continue to decrease in both countries (Anistratenko and Anistratenko 2018; Popa et al. 2009; Velde et al. 2019).

Biodiversity conservation is a complex task which involves different interests of various actors. Therefore, it is crucial that all types of stakeholder organizations are participating and interact at different stages of the process (Durham et al. 2014). Effective exchange of scientific information, knowledge and conservation management experiences between stakeholder organizations determine the positive outcomes for biodiversity conservation (Cash et al. 2003; Francis and Goodman 2010; Wasserman and Faust 1994). Social network analysis (SNA) is a commonly used tool to map and quantify these interactions. Social networks, defined as the sets of relationships among the stakeholder organizations, work as channels that facilitate the flow of information and provide opportunities for joint action and collaboration (Barnes et al. 2016; Ernoul and Wardell-Johnson 2013; Haythornthwaite 1996). SNA uses a combination of mathematical formulae and models to describe and quantify the existing links among organizations (Wasserman and Faust 1994). In recent years, SNA has gained increased attention across a variety of domains including biodiversity conservation (Hauck et al. 2016; Sandström and Rova 2010; Yamaki 2017) and proved to be very informative for conservation planning (Mills et al. 2014).

The structure of a social network has implications for biodiversity conservation. Social networks can vary in their properties, for example, in the number of connections, the structural position of individual stakeholders or the frequency of interactions between stakeholders. There is no single network structure that will be most beneficial in all contexts (Bodin et al. 2006; Bodin and Crona 2009). There are, however, certain network properties which are suggested to facilitate effective management of natural resources and effective conservation of biodiversity. For example, a high number of connections in a network was shown to enable improved transfer of information relevant to biodiversity conservation (Abrahamson and Rosenkopf 1997; Weimann 1982). Similarly, strong, i.e. frequent connections are desirable for effective conservation as they indicate high levels of trust (Crona and Bodin 2006; Newman and Dale 2005, 2007; Opsahl et al. 2008). Weak, or less frequent connections on the other hand, facilitate the transfer of novel information as they tend to connect dissimilar actors (Burt 2002; Granovetter 1973). Furthermore, networks in which only one or a limited number of organizations have a central position (holding the majority of relational ties) are more effective for quick mobilization of resources and decision making in the initial phase of conservation action (Leavitt 1951; Prell et al. 2009). On the contrary, networks with more organizations in a central position are more suitable for long-term environmental planning and complex problem-solving (Crona and Bodin 2006). In summary, whether a network is optimal or not depends on the local context, the organizations that are involved, and the phase of the conservation process (Cowling and Wilhelm-Rechmann 2007; Crona and Bodin 2006; Olsson et al. 2004).

Merely the structural analysis of a network may not be sufficient to fully understand all the processes and dynamics within the network. Therefore, a qualitative analysis of the data provided by the stakeholders is very important to inform and explain the results of the SNA (Herz et al. 2015). Qualitative data on the nature and content of reported interactions, as well as the additional

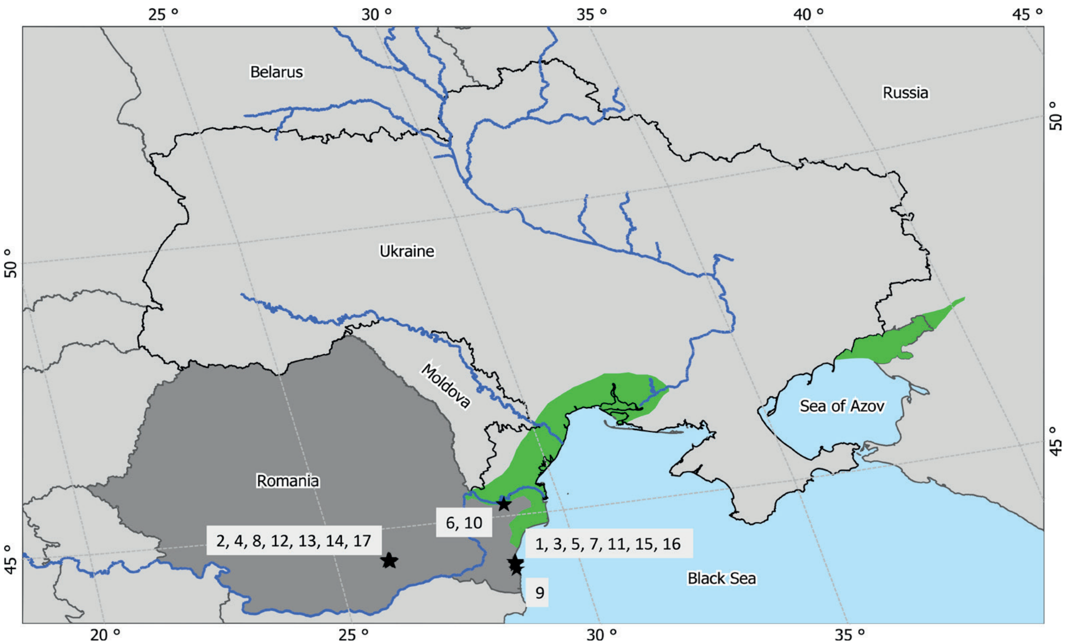


Figure 5.1. Map of the study area. Black stars on the map represent the stakeholder institutions (see IDs in Table 5.1). Green shading indicates major Pontocaspian habitats.

social variables, such as the funding schemes, stability and functioning of organizations, the implementation capacity and the governance arrangements, amongst others provide a deeper understanding of how the network functions and translates into conservation action (Cowling and Wilhelm-Rechmann 2007). Combining a quantitative structural analysis of the network data with a qualitative analysis of the interactions is referred to as the mixed-method approach (Hauck et al. 2016; Kowalski and Jenkins 2015).

Here we employ the mixed-method approach to analyze the information sharing network of stakeholders, which are involved in Pontocaspian biodiversity conservation in Romania and compare this network to the similar stakeholder network of Ukraine, which was studied using the same analytical approach (Gogaladze et al. 2020b). This study is part of the Horizon 2020 'Pontocaspian Biodiversity Rise and Demise' (PRIDE) program (http://www.pontocaspian.eu/) which was designed to generate scientific knowledge on PC biota and guide effective conservation action. We assess whether the different socio-political contexts in Romania and Ukraine result in differences in the social network structure of stakeholders, the content of the interactions and the external social variables which may help or hinder the functioning of the network. Importantly, we aim to identify how differences and/or similarities in the two networks translate into PC biodiversity conservation. We conclude the paper with recommendations for improved national and cross-border conservation efforts.

Table 5.1. List of the 17 selected stakeholders from Romania divided into three stakeholder categories.

ID	Abbreviation	Category	Organization name	Department/Service
1	CMSN	Acad	CMSN - Museum of Natural Sciences, Constanța	Delfinariu, Constanta
2	GAM	Acad	Grigore Antipa National Museum of Natural History	
3	GEcM	Acad	Constanta Branch of the National Institute for Research and Development on Marine Geology and Geo-ecology – GeoEcoMar	
4	IBB	Acad	Institute of Biology Bucharest, Romanian Academy	Department of Microbiology
5	OUC	Acad	Ovidius University of Constanta	The Faculty of Natural and Agricultural Sciences
6	DDNI	Acad	The Danube Delta National Institute for Research and Development	Biodiversity Conservation and Sustainable use of Natural Resources
7	NIMR	Acad	The National Institute of Marine Research and Development "Grigore Antipa"	
8	UB	Acad	University of Bucharest	Department of Paleontology
9	AZS	Acad	Marine Biological Station of Agigea	
10	DDA	Gov	Danube Delta Biosphere Reserve Authority	
11	LAC †	Gov	Local Environmental Protection Agency in Constanta	
12	ANPA †	Gov	Ministry of Agriculture and Rural Development of Romania	National Agency for Fisheries and Aquaculture
13	MOE	Gov	Ministry of Environment of Romania	Biodiversity Directorate
14	MWF	Gov	Ministry of Waters and Forests	Department for Water, Forests and Fishery
15	MN	NGO	ONG Mare Nostrum	
16	OC	NGO	SEOPMM Oceanic Club	
17	WWF	NGO	WWF Romania	

† Institutions that could not be interviewed for which relationships were imputed

5.2 Materials and methods

5.2.1 Stakeholder identification and prioritization

We applied the whole network analysis approach to examine the stakeholder interactions in Romania. A whole network approach requires the definition of network boundaries by establishing a list of relevant stakeholders; and the collection of responses from all stakeholders of the network about each other (Haythornthwaite 1996). We defined a stakeholder as an organization who is involved and influences or is influenced by the Pontocaspian biodiversity research and conservation activities (Durham et al. 2014; Gogaladze et al. 2020b). Based on this definition we initially identified 23 stakeholder institutes in Romania through online research and consultations with partners in the PRIDE project. After engagement, stakeholders which were found to lack any activity or interest in (conservation of) Pontocaspian biodiversity were omitted, resulting in a final list of 17 institutes (Table 5.1, Fig. 5.1). We assigned these stakeholders to three different categories based on their function and responsibilities, knowingly academic (Acad), governmental (Gov) and nongovernmental organizations (NGO). For comparison, the Ukrainian network consisted of 22 stakeholders of which nine were academic institutions, five governmental organizations, three nongovernmental organizations and five protected areas (Pa) (Gogaladze et al. 2020b).

The Danube Delta Biosphere Reserve Authority (DDA) administers the biosphere reserve and serves as a local environmental agency. Besides the administration, it has educational and regulatory (e.g. issuing research permits) functions within the biosphere reserve. The analogous organization in Ukraine, the Danube Biosphere Reserve (DBR) does not have administrative and regulatory functions but instead focuses on research, environmental monitoring and education, as well as on ecotourism. DDA was under commission of the Ministry of Environment of Romania until July 2017, but was transferred under commission of the Romanian Government one week before the interview (July 2017). Presently, DDA is again back under commission of the Ministry of Environment. During the interview, DDA identified itself as a governmental organization and was therefore grouped with governmental organizations.

5.2.2 Data collection

We obtained the qualitative and quantitative network data using an identical survey questionnaire that was previously used in a similar study in Ukraine (Gogaladze et al. 2020b). We interviewed the staff members of the institutions or relevant departments during July 2017. Interviews with staff members were undertaken with the knowledge and consent of the organizations to which the staff members were affiliated. Persons that were selected for the interview were all in a central position in the organization and thus aware of most, if not all, organizational aspects relevant to the network analysis. Each stakeholder organization was interviewed about each other organization from the list (Table 5.1) using the same questions. We extracted the meaning and content of interactions from the interviews and no prior data was used.

We compiled data on the context and the content of interactions among the stakeholders using the question asking interviewees to describe their professional relationships. Next, we asked the interviewees whether the described professional link involved or was related to Pontocaspian (PC) biodiversity. We were mainly interested in PC biodiversity conservation related information, so when the reported interaction between stakeholders was not related to PC biota, we refrained from posing subsequent questions and continued with the next stakeholder from the list (Table 5.1). Once a PC biodiversity related link was established, the interviewee was asked whether s/he considered the existing relationship sufficient or insufficient to achieve desired levels of collaboration and for what reasons.

We collected the SNA data asking the interviewees to rank the reported PC biodiversity related links based on the frequency of interaction (Gogaladze et al. 2020b). We used frequency of contact as a measure of strength (weight) of the relationship (see (Prell et al. 2009), (Paletto et al. 2015)). We defined five weight categories ranging from no contact to very frequent contact (0-4) and integrated the strength definitions as a table in the questionnaire to provide reference for the interviewees.

Answers to the questions allowed the generation of directed, weighted, values of information and knowledge transfer in the network (see the collected raw data in Appendix 5.1).

5.3 Analysis

5.3.1 Social network analysis

For readability, we provide the full SNA methodology and term definitions in Appendix 5.2. We translated the collected interviews into an adjacency matrix, a square matrix reporting weights (strength) of all the relational ties (Appendix 5.1). We considered only confirmed information sharing links i.e., relational links described by both stakeholders involved. Unconfirmed links (16% of all the reported relationships) were considered unreliable and were omitted from the study. Tie-strength values of confirmed relationships between pairs of stakeholders did not always match. In case of bi-directional relationship, tie values were left as reported by the stakeholders. In case of unidirectional confirmed links, we selected the lowest and therefore most conservative tie values. Two institutions could not be interviewed resulting in some missing network data. We imputed the missing data using the imputation-by-reconstruction method (Stork and Richards 1992). We visualized the sociogram using the CRAN R package 'igraph' (Csardi and Nepusz 2006).

The basic network statistics including number of actors and relational ties, graph density and centralization index were calculated using the CRAN R package 'igraph' (Csardi and Nepusz 2006). The mean shortest distance was calculated using the CRAN R package 'tnet' (Opsahl 2009) because the 'igraph' package does not take edge weights into account when measuring the shortest distance. We used frequency of contact as a measure of strength of the relationship and defined strong relationships as the weights ≥3 on a scale ranging from no contact to very frequent contact.

Centrality of individual nodes was calculated using degree centrality and betweenness centrality values. We calculated node-level statistics using the CRAN R package 'tnet' (Opsahl 2009) which considers tie weights and corrects for the number of intermediary nodes. Central stakeholders were regarded as those with centrality scores higher than, or equal to the third quartile threshold values (Grilli et al. 2015; Paletto et al. 2015; Yamaki 2017).

Brokerage was measured by combining quantitative and qualitative approaches. Brokers are nodes which are between other nodes in a network and have the power to control the flow of information (Burt 1992, 2002, 2004). Quantitatively, brokerage was measured through betweenness centrality and Burt's constraint metrics (Burt 2002, 2004). Qualitatively, we examined the network narratives and extracted evidence that stakeholders are actually engaging in brokering behavior, such as mobilization of information, deliberation between different types of stakeholders and mediating between working groups to address conservation issues (Fazey et al. 2013). Here, we regarded stakeholders as brokers when they had high betweenness scores, low Burt's constraint values, and were engaged in brokering behavior. We used only the strong ties (≥ 3) to calculate betweenness centrality and Burt's constraint metrics as these reflect regular contacts. We calculated Burt's constraint utilizing CRAN R package 'igraph' (Csardi and Nepusz 2006).

Finally, we used a null-model test to identify the presence of 'network homophily' in the network. 'Network homophily' is the selective linking between actors based on specific attributes, in our case the category of stakeholder institutes (Newman 2003). With a null-model test, we tested whether densities within and between stakeholder groups (defined by the stakeholder category) were significantly higher or lower than random expectation.

5.3.2 Qualitative analysis

We used the 'inductive approach' for qualitative analysis, so the themes (recurrent unifying concepts or statements about the content/subject of the inquiry) of interaction and perceived sufficiency of interaction were determined based on the collected data and not on prior knowledge or assumptions (Bradley et al. 2007; Ryan and Bernard 2003). The themes were established from the collected interviews based on repetitions (Bogdan and Taylor 1975). We used a 'constant comparison' method to refine the dimensions of established themes and to identify the new themes (Glaser et al. 1967). We then counted the identified themes and determined their relative importance based on the order of frequency. We grouped the identified themes of interaction based on similarity in two categories, knowingly 'collaboration relations' – links between the stakeholders consisting of joint action, and 'communication relations' – links between the stakeholders mostly used for conveying information.

5.3.3 Ethics statement

The social network analysis of stakeholder organizations which we conducted here is not subject to ethical screening as for example is required for medical and/or socio-medical studies, which involve personal data. As such, we did not conduct a priori ethics review nor is there any established procedure within our organization (Naturalis Biodiversity Center) which could be followed. We informed all participants prior to the interviews that they were being interviewed on behalf of the organization which they represent, and that the results would be part of a publication. We assured all participants that they would not be individually identifiable and asked for their consent.

5.4 Results and discussion

Conservation of Pontocaspian (PC) biodiversity is critically dependent on adequacy of conservation measures and coordination of actions across their distribution range - the northern part of the Black Sea and the Caspian Sea region. This paper assesses the adequacy of stakeholder networks for conservation in two countries covering a large part of the native range of PC biota. We compare the social network structures of stakeholders involved in biodiversity conservation in Romania and Ukraine, based on new data from the former and data from a previous published paper from the latter [17]. Then we discuss the implications of the Romanian results for effective conservation and compare these to the findings from Ukraine. We examine the challenges within, as well as beyond

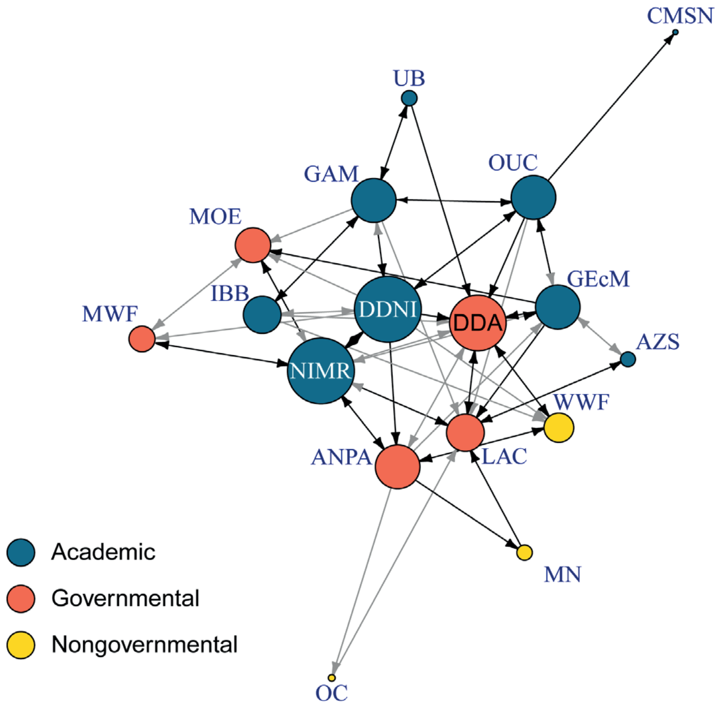


Figure 5.2. Sociogram of Romanian stakeholders involved in Pontocaspian biodiversity conservation and conservation planning. Nodes represent organizations (see Table 5.1 for institution acronyms). The size of the nodes corresponds to the node strength (sum of weights of all its links). Arrows represent relationships between the nodes. Black arrows represent strong relationships (value ≥3). Gray arrows represent weak relationships (value < 3).

the network structure for optimal PC biodiversity conservation and provide recommendations for improved cross-border conservation efforts.

5.4.1 Network structure

The Romanian network was smaller compared to Ukrainian one (17 vs. 22 stakeholders respectively) and also less connected. In Romania, 15 out of the 17 stakeholder institutions were interviewed (covering 88% of the network data). Fourteen organizations were interviewed through face to face in-depth interviews and one organization through an electronic questionnaire via email. The remaining two institutions could not be reached and data were imputed (Table 5.1). The studied network in Romania was not well connected (Fig. 5.2) with a total number of 63 relational ties out of 272 potential ties, resulting in a network edge density measure of 23% (Table 5.2). For comparison, the Ukrainian network had an edge density value of 41%. On average each organization in Romania had 7 relational ties with other stakeholders in the network, while in Ukraine each stakeholder had

Table 5.2. Network statistics for Romanian stakeholder network compared to the previously published Ukrainian stakeholder network (in grey) (Gogaladze et al. 2020b).

Network data	Romania	Ukraine
Total actors	17	22
Total No. of ties	63	191
Mean degree	7	17
Density (%)	23	41
Degree of centralization (%)	20	38
Tie reciprocity (rho)	0.38	0.78
Tie reciprocity (rho) excluding the Gov. organizations	0.79	0.76
Strong/weak ties (%)	59/41	61/39
Mean shortest distance	2.2	1.5

on average 17 ties. This resulted in larger mean distance between stakeholders in the Romanian network compared to Ukrainian one (2.2 vs 1.5 respectively). The Romanian network had a lower degree of centralization score (20%) than the Ukrainian network (38%), meaning that the former was less centralized than the latter. The correlation of incoming and outgoing ties, although positive in both networks, was lower in Romania compared to Ukraine (rho = 0.38 in Romania vs. rho = 0.78 in Ukraine) indicating that information exchange was in general less reciprocated in Romania (Table 5.2). When governmental organizations (including the DDA) were omitted from the Romanian network, the correlation increased (rho = 0.79), suggesting that the governmental organizations in Romania received information from multiple sources but did not share similarly. In both countries, the majority of relationships were strong (59% in Romania and 61% in Ukraine), indicating regular interactions.

5.4.2 Network relations

Unlike in Ukraine, the majority of interactions among stakeholder organizations in Romania consisted of 'collaboration relations' while transfer of information was less common (Fig. 5.3, Table A5.3.1). Interactions in Romania were mostly achieved through joint projects. For example, the collaboration themes 'environmental projects', 'sturgeon conservation' and 'conservation planning' were all based on common projects (Table A5.3.1). Within these projects, exchange of relevant information and data was easily achieved, as indicated by the interviewees. Outside projects, however exchange of comprehensive data in Romania was either not possible or was subject to payment. Thirty-two relational links in the network were represented by a single theme of interaction. Twenty-three links had 2 themes of interaction, seven links had 3 themes of interaction and 1 link had 5 themes of interaction. Similar to Ukraine, links represented with more themes were significantly stronger than links represented with less themes (Fig. A5.3.1).

In Romania, like in Ukraine, Pontocaspian species played a minor and mostly incidental role in inter-organizational relations (Fig. 5.3, Table A5.3.1), indicating low priority for PC biodiversity conservation. Collaborative interactions theme 'conservation planning' involved biodiversity

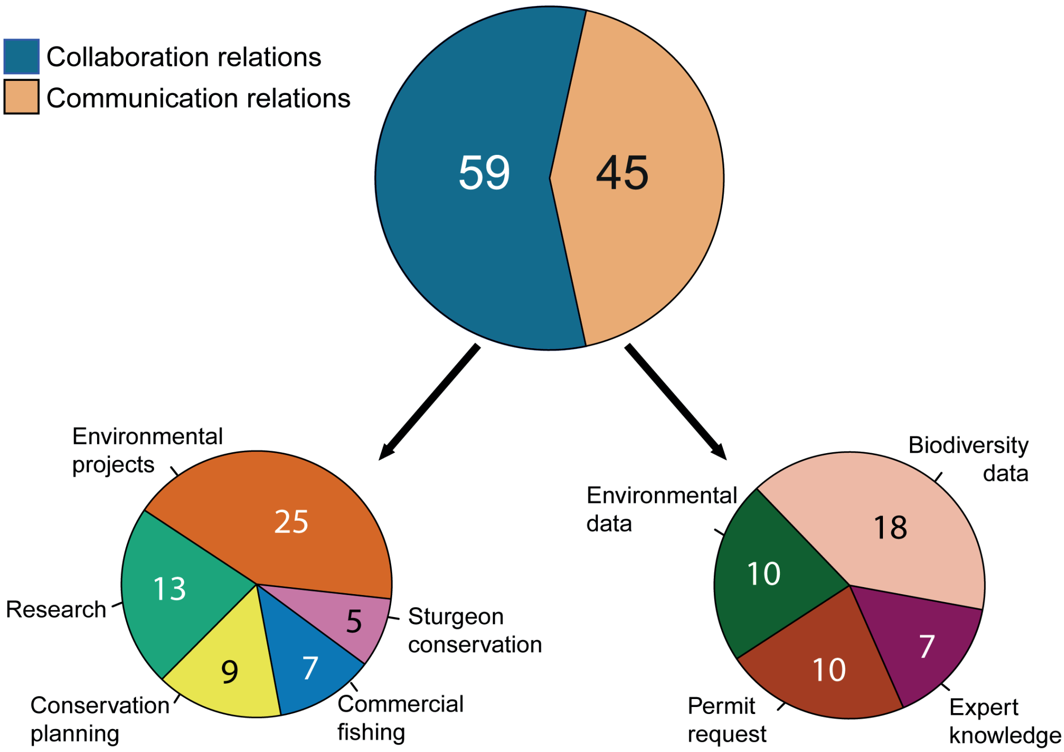


Figure 5.3. Frequencies of interaction themes among the stakeholder organizations. Values in the pie charts represent absolute number of times each theme was mentioned. See theme definitions in Table A5.3.1.

monitoring according to the EU Habitats Directive (Article 17), and planning of conservation activities within Natura 2000 sites, coinciding with PC habitats (e.g., Razim-Sinoe Lake Complex as a Natura 2000 site https://natura2000.eea.europa.eu/?query=Natura2000Sites_9883_1, Site Code: ROSPA0031). Furthermore, the theme 'Research' involved joint fieldwork and publications on the biodiversity of the Black Sea coastal areas, lagoons, rivers and lakes, which also cover the PC habitats. Interactions within the 'commercial fishing' theme involved some PC fish species such as the Pontic shad and some invasive species, such as the veined Rapa whelk, which is potentially harmful to native PC species. Similar to Ukraine, 'sturgeon conservation' was the only collaborative theme, which directly targeted PC biodiversity conservation. This theme, however, primarily focused on sturgeon species and other PC groups were left out. Communication relations mostly included a) information transfer related to reporting obligations to the EU (Fig. 5.3, Table A5.3.1; themes 'biodiversity data' and 'environmental data'), b) administrative work to implement the research projects (theme 'permit request') and c) sharing of project management experiences and advice; all of which occasionally covered the PC habitats. This is indicative of low priority for PC biodiversity conservation on both the national and European agendas, with the notable exception of sturgeon species (ICPDR 2015). Individual scientific organizations, such as Grigore Antipa National Museum of Natural History, Constanta Branch of the National Institute for Research and Development on Marine Geology and Geo-ecology – GeoEcoMar, and the Danube Delta Research Institute did possess PC species occurrence and distribution data, but they reported that this data is not utilized because governmental organizations and NGOs file no data requests (Table 5.4, Table A5.3.1).

5.4.3 Perceived sufficiency of network relations

A total of 19 relational ties (44% of 43 ties for which sufficiency was indicated by the interviewed stakeholders) were reported to be insufficient in Romania to achieve the desired levels of collaboration and information exchange (Table A5.3.2). We identified 3 themes of insufficient interactions – 'lack of funding', 'political constraints' and 'institutional turnover'. For comparison, in Ukraine 31% of relational links were construed as insufficient. The causes for insufficient relationships were different in two countries. 'Lack of funding' in Romania (mentioned 10 times), and 'budget constraints' in Ukraine (mentioned 18 times) were the most prominent factors limiting collaboration. Besides the general lack of funding available for research and conservation, which was a common characteristic of both themes, 'budget constraints' also referred to unfavorable funding schemes in Ukraine which restricted the participation of different stakeholder categories in a project (Gogaladze et al. 2020b). However, 'budget constraints' did not have effect on exchange of information in Ukraine, while 'lack of funding' in Romania affected the access to biodiversity and environmental information (see Table A5.3.2). Besides publicly funded projects in Romania, the EU LIFE Program is the major source for conservation funding (Hermoso et al. 2017). An earlier study on collaboration networks across Europe found that once a project was awarded to an organization in Romania, such organization became less prone to collaborate with other organizations in other projects, so project management experiences were not shared among stakeholders (Nita et al. 2016). This was attributed to difficulties in the implementation of EU LIFE projects (Nita et al. 2016). Additionally, according to our findings the reduced collaboration occurred also due to institutional competition among stakeholders which encouraged organizations to keep data to themselves as a competitive advantage to attract future grants (see Table A5.3.2; theme 'lack of funding').

'Political constraints' (mentioned 6 times) and 'institutional turnover' (mentioned 3 times) were reported only in Romania and not in Ukraine. Continuous institutional rearrangements were found to complicate firstly the establishment and secondly the maintenance of relationships in Romania (Table A5.3.2; theme 'institutional turnover'), resulting in low network density (Table 5.2). For example, the Ministry of Environment reported an absence of relationship with DDA (Fig. 5.2), and described the situation as follows: "DDA used to be under our structure until recently, but they are now coordinated by the government and we do not know how the new dialog will be because we are currently in a process of rearrangements". Institutional turnover also resulted in many unconfirmed relations. For example, out of 7 outgoing ties from the Marine Biological Station of Agigea (AZS)

5 were not confirmed (Appendix 5.1) as AZS was still deemed to be part of the University of Iasi and not yet recognized as an independent organization by many of the stakeholders. This finding corroborates an earlier study which suggested that continuous institutional reforms of the public sector is a result of adjustments to the EU institutional structures which does not always have positive outcomes in Romania (Vasile 2013). According to the same study, however, continued reforms of public sector are necessary to ensure access to national funds for scientific research (Vasile 2013). Therefore, institutional turnover may be expected to persist in the coming years in Romania.

Unlike in Ukraine, the involvement of governmental organizations in the studied network was limited by bureaucratic barriers (Table A5.3.2; theme 'political constraints'), which resulted in few reciprocated ties between governance actors and other stakeholder categories (Table 5.2). Lack of reciprocated communication (governmental stakeholders receiving information from multiple sources but not sharing back to the network) is indicative of a strong hierarchy in conservation governance (Lazega et al. 2017). According to literature, stakeholder engagement in conservation planning is often interpreted by the governmental organizations in Romania as intersectoral cooperation and engagement, which results in seeking collaboration with other governmental organizations and international actors rather than in collaboration with local organizations and NGOs, resulting in hierarchical governance systems (Kluvankova-Oravska et al. 2009; Stringer and Paavola 2013; Wesselink et al. 2011). However, the theme 'legal limitations' which in Ukraine mostly referred to contradicting national laws and uncoordinated actions of regional administrations (Gogaladze et al. 2020b), was not mentioned in Romania, indicating higher consistency in conservation policies in Romania. In both countries most of the insufficient relationships were represented by strong links, suggesting that frequent interactions were not a guarantee for effective collaboration (see Table A5.3.2).

5.4.4 Stakeholder centrality and brokerage

In Romania five central stakeholders were identified based on their degree centrality scores (Table 5.3), compared to six in Ukraine (Gogaladze et al. 2020b). In both networks three out of nine academic institutions had a degree centrality score higher than or equal to the third quartile threshold value (≥11 in Romania and ≥20 in Ukraine), indicating high involvement of these organizations in the exchange of relevant information. Unlike in Ukraine, where the major decision-making organization (Ministry of Ecology) was the most central stakeholder, in Romania, the analogous institution (Ministry of Environment) was not actively involved in the network. Instead, the Local Environmental Protection Agency in Constanta (LAC) was the central governmental institution with high degree centrality score. The Danube Delta Biosphere Reserve Authority (DDA) in Romania and the Danube Biosphere Reserve Administration (DBR) in Ukraine were both active in stakeholder networks with high degree centrality scores. Nongovernmental organizations had few connections in both countries. All the central stakeholders in Ukraine and Romania had more strong than weak connections.

Two out of six central stakeholders in Romania, namely the National Institute of Marine Research and Development "Grigore Antipa" (NIMR), and the Danube Delta Biosphere Reserve Authority (DDA) had a structurally favorable position to act as brokers based on betweenness centrality and Burt's constraint scores (Table 5.3). Qualitative data, however, showed that these structurally well-positioned organizations were not engaging in brokering behavior with regard to Pontocaspian biodiversity. From network narratives we found that NIMR was a national focal point in many international bodies, such as UNESCO, the Black Sea Commission and GEF/Black Sea, among others, and very actively involved in the Black Sea Biodiversity conservation. However, its primary focus was on Marine and not on Pontocaspian biodiversity conservation (Table A5.3.3). In the studied network NIMR was collaborating with other organizations, e.g., with the Ministry of Environment, Danube Delta National Institute for Research and Development and DDA on conservation planning in Natura 2000 sites, which sometimes incidentally involved PC habitats. But it did not have any incentive to initiate PC biodiversity relevant conservation actions, either due to low priority for PC biodiversity conservation or lack of knowledge on PC species. The second structurally well positioned organization to act as broker was DDA. This organization was a major local administrative body and was found to mostly request and receive information from other stakeholders but rarely communicated the knowledge back to the network (Tables 5.2 and 5.3, Table A5.3.3). From the narratives we learned that this organization was experiencing frequent institutional turnover and was politically constrained (see Table A5.3.2), which complicated the establishment of relationships. As a result, DDA was not found to facilitate any brokering behavior and served as a local protected area administrator and a data aggregator (Table 5.3).

WWF accounted for high betweenness values in both networks; however, they did not directly bridge many disconnected nodes (indicated by their high Burt's constraint scores). The qualitative data showed that WWF Romania and WWF Ukraine were actively involved in the conservation of sturgeon species (Table A5.3.3) through the enforcement of conservation laws and awareness raising (Gogaladze et al. 2020b). They had large number of volunteers in both countries and sometimes brought the otherwise disconnected stakeholder organizations together for joint conservation action. Their work, however, mostly focused on charismatic PC species and the wider PC taxa was absent from their conservation agenda.

5.4.5 Stakeholder group connectivity

Across the Romanian network, different stakeholder categories had various tie densities, but connectedness was not significantly higher than random expectation indicating the absence of network homophily (Table 5.4). In Ukraine, strongly connected academic institutions were found with a significantly higher within group density value than expected by chance suggesting high levels of connectedness within this group (Gogaladze et al. 2020b). Most relations among stakeholder

Table 5.3. Node-specific centrality measures and interaction categories from Romania. Values between brackets under the 'Degree centrality' represent the in-degree and out-degree measures respectively. In bold are values higher than, or equal to the third quartile threshold (lower or equal to the first quartile threshold in case of 'Burt's constraint'). Burt's constraint value for OC is not defined (NA) as the calculation was based only on strong ties (≥ 3).

Abbr.	Degree centrality	No. ties Strong/ weak	Betweenness centrality	Burt's constraint	Collaboration relations	Communication relations
DDNI	13 (4, 9)	7/6	57	36	15 (6, 9)	14 (3, 11)
NIMR	13 (6, 7)	9/4	89	25	16 (8, 8)	4 (1, 3)
DDA	12 (9, 3)	8/4	54	25	10 (6, 4)	14 (13, 1)
GAM	11 (5, 6)	7/4	45	32	13 (4, 9)	8 (3, 5)
LAC †	11 (8, 3)	7/4	39	26	6 (4, 2)	11 (9, 2)
GEcM	10 (4, 6)	7/3	20	36	8 (4, 4)	8 (0, 8)
ANPA †	10 (4, 6)	6/4	64	36	9 (3, 6)	2 (2, 0)
OUC	9 (3, 6)	7/2	48	32	8 (5, 3)	6 (2, 4)
MOE	8 (5, 3)	2/6	0	66	8 (4, 4)	4 (4, 0)
IBB	6 (2, 4)	2/4	0	100	6 (3, 3)	6 (2, 4)
WWF	6 (4, 2)	4/2	49	50	7 (4, 3)	4 (3, 1)
MWF	5 (3, 2)	2/3	0	100	4 (2, 2)	1 (1, 0)
AZS	4 (2, 2)	2/2	0	100	4 (2, 2)	2 (1, 1)
UB	3 (1, 2)	3/0	0	56	2 (2, 0)	2 (0, 2)
MN	2 (1, 1)	2/0	0	50	1 (1, 0)	1, (0,1)
OC	2 (1, 1)	0/2	0	NA	1 (1, 0)	1, (0,1)
CMSN	1 (1, 0)	1/0	0	100	0	1 (1, 0)

† Institutions that could not be interviewed for which relationships were imputed

categories in Romania were collaboration relations, with the exception of links among academic and governmental organizations, which mostly consisted of knowledge transfer (Table 5.4). When in contact, academic institutions requested research permits from governmental organizations and reported on study results (theme 'permit request'). Additionally, governmental organizations were found to regularly request environmental and biodiversity data from academic organizations for reporting to the EU and international treaties (themes 'biodiversity data' and 'environmental data'). Some of the links among these stakeholder groups were insufficient due to political constraints, institutional turnover, and/or lack of funding (Table 5.4).

Nongovernmental organizations were marginally involved in both Romanian and Ukrainian networks. In Romania, NGOs were significantly less connected to the academic institutions than expected by chance and had no PC biodiversity related links among themselves (Table 5.4). In Ukraine, NGOs were also significantly less connected to academic organizations and had only two PC biodiversity related links among themselves (Gogaladze et al. 2020b). Marginal involvement of NGOs in Romania has been observed in a previous study in the broader conservation context of the Natura 2000 governance network (Manolache et al. 2018), indicating that our findings may not be unique to PC biodiversity conservation network. Effective biodiversity conservation requires

Table 5.4. Stakeholder group relations. Values between brackets under 'Category (No. ties)' represent the number of existing relational ties in Romania within and between stakeholder groups.

Category (No. ties)	Density (%)	No. ties strong/ weak	Insufficient interactions (No. mentioning)	Collaboration relations (No. mentioning)	Communication relations (No. mentioning)
Gov-Gov (6)	30	2/4	N/A	Conservation planning (4) Commercial fishing (2)	Environmental data (2)
Acad-Acad (21)	29	14/7	Lack of funding (7)	Projects (14) Research (13)	Biodiversity data (12)
NGO-NGO (0)	0*	NA	NA	NA	NA
Gov-NGO (8)	14	6/2	Political constraint (2)	Sturgeon conservation (4) Projects (2) Commercial fishing (2)	Expert knowledge (2) Environmental data (1)
Acad-Gov (26)	14	15/11	Political constraint (4) Institutional turnover (3) Lack of funding (2)	Projects (9) Conservation planning (5) Commercial fishing (3)	Permit request (10) Biodiversity data (6) Environmental data (6) Expert knowledge (3)
Acad-NGO (2)	1.5*	0/2	Lack of funding (1)	Sturgeon conservation (1)	Expert knowledge (2) Environmental data (1)

An * indicates significant difference from random expectation ($p < 0.05$) according to the null-model test.

information exchange between diverse stakeholder categories (Newman and Dale 2007; Prell et al. 2009), which awards greater stakeholder ownership to conservation outcomes and ensures equal spreading of the costs and risks of conservation actions (Ostrom et al. 1999). Therefore, more interaction between NGOs and other stakeholders will likely benefit conservation of PC biodiversity.

5.4.6 Conservation implications of the Romanian vs. Ukrainian networks

According to network theory (Crona and Bodin 2006; Fazey et al. 2013; Leavitt 1951) the observed landscape of stakeholder interactions in Romania is structurally suboptimal – it is decentralized, has few and unreciprocated ties, and few structurally well positioned stakeholder organizations which lack incentives to utilize their favorable positions to initiate PC biodiversity related actions (Tables 5.2 and 5.3, Fig. 5.2). Decentralized networks are suitable for long-term environmental planning and complex problem solving, as a result of stakeholders across multiple disciplines contributing to the solution of a problem (Crona and Bodin 2006). A centralized network with one or few very central stakeholders, however, usually is more effective in the initial phase of the conservation process when resources need mobilization and the central coordination of joint actions is required (Crona and Bodin 2006; Olsson et al. 2004). While social and political setting in Romania and Ukraine to deal with biodiversity conservation issues are different, in terms of PC biodiversity conservation it can be argued that the two countries are in a similar, initial phase. In both countries PC biodiversity is recognized to be threatened and partly included in legal documents (e.g. see Akimov 2009; Cuttelod et al. 2011; Dumont et al. 1999), but is not yet included in conservation planning processes and implementation as it is absent from collaboration relations between relevant stakeholders in both countries (Table 5.4, Fig. 5.3, Table A5.3.1). If supplied with knowledge on PC biodiversity and the right incentives, in the initial phase of conservation a well-connected, centralized network in Ukraine is better placed to translate knowledge into effective conservation actions (Gogaladze et al. 2020b) through engaging the central, powerful stakeholders (Crona and Bodin 2006; Olsson et al. 2004). The Romanian network on the other hand in its current stage is less suited to facilitate improvements as it is decentralized with marginal involvement of governance actors and NGOs (Tables 5.2 and 5.4).

Besides the lack of knowledge on PC biodiversity and the incentives to initiate conservation actions, the stakeholder networks in both countries are challenged by the additional social variables, most notably the limited available funding for biodiversity conservation (Table A5.3.2). In Romania collaboration stopped when the funding period was finished and projects were concluded. In Ukraine, organizations continued to collaborate and exchange information beyond the duration of projects (Gogaladze et al. 2020b). Romanian stakeholders were involved in many more projects than Ukrainian stakeholders (Fig. 5.3, Table A5.3.1), and many of these projects were EU funded (Nita et al. 2016). Yet, the Romanian network was less dense than the Ukrainian one due to the difficulty of implementing EU projects, which prevented organizations awarded an EU project to participate in other projects (Nita et al. 2016), resulting in a low network density (Table 5.2, Fig. 5.2). Similarly, the authoritative state governance system was more consequential for PC biodiversity conservation in Romania (Table A5.3.2; theme 'political constraints') than in Ukraine (Gogaladze et al. 2020b), resulting in lack of collaboration between governance actors and other stakeholder categories in Romania (Tables 5.2 and 5.4). Contrary to our findings, it was suggested that the accession to the EU has played a major role in transposing the environmental governance and biodiversity conservation practices towards more collaborative, inclusive system in Romania (Stringer and Paavola 2013). However, challenges remain, which are suggested to be caused by lack of previous experience with the participatory conservation practices (Stringer and Paavola 2013). Consequently, improvements can be expected in Romania as the collaborative system of conservation matures. Importantly, while in Ukraine contradicting national laws and uncoordinated actions of regional administrations were common (Gogaladze et al. 2020b), they were not the case in Romania; indicating higher consistency in conservation policies in Romania, which in turn may be the result of the accession to the EU Acquis.

5.4.7 Coordinating joint Pontocaspian biodiversity conservation actions

Romania and Ukraine share the Danube Delta, the Black Sea coastline and associated habitats in which Pontocaspian biota occurs (Fig. 5.1), which may benefit from a coordinated action of both countries (Baboianu 2016). Some of the PC species, e.g. the sturgeon species, are mobile and not limited to the administrative and political boundaries (Strat et al. 2017). Furthermore, PC species have a patchy distribution in Ukraine and Romania and face similar pressures in both countries (Semenchenko et al. 2015; Velde et al. 2019; Zhulidov et al. 2018). Cross-border collaboration is therefore instrumental to achieve common conservation objectives and optimal conservation action (Baboianu 2016; Kittinger 1997). Sharing the management experiences and best practices among the organizations from both countries can help to the development of common organizational awareness and embolden joint efforts and understanding (Kittinger 1997; Munteanu et al. 2013)

The great significance of cross-border collaboration has been recognized by international conventions and the EU, which resulted in several collaborative projects (The World Bank study team 2014). In our interviews we did not specifically address cross-border collaboration between Romania and Ukraine with regard to PC biodiversity, but from the network narratives we learned that institutions in both countries are aware of each other and some collaboration exists. Established programs relevant to PC biodiversity conservation are the cross-border cooperation program (within the European Neighborhood Instrument - https://www.euneighbours.eu/en) and the EU LIFE program. The former includes the "Black Sea", "Danube", and other bilateral or trilateral (including Moldova) ecological programs with substantial budgets. Usually in their formulations the term "Pontocaspian" does not exist, but these projects mainly concern the habitats of PC fauna (Danube Delta and Prut River, Lower Dniester and the Black Sea coastline of Ukraine, Romania and Bulgaria). The EU LIFE program targets Danube sturgeons. For other PC taxa we did not find evidence for deep collaboration. The PRIDE project (http://www.pontocaspian.eu/) was a pioneering EU funded project, which, in collaboration with WWF Ukraine, attempted to integrate the entire PC community in the sturgeon related awareness raising activities for different coastal protected area administrations and local residents in Ukraine. Future projects that can extend the current organizational focus from flagship species to the entire PC biota in Ukraine and Romania are critically important. Such projects can be expected to raise awareness of the need of PC biodiversity conservation and increase the interest of governmental and nongovernmental organizations to collaborate more and exchange the relevant information.

5.5 Conclusions

We found structurally different networks of stakeholder organizations in Romania and Ukraine. However, PC biodiversity was not a driver of inter-organizational relations in either of the countries, resulting in incidental coverage of this biota in conservation practices. In an earlier study from Ukraine, we concluded that the maintenance of existing network is a necessary base, and can be expected to result in increased conservation action if the content of interactions is improved and funding and legal limitations are resolved. In Romania, such social variables are more consequential for the network functioning resulting in a hierarchical, non-inclusive system of conservation planning, continuous institutional reforms, and reduced collaboration. Improvements can be expected, however, as the adjustments to the EU institutional structures and the participatory conservation governance systems mature in Romania. Fostering cross-border collaboration through new calls for project proposals from the state and the EU budgets, which involve wider Pontocaspian taxa, will likely increase the PC conservation awareness and interest of different types of stakeholders in both countries to engage more in the conservation actions related to PC biota. Extending the Sturgeon networks to the other, non-charismatic Pontocaspian species may be a preferable course to initiate such action.

Acknowledgments

We would like to thank Professor Marius Stoica and Lea Rausch from the University of Bucharest, and Dr. Luis Ovidiu Popa, Alberto Martinez Gandara, Oana Paula Popa and Ana-Maria Krapal from the Grigore Antipa National Museum of Natural History for their invaluable assistance and support in Romania and helping to arrange meetings with stakeholders. We also thank all the interviewed stakeholders for finding time to meet and for providing honest and thorough answers to the survey questions. We acknowledge Cristina Sandu from the International Association for Danube Research for helpful comments on earlier drafts of this paper. We would like to also acknowledge our colleagues from Naturalis Biodiversity Center: Nieke Knoben, for the assistance in developing the questionnaire and Caroline van Impelen for organizational support. Finally, we thank our reviewers who gave us invaluable comments that improved our work considerably.

Author contributions

Conceptualization: AG, NR, KB, FPW. Data collection: AG. Formal analysis: AG, NR. Methodology: AG, NR, KB, FPW. Validation: NR, KB, CI, BP, MOS, NG, VA, FPW. Writing – Original Draft: AG, NR, KB, FPW. Writing – Review & Editing: CI, BP, MOS, NG, VA.

Appendices

Appendix 5.1. Raw data used for performing the network analyses.
Appendix 5.2. Social network analysis methods.
Appendix 5.3. Results on identified themes

Appendix 5.1. Raw data used for performing the network analyses.

Table A.5.1.1. Raw data used for performing the network analyses: Reported strength of relationships between the stakeholders, ranging from no contact (value 0) to very strong contact (value 4). Values 1, 2 and 3 represent 'very weak contact', 'weak contact' and 'strong contact' respectively (see the full definition of strength categories in chapter 4). Value 9 represents the links that have been reported by one stakeholder but not confirmed by the other stakeholder. These links were not considered in SNA and only used to calculate the confirmation rate.

CMSN	GAM	GEcM	IBB	OUC	DDNI	NIMR	UB	AZS	LAC	ANPA	MOE	MWF	MN	OC	WWF	DDA	
CMSN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GAM	0	0	0	3	3	3	0	3	0	1	0	2	0	0	0	0	9
GEcM	0	0	0	0	4	9	2	0	1	3	0	3	0	0	0	0	3
IBB	0	3	0	0	0	2	0	9	0	0	0	9	0	0	0	2	2
OUC	3	3	1	0	0	3	0	0	0	2	0	0	0	0	0	0	3
DDNI	0	2	0	2	4	0	4	9	0	0	3	2	2	0	0	2	4
NIMR	0	0	3	0	0	3	0	0	0	3	4	4	4	0	0	0	2
UB	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
AZS	0	0	1	0	0	0	9	9	0	3	0	9	9	0	0	0	9
LAC	0	0	0	0	0	0	2	0	3	0	0	0	0	0	0	0	3
ANPA	0	0	2	0	0	0	4	0	0	0	0	0	0	3	2	3	2
MOE	0	2	0	0	0	0	2	0	0	0	0	0	2	0	0	0	0
MWF	0	0	0	0	0	0	4	0	0	0	0	2	0	0	0	0	0
MN	0	0	0	0	0	0	0	0	0	3	0	9	0	0	0	0	0
OC	0	0	0	0	0	0	0	0	0	2	0	9	0	0	0	0	0
WWF	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	3
DDA	0	0	0	0	0	0	0	0	0	3	2	0	0	0	0	3	0

Table A.5.1.2. Raw data used for performing the network analyses: Tie content. Values represent the following themes: 1 – 'Biodiversity data'; 2 – 'Environmental projects'; 3 – 'Research'; 4 – 'Permit request'; 5 – 'Environmental data'; 6 – 'Commercial fishing'; 7 – 'Expert knowledge'; 8 – 'Sturgeon conservation'; and 9 – 'Conservation planning' (see theme descriptions in Table A5.3.1). NC stands for 'not confirmed'. Such themes of unconfirmed links were omitted from the analysis.

	CMSN	GAM	GEcM	IBB	OUC	DDNI	NIMR	UB	AZS	LAC	ANPA	MOE	MWF	MN	OC	WWF	DDA
CMSN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GAM	0	0	0	1;2	2;3	1;2;3	0	2;3	0	2;4	0	1;2;7	0	0	0	0	4(NC)
GEcM	0	0	0	0	1;3	1(NC)	2;3	0	1;3	1;5	0	1	0	0	0	0	4;5;7
IBB	0	1	0	0	0	1;2;3	0	1;2;3(NC)	0	0	0	1(NC)	0	0	0	7;8	4
OUC	1	1;2	3	0	0	1;2	0	0	0	4	0	0	0	0	0	0	4
DDNI	0	2;3	0	1;2;3	1;3;2	0	2;3	1;2(NC)	0	0	4	1	1	0	0	5;7	1;2;4;5;7
NIMR	0	0	2	0	0	2	0	0	0	5;9	6	2;9	2	0	0	0	2;5;4
UB	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
AZS	0	0	3	0	0	0	2;3(NC)	2;3(NC)	0	4;9	0	7;9(NC)	7;9(NC)	0	0	0	4(NC)
LAC	0	0	0	0	0	0	5	0	9	0	0	0	0	0	0	0	5;9
ANPA	0	0	6	0	0	0	6	0	0	0	0	0	0	6	6	8	6
MOE	0	2	0	0	0	0	2;9	0	0	0	0	0	9	0	0	0	0
MWF	0	0	0	0	0	0	2	0	0	0	0	9	0	0	0	0	0
MN	0	0	0	0	0	0	0	0	0	7	0	5;9(NC)	0	0	0	0	0
OC	0	0	0	0	0	0	0	0	0	5	0	4;7(NC)	0	0	0	0	0
WWF	0	0	0	0	0	0	0	0	0	0	8;7	0	0	0	0	0	2;8
DDA	0	0	0	0	0	0	0	0	0	5;9	6	0	0	0	0	2;8	0

Table A.5.1.3. Raw data used for performing the network analyses: Perceived sufficiency of reported interactions by the interviewed stakeholders. Values represent the following themes: 1 – 'Sufficient'; 2 – 'Unknown/not indicated by the stakeholder'; 3 – 'Lack of funding'; 4 – 'Political constraints'; and 5 – 'Institutional turnover' (see insufficient theme descriptions in Table A5.3.2). NC stands for 'not confirmed'. Such themes of unconfirmed links were omitted from the analysis.

	CMSN	GAM	GEcM	IBB	OUC	DDNI	NIMR	UB	AZS	LAC	ANPA	MOE	MWF	MN	OC	WWF	DDA
CMSN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GAM	0	0	0	1	1	1	0	1	0	1	0	1	0	0	0	0	1(NC)
GEcM	0	0	0	0	1	3(NC)	3	0	3	4	0	4	0	0	0	0	1
IBB	0	2	0	0	0	2	0	1(NC)	0	0	0	4;5(NC)	0	0	0	1	2
OUC	3	1	1	0	0	1	0	0	0	5	0	0	0	0	0	0	4
DDNI	0	3	0	1	1	0	3	3(NC)	0	0	1	1	1	0	0	3	3
NIMR	0	0	3	0	0	1	0	0	0	1	3	5	5	0	0	0	1
UB	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
AZS	0	0	3	0	0	0	3(NC)	0	0	4	0	4;5(NC)	5(NC)	0	0	0	3(NC)
LAC	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	0	2
ANPA	0	0	2	0	0	0	2	0	0	0	0	0	0	2	2	2	2
MOE	0	2	0	0	0	0	2	0	0	0	0	0	2	0	0	0	0
MWF	0	0	0	0	0	0	2	0	0	0	0	2	0	0	0	0	0
MN	0	0	0	0	0	0	0	0	0	4	0	4(NC)	0	0	0	0	0
OC	0	0	0	0	0	0	0	0	0	2	0	5(NC)	0	0	0	0	0
WWF	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	4
DDA	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	1	0

Appendix 5.2. Social network analysis methods.

Two institutions could not be interviewed resulting in missing network data. We imputed the missing data using the imputation-by-reconstruction method (Stork and Richards 1992). The preconditions for employing this method are: 1) respondents shall be similar to non-respondents, and 2) the obtained description of the relational link (from the respondent) shall be reliable. A Chi-squared test revealed no significant differences in the distribution of weights of received relationships between the respondents and non-respondents (p-value = 0.98), meaning that respondents are similar to non-respondents. Furthermore, the confirmation rate (proportion of relational links described similarly by both nodes involved) was 84 % indicating that the descriptions of relational links (provided by the respondents) can be considered as reliable. Therefore, we used the reconstruction method to impute the missing ties in the network.

We calculated the basic network characteristics such as number of actors and relational ties, graph density and centralization using CRAN R package 'igraph' (Csardi and Nepusz 2006). The mean shortest distance was calculated using the CRAN R package 'tnet' (Opsahl 2009) because the 'igraph' package does not take edge weights into account when measuring the shortest distance. Graph density is the extent to which nodes are connected to each other in the network. It is calculated by dividing the number of existing ties by all the possible ties in a network (Scott 1991; Wasserman and Faust 1994). Network centralization is the extent to which certain actors are more connected in the network than the others (Freeman et al. 1979; Wasserman and Faust 1994). A centralized network is one where only one or few actors are having the majority of the ties. Such a network has a high overall centralization score (on a 0 to 1 scale, 0 being completely decentralized and 1 fully centralized). Shortest distance is a minimum number of steps that the nodes are away from each other in a network; in weighted networks the tie weights are taken under consideration (Opsahl et al. 2010). We used frequency of contact as a measure of strength of the relationship and defined strong relationships as the weights higher or equal to 3 on a scale ranging from no contact to very frequent contact (S1 Text).

We measured the centrality of individual nodes using degree centrality and betweenness centrality values. Degree centrality is the number of connections a particular actor has with all the other actors in a network (Freeman 1978). We calculated the degree of a node through an in-degree and out-degree values. In-degree of a node is the number of in-coming links to it from the other nodes in a network and the out-degree of a node is the number of out-going links from this node to the other nodes in a network (Kleinberg 1998). Furthermore, we measured and used the node strength values (extension of the degree centrality to the sum of tie weights when analyzing weighted networks) to determine the size of the nodes in a sociogram (Barrat et al. 2004; Newman and Girvan 2004; Opsahl et al. 2008). Betweenness centrality measures the extent to which a node is among other nodes in a network (Freeman 1978). For weighted networks the betweenness centrality measure is based on algorithm of shortest path distance (Brandes 2001; Dijkstra 1959) which was lately further developed to integrate the cost of intermediary nodes in the formulae (Opsahl et al. 2010). We calculated node-level statistics using the CRAN R package 'tnet' (Opsahl 2009) which considers tie weights and corrects for the number of intermediary nodes. We regarded the central stakeholders as the ones with centrality scores higher than the third quartile threshold values (Grilli et al. 2015; Paletto et al. 2015; Yamaki 2017).

We measured brokerage combining quantitative and qualitative approaches. Brokers are the nodes which are between other nodes in a network and have the power to control the flow of information (Burt 1992, 2002, 2004). Quantitatively, brokerage was measured through the betweenness centrality and the Burt's constraint metric (Burt 2002, 2004). Betweenness centrality locates the brokers structurally, with respect to all the other actors in the network. Burt's constraint, however, is a local measure of brokerage based on the triadic closure principle. A node connecting two disconnected nodes in an incomplete triad has a power to broker. Such nodes have low Burt's constraint score, i.e. their behavior is not constrained by the other disconnected nodes in a triad (Burt 1992; Francis and Goodman 2010). Qualitatively, we examined the network narratives and searched for the evidence that the stakeholders are actually engaging in brokering behavior. Brokering behavior in the context of biodiversity conservation implies the mobilization of information, deliberation between different types of stakeholders and potentially the mediation through working groups to address conservation issues (Fazey et al. 2013). In our study, we regarded the stakeholders with high betweenness scores, which also accounted for low Burt's constraint values, and were involved in brokering behavior as brokers. We used only the strong ties (≥ 3) to calculate betweenness centrality and Burt's constraint metric as they reflect regular contacts. We calculated Burt's constraint utilizing CRAN R package 'igraph' (Csardi and Nepusz 2006).

Finally, we used a null-model test to identify the presence of 'network homophily' in the network. 'Network homophily' is the selective linking between actors based on specific attributes, in our case the category of stakeholder institutes (Newman 2003). With a null-model test, we tested whether densities within and between stakeholder groups (defined by the stakeholder category) were significantly higher or lower than the random expectation. We randomly assigned nodes to the stakeholders proportional to the true network and subsequently assessed the stakeholder's within and between group densities replicated 1000 times, resulting in 1000 stakeholder group density values. We ranked the obtained 1000 random values from low to high and compared the actual within and between group densities to the randomized results. If the actual density values were larger than the upper or smaller than the lower 2.5% threshold value of the random distribution, we regarded the true within or between group densities to be significantly higher or lower than expected by random chance.

Appendix 5.3. Results on identified themes

Table A5.3.1. Identified themes of stakeholder interactions and their descriptions. 'Frequency' reports the number of mentioning of identified themes by the interviewees. Numbers between brackets reflect how many times the theme was associated to strong vs. weak relational links.

Category	Theme name	Theme description	Frequency (strong/weak)
Collaboration relations	Environmental projects	Stakeholders are partners in joint environmental projects, which involve PC habitats, and exchange information according to the project needs. Projects mentioned by the stakeholders were e.g. EU LIFE projects on implementing EU Habitats Directive through generating knowledge for Article 17 reporting; projects on establishing limits on organic pollutants.	25 (16/9)
	Research	Stakeholders conduct joint fieldworks and publish scientific papers on biodiversity of the Black Sea coastal lagoons, lakes and rivers, which sometimes involve Pontocaspian species and habitats.	13 (6/7)
	Conservation planning	Stakeholders co-manage protected areas and Natura 2000 sites, plan conservation activities within Natura 2000 network of protected areas, provide scientific support for nominating and establishing new protected areas; and jointly develop and implement nature restoration projects.	9 (6/3)
	Commercial fishing	Stakeholders are involved in joint management and planning of commercial fishing activities, which sometimes concerns Pontocaspian species and habitats, e.g. Pontic shad in Danube Delta. This collaborative theme involves exchange of information on amount of fish catch per year, the vessels, the quotes and the species that are being caught; also, the strategies and policy related to fishing and the control of fishing activities.	7 (3/4)
	Sturgeon conservation	Stakeholder organizations are partners in sturgeon conservation related projects, for example, the "LIFE for Danube Sturgeons" (https://danube-sturgeons.org/the-project/).	**5 (4/1)**
Communication relations	Biodiversity data	Stakeholders exchange information related to Pontocaspian habitats and/or species outside the projects. This theme involves requesting the data, mostly by the governmental organizations for reporting to the EU, with or without payment for data.	18 (12/6)
	Environmental data	Stakeholders exchange information on the state of environmental conditions. For example, information on water quality parameters, silt deposition and evolution of the Black Sea shoreline, hydrological data, informing on facts of transgression from the field, environmental impact assessment results for exploitation of biological resources.	10 (6/4)
	Permit request	Academic stakeholders apply for permits of research to the governmental organizations and report on generated study results as obliged by the law. Research occasionally includes Pontocaspian species and habitats.	10 (6/4)
	Expert knowledge	Stakeholders share expert knowledge, advice, recommendations, consultations and experiences on different biodiversity initiatives, ecosystem restoration projects, decisions and investments. Shared knowledge occasionally pertains to Pontocaspian species and habitats.	7 (4/3)

Table A5.3.2. Identified themes of insufficient interaction and their description. 'Frequency' reports total number of times a theme was mentioned. Values between brackets represent number of times theme characterized strong vs. weak relational links.

Name	Description	Frequency (strong/weak)
Lack of funding	Desired levels of collaboration cannot be achieved due to shortage of finances which translates into either of the two scenarios: 1) Organizations are open for collaboration but have no common projects in which to collaborate; or 2) Scientific organizations that hold most biodiversity information (e.g. DDNI and GAM) do not share information for free so the organizations which are in need of information but cannot afford it reported interaction as insufficient. Scientific organizations in Romania are insufficiently funded by the government and data quality, availability and persistence are dependent on their success to find additional funding.	10 (5/5)
Political constraints	Governmental organizations are not open for consultations and collective, joint conservation planning because they are strongly influenced by the politics. Academic and non-governmental organizations express interest in more collaboration and exchange of information with the governmental authorities, while the government does not respond due to different interests or priorities.	6 (6/0)
Institutional turnover	Desired levels of interaction cannot be achieved due to continuous institutional reforms, which result in confusion among the organizations and continuous need for new agreements and dialog on the new format of collaboration frameworks. For example, from the interviews we learned that the Ministry of Environment (MOE) and Ministry of Waters used to be one organization, but were split up shortly before the interview; the Danube Delta Biosphere Reserve Authority (DDA) was transferred from the MOE to central government one week before the interview, but currently operates again under the commission of the MOE; and the Marine Biological Station of Agigea (AZS) became a separate organization 1 year before the interview, previously being a research station of the University of Iasi.	3 (2/1)

Table A5.3.3. Number of mentioning of interaction themes by individual stakeholders. Values between brackets represent No. times the theme characterized the incoming and the outgoing ties respectively.

			Collaboration relations					Communication relations			
Abbr.	**Legal status**	**Degree**	**Environmental projects**	**Research**	**Conservation planning**	**Commercial fishing**	**Sturgeon conservation**	**Biodiversity data**	**Environmental data**	**Permit request**	**Expert knowledge**
DDNI	Acad	13 (4,9)	9 (4,5)	6 (2,4)	0	0	0	8 (3,5)	2 (0,2)	2 (0,2)	2 (0,2)
NIMR	Acad	13 (6,7)	9 (4,5)	2 (2,0)	3 (1,2)	2 (1,1)	0	0	3 (1,2)	1 (0,1)	0
DDA	Gov	12 (9,3)	4 (3,1)	0	2 (1,1)	2 (1,1)	2 (1,1)	1 (1,0)	5 (4,1)	6 (6,0)	2 (2,0)
GAM	Acad	11 (5,6)	9 (3,6)	4 (1,3)	0	0	0	6 (3,3)	0	1 (0,1)	1 (0,1)
LAC †	Gov	11 (8,3)	1 (1,0)	0	5 (3,2)	0	0	1 (1,0)	6 (4,2)	3 (3,0)	1 (1,0)
GEcM	Acad	10 (4,6)	2 (1,1)	5 (2,3)	0	1 (1,0)	0	4 (0,4)	2 (0,2)	1 (0,1)	1 (0,1)
ANPA †	Gov	10 (4,6)	0	0	0	7 (2,5)	2 (1,1)	0	0	1 (1,0)	1 (1,0)
OUC	Acad	9 (3,6)	4 (2,2)	4 (3,1)	0	0	0	4 (2,2)	0	2 (0,2)	0
MOE	Gov	8 (5,3)	4 (2,2)	0	4 (2,2)	0	0	3 (3,0)	0	0	1 (1,0)
IBB	Acad	6 (2,4)	3 (2,1)	2 (1,1)	0	0	1 (0,1)	4 (2,2)	0	1 (0,1)	1 (0,1)
WWF	Ngo	6 (4,2)	2 (1,1)	0	0	0	5 (3,2)	0	1 (1,0)	0	3 (2,1)
MWF	Gov	5 (3,2)	2 (1,1)	0	2 (1,1)	0	0	1 (1,0)	0	0	0
AZS	Acad	4 (2,2)	0	2 (1,1)	2 (1,1)	0	0	1 (1,0)	0	1 (0,1)	0
UB	Acad	3 (1,2)	1 (1,0)	1 (1,0)	0	0	0	1 (0,1)	0	1 (0,1)	0
MN	Ngo	2 (1,1)	0	0	0	1 (1,0)	0	0	0	0	1 (0,1)
OC	Ngo	2 (1,1)	0	0	0	1 (1,0)	0	0	1 (0,1)	0	0
CMSN	Acad	1 (1,0)	0	0	0	0	0	1 (1, 0)	0	0	0

† Institutions that could not be interviewed for which relationships were imputed

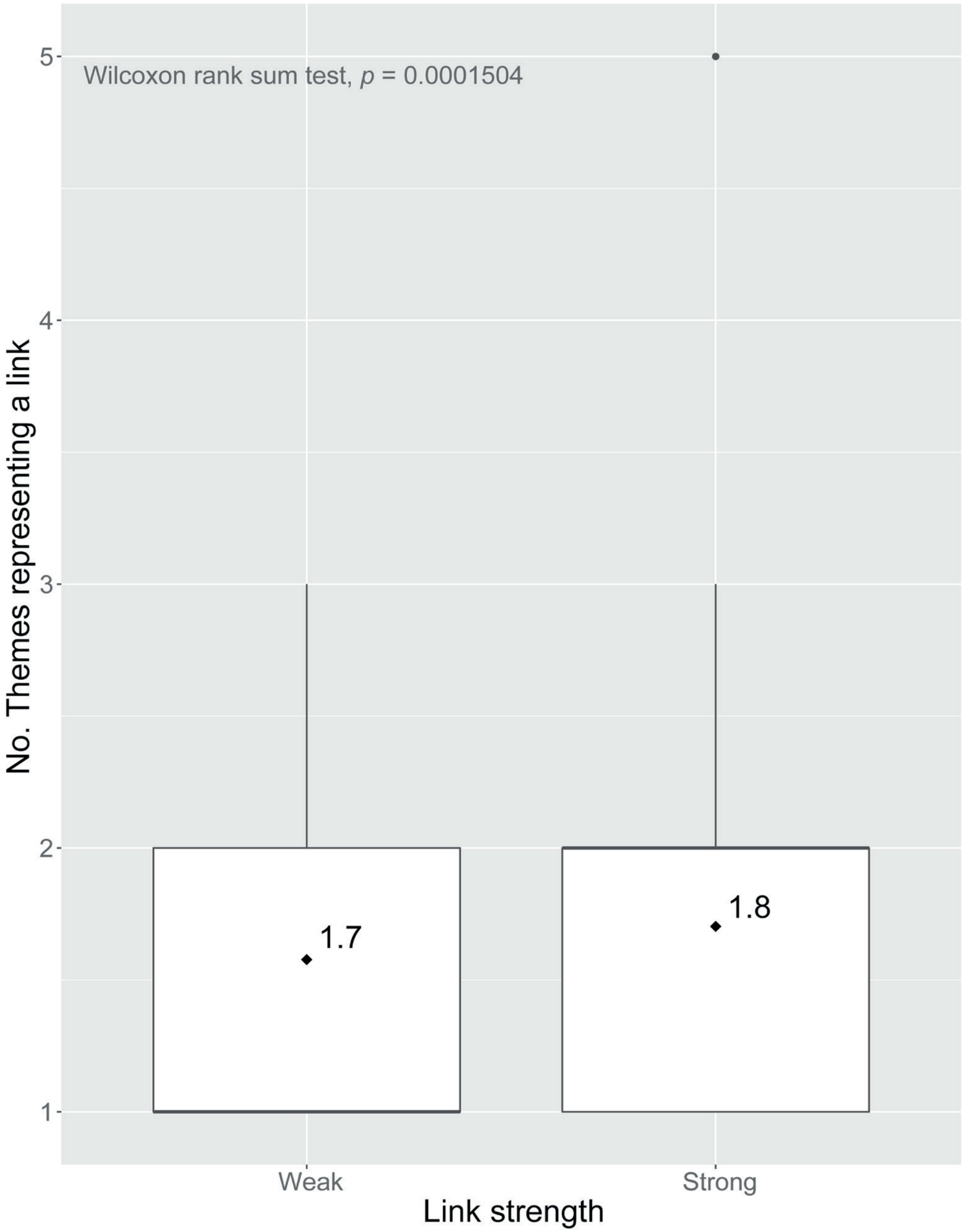


Figure A5.3.1. Boxplot on number of themes representing a link and the strength of the link. Horizontal lines in the boxes represent the median values. Diamonds represent the mean number of the themes.

6

Synthesis: Towards effective conservation of threatened Pontocaspian biota in the Black Sea region

6.1 Introduction

The unique Pontocaspian (PC) biota of the Black Sea – Caspian Sea region, like many other biotas worldwide are in severe decline due to human development and interventions (CBD 2020). Current approaches to biodiversity conservation, especially when it comes to invertebrates, feature significant shortcomings and are not effective (Brechin et al. 2002; CBD 2020). Often, the lack of knowledge on species identities, distribution trends and ecology as well as the socio-political systems within which conservation is embedded provide major limitations to establish effective conservation regimes.

This thesis aims to contribute to the establishment of an effective PC biodiversity conservation regime in the Black Sea Basin (BSB) by answering scientific questions to set the research and policy agenda required for improving PC biodiversity data collection, promoting PC biodiversity awareness and establishing a meaningful conservation regime. Specifically, the thesis aims to answer the following research questions: 1) What are the current status and trends in PC invertebrate species and populations in the BSB? 2) What are the direct anthropogenic drivers of PC biodiversity change (either positive or negative)? 3) Are there areas in the BSB that can support viable PC populations today, that could be considered as priority areas in conservation planning? 4) What is the current legal and political framework to support PC biodiversity conservation in the Danube Delta - a prime PC biodiversity hotspot shared by Romania and Ukraine? 5) Who are the practitioners and stakeholders of PC biodiversity conservation in Romania and Ukraine? 6) How are the stakeholder networks arranged in Romania and Ukraine? 7) Are stakeholder institutional alignments optimal for PC biodiversity conservation in these neighboring countries? 8) What social variables, external to the stakeholder network properties help or hamper PC biodiversity conservation in Romania and Ukraine? The aim of this chapter is to reflect on the results of the previous chapters of this thesis and how they together may promote conservation actions aimed at PC biodiversity in Romania, Ukraine and surrounding areas of the BSB.

6.2 Scientific knowledge on the PC biota and habitats is inadequate

Scientific knowledge is the basis of effective conservation planning and management (Cash et al. 2003; Francis and Goodman 2010; Pullin and Knight 2001; Pullin et al. 2004) and newly assembled data show that this is inadequate. In chapter 2, ten regions in the BSB are identified, documented and mapped that contain 20th and/or 21st century occurrences of endemic PC mollusk species. They fall within Bulgarian (BU), Romanian (RO), Moldavian (MD), Ukrainian (UA), and Russian (RU) territories. The 10 regions are: 1) Bulgarian coastal lagoons and limans, 2) Lower Danube River (Fig. 2.6), 3) Danube Delta – Razim Lake System (Fig. 2.6), 4) Dniester Liman (Fig. 2.7), 5) Tiligul Liman (Fig. 2.8), 6) Berezan Liman (Fig. 2.8), 7) Dnieper-South Bug Estuary (Fig. 2.8), 8) Taganrog Bay – Don Delta (Fig. 2.9), 9) SE Azov Sea coast and 10) Tsimlyansk Reservoir (Fig. 2.9). A very strong decline of PC species and communities during the past century is evident in all the regions except for Taganrog Bay-Don Delta (8) and Tsimlyansk Reservoir (10). The observed decline is driven by 1) damming of rivers, 2) habitat modifications negatively affecting salinity gradients, 3) pollution and eutrophication, 4) invasive alien species and 5) climate change (chapter 2). Four out of these 10 regions contain the entire spectrum of optimal ecological conditions to support PC communities and still host threatened endemic PC species. These four regions are the Danube Delta – Razim Lake system (3), Dniester Liman (4), Dnieper-South Bug Estuary (7) and the Taganrog Bay-Don Delta (8), which we refer to as the 'optimum PC habitats'. More specifically, we define optimum PC habitats as waterbodies (lakes, estuaries, bays, river stretches) where at least one endemic PC species of two different families co-occur. This operational definition is based on mollusk species and will need expansion with representatives of other PC groups such as crustaceans and fish. Results of this study improve our understanding of PC biodiversity trends and will inform and greatly benefit future research. Furthermore, identification of optimum PC habitats is directly applicable for conservation planning as it will enable targeted PC biodiversity conservation actions.

One of the main limitations in assessing the status of PC invertebrate species is that for most of the PC groups (e.g., copepods, amphipods, decapods, gobies, etc.) no up-to-date taxonomic overview exists (but see Sands et al. 2020 for mollusk species; Wesselingh et al. 2019). Each taxonomic group within the PC invertebrate community, including the mollusks, contains disputed species (chapter 2). Pontocaspian invertebrate species groups often have few diagnostic characters, large morphological variability and wide autecological tolerances. Together with a fragmented institutional landscape, a taxonomic tradition of splitting single species into multiple species based on small differences and problems derived from applying various species concepts to geographically and ecologically separated biota has resulted in extensive synonymy (Wesselingh et al. 2019). Molecular techniques to establish the PC species boundaries has been applied only to few mollusk groups, e.g., Dreissenidae (Therriault et al. 2004), Monodacna colorata (Popa et al. 2011), Neritidae (Sands et al. 2020). In addition, the collection of living PC specimens is severely hampered by the demise of PC species. These factors together have led to a situation where knowledge on species distributions and abundances, population trends, life history traits, functional roles and sensitivity to changes in the environment is lacking for almost all PC invertebrate species. Moreover, historical distribution data are often imprecise and also hampered by uncertainties in species identifications.

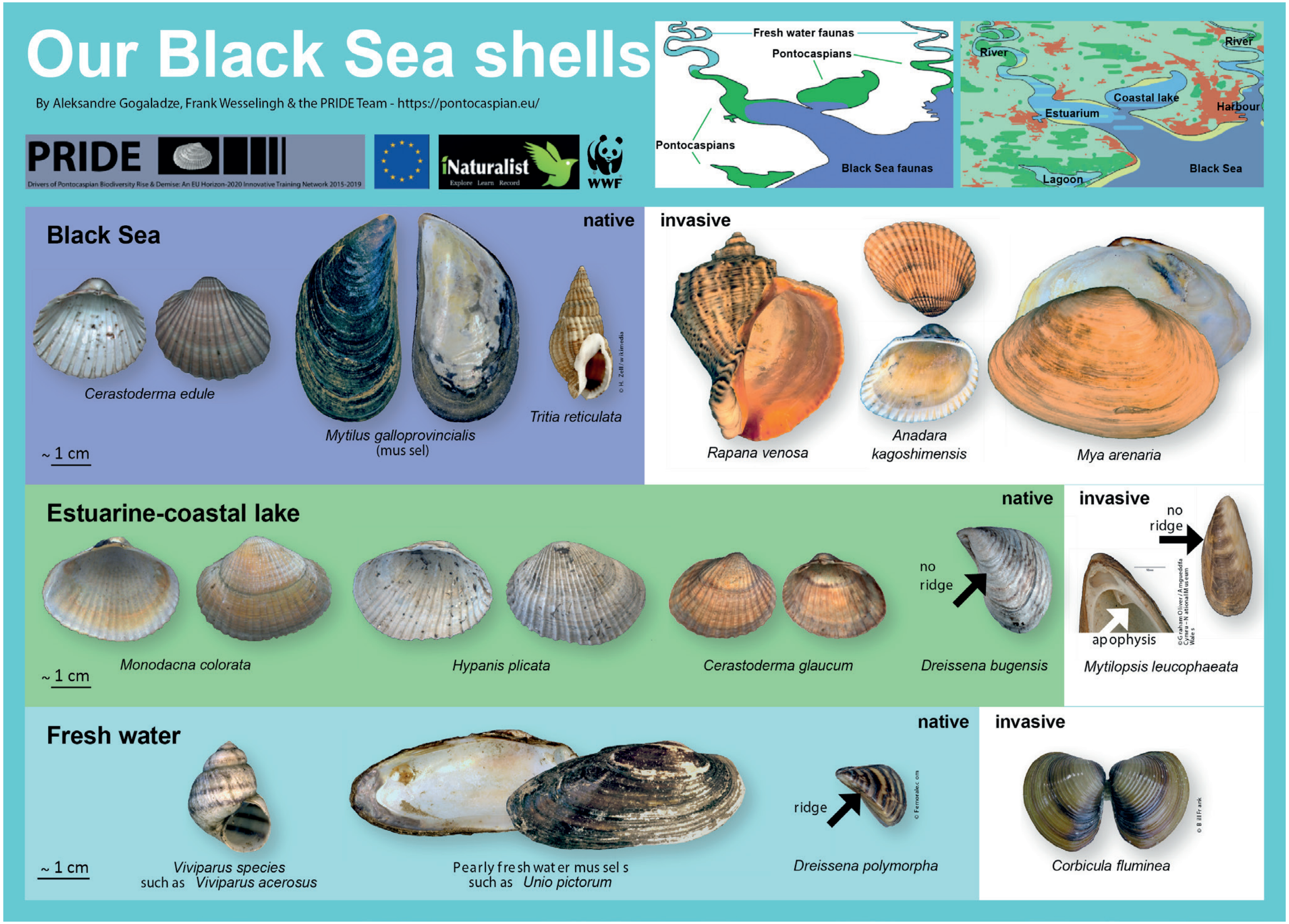
6.3 PC biodiversity can only be addressed by transnational cooperation

Identified PC habitats in the BSB cross national boundaries, and PC species and populations are currently managed by different legal arrangements, institutional designs and governance systems. In chapter 3 of this thesis the legal landscape that regulates the PC biodiversity conservation in the Danube Delta, a prime PC biodiversity hotspot shared by Romania and Ukraine, is defined and identified. Using a mix of quantitative and qualitative research methods we show that current legal arrangements do not provide sufficient protection to the PC invertebrate species. Specifically, we demonstrate that PC invertebrate species are underrepresented in global, EU and national Romanian and Ukrainian legal documents. PC habitats, which are characterized by specific salinity regimes, are not well classified and also underrepresented in international and national legal documents. Due to the great significance of Danube Delta as Europe's largest water purification system and an important wildlife area, most of the PC habitats are covered by the existing network of protected areas. However, for most of the protected areas the management plans are not in place. When in place, they do not address the PC biodiversity, providing incidental and therefore sub-optimal protection to the PC biota.

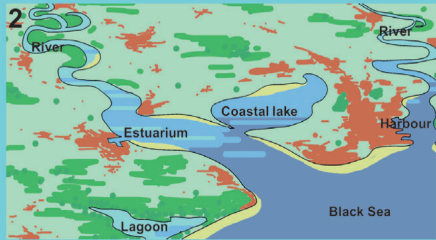
Legal coherence, that is the complementarity of action (mutual reinforcement), is important for effective and efficient transboundary conservation actions (Gomar et al. 2014). However, PC biodiversity related Romanian and Ukrainian national legislations are neither vertically coherent (i.e., coherent with global treaties and the EU Directives), nor horizontally coherent (i.e., coherent with each other). This hampers cross-border collaboration and effective PC biodiversity conservation action. For example, laws to regulate the management of Emerald sites in Ukraine are not yet into force, resulting in absence of management plans, while the analogous Natura 2000 sites have management plans in place (European Commission 2019). Furthermore, Laws and regulations that list the PC species and/or habitats need to be updated and amended according to the best available scientific knowledge to ensure consistency in the listed habitats and the species names. Finally, we concluded that sturgeons as surrogate species do not provide sufficient protection to the PC invertebrate communities because sturgeon habitats do not encompass the entire PC range. Even where sturgeons co-occur with invertebrate PC communities, the extent to which sturgeon conservation measures benefit the background invertebrate communities is unclear and requires further study.

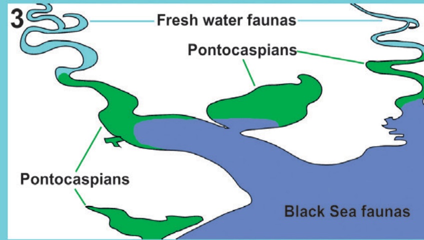
Our Social Network Analyses (SNA) of the stakeholder interactions (chapters 4 and 5) did not specifically address cross-border collaboration frameworks between Romania and Ukraine on topics related to PC biodiversity conservation. However, narratives showed that institutions in both countries are aware of each other and that some collaboration exists. The great significance of cross-border collaboration in the Danube Delta has been recognized by international conventions and the

Figure 6.1. Front and back pages of the PC mollusk species identification leaflet (English version). Romanian, Ukrainian and Russian versions are available online (https://pontocaspian.eu/).



Discover the unique mollusk fauna of the Black Sea





1 Our unique Black Sea shells

The Black Sea has a unique biodiversity including the endemic "Pontocaspian" mollusks. These Pontocaspian species evolved in low salinities of the Caspian and Black Seas over the past few million years. They occur nowhere else in the world! However, pollution, habitat destruction, climate change and invasive species are threatening these unique species. In order to improve conservation efforts we need more information on the distribution of the Pontocaspian species and the invasive species that threaten them. This is where we need your help.

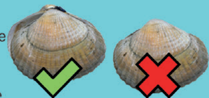
4 You can help!

Are you going out to a local beach, harbor, estuary, lake or river? Take this leaflet with you! You can help us identify the presence of three Pontocaspian target species (*Monodacna colorata, Hypanis plicata, Dreissena bugensis*) and an invasive species (*Mytilopsis leucophaeata*) that is potentially harming our unique Pontocaspians. Your observations help us to detect where healthy populations are living and where invasive species are a threat. By reporting sighting and photos of these species we can protect our unique biodiversity of the Black Sea region!

2 What shells are we looking for?

Pontocaspian species are rare, they live in lakes, rivers and estuaries in the coastal zone where the salinities are low. In this leaflet you will find ways to distinguish the Pontocaspian species from freshwater and marine species and from invasive species that threaten them. These destructive invasive species have come from as far as the Caribbean!

5 How to report



We need fresh material from the four species, so we are looking for specimens that still have the two valves attached. Please take a picture of the shells, record locality information (preferably GPS coordinates), date and species name (if known). Repeat the above for each species at a locality. At home, you can upload the pictures and information to the i-Naturalist portal (**www.inaturalist.org**) sending it directly to our scientists.

3 What do shells tell us?

Shells can tell us a lot about the environmental conditions such as salinity, water movement and turbidity. They can also be used as indicators of pollution. Shells can be old. We are particularly interested in fresh shells so that we know environmental conditions and change in recent years.

6 Uploading observations using the iNaturalist app or website

Download and install the **iNaturalist app** on your smartphone. Create an account and sign in. To upload observations to the PRIDE project you have to join the iNaturalist "PRIDE" project. Open menu → projects → search for "PRIDE" → Join. Now, observations can be added to the "PRIDE" project. Take a picture of the shell → Add species name if known, leave blank if unknown; date and location will be added automatically → go to Add to Project(s) → select PRIDE and tap the check sign "✓"; now project has been selected → tap the check sign "✓" once more to submit the picture to PRIDE.

For the iNaturalist website Go to <**www.iNaturalist.org**> and sign up. To add an observation go to <+Add observations> → upload your picture → fill in additional information under <Details>. Then go to the <Projects> tab → type and select "PRIDE". If you only have one observation select <Submit 1 observation>. If you have several observations go to <+Add> tab in the top left corner → select photo(s) → a new window opens and you repeat the above procedure. Finally, submit your observations by selecting <Submit an observation>. With your contribution we are able to update the species distribution maps and identify conservation priority areas. Updated maps that include your observations will be posted on **www.pontocaspian.eu**

PRIDE
Drivers of Pontocaspian Biodiversity Rise & Demise: An EU Horizon-2020 Innovative Training Network 2015-2019

iNaturalist Explore Learn Record

WWF

Please cite as: Gogaladze, A., Wesselingh, F.P. & the PRIDE team. Discover the unique mollusk fauna of the Black Sea. Visit us at www.pontocaspian.eu

EU, which resulted in several collaborative projects (The World Bank study team 2014). Established programs relevant to PC biodiversity conservation in the Danube Delta are the cross-border cooperation program (within the European Neighborhood Instrument - https://www.euneighbours.eu/en) and the EU LIFE program. The former includes the "Black Sea", "Danube", and other bilateral or trilateral (including Moldova) ecological programs with considerable budgets. Usually in their formulations the term "Pontocaspian" does not exist, but these projects mainly concern the habitats of PC fauna (Danube Delta and Prut River, Lower Dniester and the Black Sea coastline of Ukraine, Romania and Bulgaria). The EU– 'LIFE for Danube Sturgeons' project (https://danube-sturgeons.org/the-project/) targets only the sturgeon species and for other PC taxa we did not find evidence for transnational collaboration.

During the EU-funded PRIDE project (http://www.pontocaspian.eu/) we collaborated with WWF in Ukraine to include PC biota in existing sturgeon related awareness raising activities for different coastal protected area administrations and local residents in Ukraine. Representatives of four coastal protected areas were trained as trainers in Kherson in August 2017, aiming to transfer knowledge and raise awareness of the unique PC biodiversity to the visitors of the protected area visitor centers (https://wwf.panda.org/?309051/ponto-kaspian-trip). Furthermore, students from Odessa Ecological University and Kherson Agricultural University, which were selected and trained by WWF in Ukraine as ambassadors of sturgeon conservation, the so-called 'sturgeon-watchers', received further training from PRIDE program on recognizing wider PC invertebrate taxa (https://danube-sturgeons.org/sturgeon_watchers_in-ukraine/). Later, 'Sturgeon-watchers', together with the PC biodiversity expert from NASU Institute of Marine Biology and the entire team from the National Nature Park "Tuzlovsky Limany" helped with interviewing 270 citizens in different villages of Ukraine, using a pre-developed, standardized questionnaire to measure the PC biodiversity awareness of general public (unpublished data). This same team and the WWF in Ukraine helped with the distribution of approximately 300 leaflets (Fig. 6.1) that were designed by PRIDE for raising PC biodiversity awareness through interactive citizen science. Additionally, 20 leaflets were included in the Black Sea Boxes in Ukraine (UN project aimed at raising environmental awareness in school students about the pressing Black Sea environmental problems). All these activities were conducted in Summer 2017 and it is important that such initiatives become systematic. Therefore, future projects that can extend the current organizational focus from flagship species to the entire PC biota in Romania and Ukraine are critically important. Such projects can be expected to raise awareness of the need of PC biodiversity conservation and incentivize the governmental and nongovernmental organizations to increase collaboration.

6.4 Low awareness of the PC biota impedes effective conservation

Effective planning and implementation of conservation programs, including those addressing PC biodiversity, is often limited by inadequate consideration of the social context in which conservation is embedded (Jarvis 2015). Understanding and accounting for the social systems in the BSB is imperative to inform Pontocaspian biodiversity conservation planners and account for inherently complex and dynamic interactions between people and nature (see e.g. Crona et al. 2011). In chapters 4 and 5, we identify the relevant stakeholder organizations in Ukraine and Romania, which are involved in, or concerned about PC biodiversity conservation, and study their professional interactions. Identified stakeholder organizations represent academic, governmental and nongovernmental sectors, as well as the coastal protected area administrations.

PC biodiversity plays a minor and mostly an incidental role in the identified inter-organizational interactions in Ukraine and Romania, indicating low priority for PC biodiversity conservation. The few cases where PC biota is a direct target of interactions in Ukraine and Romania comprise sturgeon-related projects. Furthermore, even though we did not include a standard question on the definition of Pontocaspian species in the questionnaire, the network narratives showed that in both countries the interviewed stakeholders have different understanding on what Pontocaspian species and habitats comprise. This indicates low institutional awareness of PC biodiversity. Coupled with the low recognition of the need for PC biodiversity conservation on the policy level (chapter 3), this results in low interest of environmental organizations to collaborate on topics related to these taxa. Consequently, PC biodiversity is only marginally, or incidentally involved in organizational interactions, with the exception of sturgeons.

6.5 National institutional frameworks suffer from a range of social factors that hamper optimal functioning

The functioning of the stakeholders' social networks in Ukraine (Fig. 4.2) and Romania (Fig. 5.2) are hampered by social variables (Figs. 4.3 and 5.3), most notably the limited funding that is available (chapters 4 and 5). In Romania funding defines collaboration, i.e., collaboration and exchange of scientific information ceases as the funding stops. In Ukraine lack of funding does not have effect on exchange of information. Besides publicly funded projects, the EU LIFE Program is the major source for conservation funding in Romania (Hermoso et al. 2017). When EU funding is awarded to an organization in Romania, it becomes less interested in collaborating with other organizations in other projects. This is argued to result from the complexity to implement EU LIFE projects (Nita et al. 2016). Additionally, reduced exchange of information occurred in Romania due to institutional competition among stakeholders which encouraged organizations to keep data to themselves as a competitive advantage to attract future grants. In Ukraine, project-based collaboration on conservation of Pontocaspian biodiversity is limited, and the exchange of information occurs mostly due to organizational mandates or voluntary actions and supporting attitudes of organizations. However, to implement conservation policies additional funding is required.

Furthermore, institutional instability and hierarchical governance systems in Romania and the legal limitations in Ukraine obstruct optimal functioning of conservation networks to address PC biodiversity decline. Continuous institutional reform in the public sector in Romania was suggested to be a result of adjustments to the EU institutional structures, which may persist in the coming years to ensure access to national funds for scientific research (Vasile 2013). The hierarchical governance system that we find in the PC network in Romania is in line with the findings of earlier research conducted by Manolache et al. (2017, 2018) who identified non-inclusive governance systems with low involvement of NGOs and private stakeholders in Natura 2000 governance networks. Contrary to our findings, Stringer and Paavola (2013) suggested that the accession to the EU has played a major role in transposing the environmental governance and biodiversity conservation practices towards more collaborative, inclusive systems in Romania. There, stakeholder engagement in conservation planning is often understood by the governmental organizations as intersectoral cooperation and engagement. This results in seeking collaboration with other governmental organizations and international actors rather than in collaboration with local organizations and NGOs, resulting in hierarchical governance systems (Kluvankova-Oravska et al. 2009; Stringer and Paavola 2013; Wesselink et al. 2011). Consequently, improvements may be expected as the EU institution and collaborative system of conservation governance matures in Romania. In Ukraine, we show that legal limitations obstruct the functioning of conservation networks, while in Romania it is not the case. Legal limitations refer to "uncoordinated action of regional administrations, and to some of the national laws that are contradictory and create confusion among conservation organizations" (Gogaladze et al. 2020b). As part of the European integration of Ukraine, significant progress has already been made in drafting new environmental laws and amending the existing laws to improve the biodiversity conservation framework (Ministry of Ecology and Natural Resources of Ukraine 2018). Refinement of the legal framework is an ongoing process and improvements can be expected in Ukraine as well.

Different social environments in Ukraine and Romania shape structurally different stakeholder networks to deal with PC biodiversity conservation challenges. Low institutional awareness of PC biodiversity is common in both countries, as is the minor role of PC biota in organizational interactions. However, the Ukrainian network is well connected and the connections are reciprocated, which means that organizations are open to receiving but also sharing the information with other organizations. In Romania, however, the network is not well connected and relationships are not reciprocated, especially when it comes to the governmental organizations. Furthermore, the Romanian network is decentralized, and the few stakeholders that are structurally well-positioned in the network lack incentives to utilize their favorable positions to initiate PC biodiversity related actions. The Ukrainian network is more centralized and central stakeholders utilize their favorable positions to mobilize information and resources, deliberate between different types of stakeholders, and coordinate research and conservation action (Table A4.2.2).

According to network theory (Crona and Bodin 2006; Fazey et al. 2013; Leavitt 1951), different types of network structures suit different conservation contexts and phases, and the suitability of structures as well as the network properties change over time (Bodin and Prell 2011). While social and political settings and larger governance architectures in Romania and Ukraine to deal with biodiversity conservation issues are different, in terms of PC biodiversity conservation it can be argued that the two countries are in a similar, initial phase, in which PC biodiversity is recognized to be threatened and is partly included in different legal documents (see chapter 3, also see Akimov 2009; Cuttelod et al. 2011; Dumont et al. 1999), but is not yet part of conservation planning processes and implementation as it is absent from collaboration relations in both countries. If supplied with knowledge on PC biodiversity and the right incentives, in the initial phase of conservation a well-connected, centralized network in Ukraine, through engaging the central, powerful stakeholders (Crona and Bodin 2006; Olsson et al. 2004), is better placed to translate knowledge into effective conservation actions than the Romanian network. The latter network is decentralized with marginal involvement of governance actors and NGOs (chapter 5, Tables 2 and 4) which may hamper knowledge dissemination and translation into conservation actions.

6.6 How can we improve the PC biodiversity conservation, restoration and management?

Clearly, agreed taxonomy and improved knowledge on PC biodiversity (e.g., distribution of species and their ecological interactions) is the first necessary step towards effective conservation. Research on PC biodiversity has a long history in the BSB, but the novel transdisciplinary and cross-border research approaches to study different aspects of PC biota are in their infancy. A resolved taxonomic framework is essential to enable standardized inventories and establish conservation status of PC species through IUCN assessments. Teams of taxonomists need to be formed to solve species delimitations using all available approaches. Additionally, standardized quantitative analyses of PC species distribution is important to establish population trends for conservation practices such as those conducted by Son (2011a, 2011b, 2011c, 2011d, 2011e, 2011f); Son and Cioboiu (2011); Son et al. (2020) for PC mollusk species. Biodiversity surveys and monitoring should be standardized and ideally be repeated multinational efforts. Baseline data should be combined from quality controlled historical records and collections, but also from the use of borehole occurrences for taxa with a fossil record such as mollusks (see, e.g., Velde et al. 2019). Not only species diversity but also genetic diversity needs to be mapped and assessed. PC species often have patchy occurrences and the current decline may result in small, genetically depleted populations. Further degradation and fragmentation of suitable habitats will lead to genetically depauperate populations and increases the risk of extinction.

Once the taxonomy and ecological status of species has been assessed, the next step would be to promote common understanding and increased awareness on PC biodiversity among general public, conservation practitioners and policy makers. Research on stakeholder organization interactions in Ukraine and Romania showed that there is no common understanding on PC biodiversity among different stakeholders and that this biota has a very low priority in the conservation agenda. Consequently, conservation practitioners lack the incentives to participate in PC biodiversity conservation related actions. However, central, powerful stakeholders and broker organizations have been identified who have the potential to mobilize stakeholder networks and quickly spread new knowledge and incentivize other stakeholders to participate in PC biodiversity conservation. Such central stakeholders can effectively utilize their favorable positions and act as brokers only if current funding schemes and legal and political frameworks are improved.

Current conservation networks and collaboration frameworks in the BSB provide opportunities for integrated, large-scale PC biodiversity conservation approaches. Sustainable management of the BSB including the coastal riverine ecosystems has a high priority for the European Union and the neighboring Black Sea countries. The Black Sea Synergy program, which was formally launched in Kiev in February 2008 and updated in June 2019, is part of the European Neighbourhood Policy aiming to develop regional cooperation around the Black Sea and is open to all Black Sea countries. It is an expression of the EU's commitment to the Black Sea region, which, building on existing schemes and regional organizations like the Black Sea Economic Cooperation (BSEC) and The Commission on the Protection of the Black Sea Against Pollution (an inter-governmental body established for implementation of the Bucharest Convention), supports the establishment of cooperation and partnerships in environmental, transport and energy sectors. Furthermore in 2017 'The Blue Growth Initiative for Research and Innovation in the Black Sea' has been launched by the European Commission (EC). Within this initiative the 'Burgas Vision Paper' (European Commission 2018) was produced as the key framework document for a shared vision of a productive, healthy, resilient, sustainable and better-valued Black Sea by 2030. In this paper a team of experts from all Black Sea countries, with the support of the EC developed a Strategic Research and Innovation Agenda (SRIA) that addresses the Black Sea biodiversity in its agenda and highlights the urgent need of its conservation and monitoring.

Some of the ongoing projects in the BSB, which are relevant to PC biodiversity are:

1) EU/UNDP project: Improving Environmental Monitoring in the Black Sea (https://oceanconference.un.org/commitments/?id=15806). This project aims to a) improve availability and sharing of marine environmental data from the national and joint regional monitoring programs aligned with the MSFD and WFD principles and the Black Sea Integrated Monitoring and Assessment Programme (BSIMAP); b) Support joint actions to reduce river and marine litter in the Black Sea basin; and c) Raise awareness on the key environmental issues and increase public involvement in the protection of the Black Sea.
2) Black Sea Connect (http://connect2blacksea.org/about-the-csa/), which is a EU Horizon 2020 coordination and support action (CSA) that coordinates the development and implementation of SRIA, based on the defined principles in the Burgas Vision Paper (European Commission 2018), links relevant stakeholder institutions and donor organizations and supports policy development, innovation and joint actions to promote to the development of the Blue Growth in the Black Sea.

3) HydroEcoNex project: Creating a system of innovative transboundary monitoring of the transformation of the Black Sea river ecosystems under the impact of hydropower development and climate change" (http://eco-tiras.org/191-new-project-hydroeconex) under the "Joint Operational Programme Black Sea Basin 2014-2020" (Ukraine, Moldova and Romania). The Overall objective of the project is the development of a unified system of innovative environmental monitoring for the provision with data and information essential in the transboundary and sustainable long-term monitoring of observed transformations in Black Sea Basin's river ecosystems, caused by hydropower operation under climate change. Hydropower construction that changes flow and salinity regimes is one of the key threats to PC biodiversity.

For more examples of Black Sea projects see http://connect2blacksea.org/black-sea-projects/.

Many of these projects do not include PC biodiversity in their provisions and framing, but they cover the PC habitats (transitional zones from freshwater to marine environments such as the Danube Delta, Lower Dniester and the Dnieper-South Bug Estuary). Full integration of native aquatic PC biodiversity in the ongoing and future initiatives is necessary for wholistic and sustainable management of the BSB and associated riverine ecosystems and biota. The abovementioned projects involve large-scale cross-border and multi-stakeholder interactions and collaboration frameworks. This is a venue that can serve as a necessary base for planning and launching effective, integrated PC biodiversity conservation measures. A common understanding of PC biodiversity and an increased scientific, social and political awareness is a necessary precondition for making such an integrated, multi-stakeholder and cross-border conservation effort successful.

In the context of recent approaches and developments, PC biodiversity can be expected to gain high visibility that will increase effective conservation approaches. The PRIDE program has brought together a large group of international experts and scientists on PC biodiversity and laid a foundation for future collaborations and joint research. Additionally, the program investigated effective outreach policies and reached out to different stakeholder groups in the BSB and the Caspian Sea Basin as well as western Europe. Now that the 'ice has finally been broken' stakeholders and end users working with PC biodiversity are more aware of their mutual interests and are coming together. In the context of EU's ever-increasing interest in biodiversity conservation (Black Sea biodiversity in particular), the newly established cross-border, cross-disciplinary PC biodiversity conservation networks have a lot to offer towards establishing an effective, transnational conservation regime for the unique and threatened PC biota.

7

Acknowledgements

As a famous Brazilian lyricist and novelist Paulo Coelho said "when you want something, all the universe conspires in helping you to achieve it", it did conspire to help me finish my PhD. Many people have helped me and participated in the journey towards finishing my PhD and I want to thank them all for everything they did for me. Some helped me with scientific parts of it, others with planning and administration, still others helped me, perhaps unconsciously, by inspiring me with their work and passion and incentivizing me to also be as successful, and still others helped me by listening to me sometimes and telling me the much-needed words that 'everything will be okay'.

My greatest acknowledgements go to my supervisors. I consider myself extremely lucky that I had the opportunity to be guided in this process by three beautiful minds and inspiring people that **Frank Wesselingh**, **Niels Raes** and **Koos Biemeijer** are. It almost makes finishing my PhD unfortunate knowing that I cannot keep bothering them with all the problems and difficulties that I encounter. They were and will be the role-models for me and it was my greatest pleasure to learn from them and work with them. We together went through a long and puzzling journey of discovering many novel sides to the Pontocaspian biodiversity conservation in an extremely challenging Pontocaspian environment. Thank you, dear Niels, Koos and Frank for guiding me, being with me and sharing with me the deepest frustrations and greatest joys that the academia can bring. I will forever be grateful.

The PRIDE project was possible because of **Frank Wesselingh** and **Caroline van Impelen**. Thank you, dear Frank and Caroline, for granting me a life-changing opportunity to be the part of PRIDE. From the days of the interview in May 2015 up until today it has been a magical experience and I could not even fantasize of a better way of spending those years. Even when I downgrade my stories from PRIDE in order not to hurt someone's feelings in a conversation by my 'bragging', they still seem like plots from the movie and hard to believe by many what used to be an everyday reality for us. It all happened thanks to you, thanks to choices you made, thanks to the experimenting, innovative and open mindsets you have. Thank you for creating such an amazing network of researchers, conservationists, entrepreneurs and students stretching from UK all the way to Kazakhstan. Thank you for extremely diverse skills and knowledge that you gave us through extensive trainings on so many disciplines from life and earth sciences to future scenario modelling and outreach techniques.

Next, I would like to thank the PRIDE team. It will be hard to explain to someone who has not been involved in PRIDE what it meant to be part of PRIDE and how close the program brough us all together. My fellow PRIDE PhD colleagues: **Sabrina van de Velde**, **Matteo Lattuada**, **Arthur Sands**, **Thomas Hoyle**, **Manuel Sala-Pérez**, **Sergei Lazarev**, **Alberto Martínez-Gándarra**, **Sri Nandini**, **Lea Rausch**, **Liesbeth Jorissen**, **Sifan Koriche**, **Diksha Bista**, **Anouk D'Hont** and **Justine Vandendorpe**, thank you for all the support, inspiration, adventures and laughs and tears we shared. You made the extremely demanding Network Training Events (NTEs) and fieldworks not only endurable but actually enjoyable. Then, I would like to thank the members from PRIDE partner organizations who helped with making my thesis a success. Thank you **Vitaliy Anistratenko** and **Olga Anistratenko** for welcoming me to Kiev, introducing me to different stakeholders and supporting me throughout the PhD. In Bucharest, I was welcomed by **Marius Stoica**, **Oana Popa**, **Luis Popa** and **Ana-Maria Krapal** to whom I am very grateful. Furthermore, I would like to thank **Ana Bianca Pavel** for her great contributions to my research and for helping me with my fieldworks in Constanta and Tulcea. Last but not least, I would like to thank **Rachel Flecker**, **Salomon Kroonenberg**, **Chris van Baak**, **Arjan de Leeuw** and **Wout Krijgsman** for having the patience to teach me geology from scratch and inspiring me with geology: I really enjoyed our conversations during the fieldworks and NTEs. Listening to them felt like I could travel back in time for millions of years and 'witness' how the sediments were forming back then. I would also like to thank **Thomas Neubauer** from whom I learned a lot about taxonomy and who has always been supportive of me and my research.

Additionally, I want to thank all the people that have made my PRIDE fieldworks and secondments possible and successful. I thank the entire WWF in Ukraine Team for hosting my secondment and for their invaluable assistance and support throughout my stay in Ukraine. Special thanks go to **Mikhail Son** from the Institute of Marine biology in Odessa for his great contributions to not only the scientific part of this thesis but to PRIDE project in general. I learned a lot from him and really enjoyed working with him. I acknowledge **Kateryna Kurakina** from Rewilding Europe for her great help with designing PRIDE bags, streakers and logos, which we used for awareness raising events and activities on Pontocaspian biodiversity. Furthermore, I thank **Prof. Ivan Moysiyenko**, from Kherson State University, and **Sergei Ovechko**, from NASU Kherson Hydrobiology Station for helping me arrange meetings with stakeholders. I am very grateful to **Ivan Rusel**, **Irina Burlachenko** and the entire professional team of the National Nature Park "Tuzlovski lymany" for hosting me and helping me with the collection of the interview data in Odessa Oblast. I thank **Angelica Curlisca** from the Constanta Dolphinarium, **Mihaela Candea** from Mare Nostrum and **Răzvan Popescu** from the OCEANIC Club for their support and for putting me in contact with relevant stakeholders. I also thank all the interviewed stakeholders for finding time to meet me and for providing honest and thorough answers to the survey questions. Finally, I am very grateful to

Ingrid Visseren-Hamakers from Radboud University Nijmegen, for her guidance and advices on researching the Pontocaspian policy landscape.

I am very grateful to my friends and colleagues from Naturalis Biodiversity Center for all the support, coffee breaks, lunches, birthday cakes and advices. Specifically, I would like to thank **Maarten van 't Zelfde** for teaching me a lot about spatial data and GIS program and for always asking me how I was doing and for always being there for me. Next, I would like to thank **Martina de Freitas Prazeres** and **Thomas Edward Roberts** for their support, encouragement, teaching me how to fly-fish and beautiful fishing experiences and for proofreading my publication. A very special thanks to all the Naturalis PhDs with whom I shared numerous lunches, cups of coffee, tea, drinks and parties: **Esther van der Ent**, **Lisette Mekkes**, **Thomas Swierts**, **Andres Rivera Quiroz**, **Iva Njunjic**, **Sofia Fernandes Gomes**, **Sander Hilgen**, **Jesus Aguirre Gutierrez** and **Tanya Semenova**. Especially, I would like to thank **Esther van der Ent** for her contagious positivity, great support, encouragement and friendship and also for teaching me ice-skating and inline-skating, for inspiring me to start running, for helping me realize that I can actually cycle long distances and for introducing me to the best ice-cream in the Netherlands. Last but not least, my sincere thanks to other Naturalis colleagues who supported me throughout: **Maaike van de Kamp-Romijn**, **Nieke Knoben**, **Dominique van der Sterren**, **Johan Mols**, **Willem Renema**, **Yuri Matteman**, **Esmée Winkel**, **Maartje Kijne**, **Fabien Bruine de Bruin**, **Cynthia Crul**, **Ate Cohen**, **Menno Schilthuizen**, **Paula Silva**, **Jan Macher**, **Debbie Wall-Palmer**, **Vincent Merckx** and **Renato Lima**.

Next, I would like to thank my dear paranymphs **Sabrina van de Velde** and **Leon Marshall**. Sabrina, it will be hard to express how grateful I am and how much I appreciate you for always being by my side, for always prioritizing my questions, or my challenges over yours even though I never asked you to, for always checking on me, never forgetting me and encouraging me with words or post cards or silly little presents like relaxing tea bags or a spinning top that said "don't give up! -x- I believe in you", for formatting my thesis and now for being my paranymph. You are a true friend and I am very happy to have met you. Leon, I am also very grateful to you and I appreciate you a lot and the reason I 'separate' you from Sabrina is because I know you and Sabrina from very different contexts. You are my good friend and I am extremely grateful to you for always being there for me, supporting and encouraging me, answering some of my challenging statistical questions, sharing with me some of the lowest and highest moments and always trying to help me. I am happy you guys will be standing next to me on my defense.

Furthermore, I would like to thank **Vicky Alcalde**, **Guilherme Herrero Bastos**, **Arjan Zwamborn**, **Hans van de Velde** and **Sonja Tierates** for always listening to me and encouraging me. Last but not least, I would like to thank my good friends from outside of Leiden: **Nedim Tuzun**, **Eleftherios Bitzilekis**, **Dea Pochkhidze**, **Maia Tskhvaradze**, **Zizi Chkhaidze**, **Goglo Kurdadze**, **Ramaz Kurdadze** and **Bacho Khachidze** for supporting me in so many ways in the path that led to the PRIDE program and continuing their support throughout PRIDE via the phone and/or video calls or the reunions we had.

Finally, I want to thank my family for all the love and support and for the necessary power that enabled me to keep going no matter what. I would like to thank my parents **Gocha Gogaladze** and **Laura Tsiklauri**, my sister **Lika Gogaladze**, my grandmother **Elene Khutsiashvili**, my aunts **Khatuna Gogaladze** and **Ketino Gogaladze** and my cousins, **Irakli**, **Giorgi**, **Tamuna**, **Elene**, **Andro** and **Lazare**:

ძვირფასო დედა, მადლობა ყველაფრისთვის, მადლობა რომ მასწავლე ადამიანების სიყვარული, მადლობა რომ მომეცი დაფასების უნარი იმისი რაც მაქვს, მადლობა დაუღალავი თანადგომისთვის, აუღწერელი სიყვარულისთვის და გამხნევებისთვის. ძვირფასო მამა, მადლობა ყველაფრისთვის, მადლობა ხელშეწყობისთვის რომ ჩემი ოცნებები რეალობა გამხდარიყო, მუდმივად გვერდში დგომისთვის, პოზიტივისთვისა და სიყვარულისთვის. ძვირფასო დაიკო მადლობა უღრმესი სიყვარულის, თანადგომისა და მუდმივი გამხნევებისთვის. ძვირფასო ელიკო ბაბო, დიდი მადლობა ყველაფრისთვის, უდიდესი სიყვარულის, დაუღალავი შრომისა და ულამაზესი ბავშვობისთვის. ძვირფასო მამიდებო და მამიდაშვილებო, მადლობა უდიდესი მხარდაჭერისთვის, დახმარებისთვის გადამედგა ის ნაბიჯები რომლებმაც დღევანდელ დღემდე მომიყვანა და დახმარებისთვის მუდმივი მზადყოფნისა და სურვილისთვის.

8

Biography

Aleksandre Gogaladze was born on July 15th 1990 in Tbilisi, Georgia. After finishing high school at the No. 122 Public School in Tbilisi in 2007, he received a BSc in Biology from the Tbilisi State University in 2011 and a MSc in Evolution, Ecology and Systematics from the Ludwig-Maximilians University of Munich in 2013. In 2013 Aleksandre joined the Ministry of Environment and Natural Resources Protection of Georgia, where he promoted environmental awareness as part of the Education Center. In 2014 Aleksandre moved to the Biodiversity Conservation Department where, among the other tasks, he coordinated the National Biodiversity Monitoring System of Georgia. In 2015 he joined the EU Horizon 2020 Pontocaspian Biodiversity Rise and Demise (PRIDE) Program.

As an Early State Researcher in the PRIDE program, Aleksandre combined the full-time employment at Naturalis Biodiversity Center with PhD studies at Leiden University supervised by Prof. Dr. J.C. (Koos) Biesmeijer, Dr. Frank P. Wesselingh and Dr. Niels Raes. At Leiden University Aleksandre's research focused on the institutional design of stakeholder organizations in Romania and Ukraine, governance architectures and the legal and political frameworks that help or hinder effective conservation of Pontocaspian biodiversity. The scientific findings of his PhD project resulted in 3 published first-author papers in international, peer-reviewed journals. In the PRIDE program, Aleksandre co-developed and implemented the program-wide communication strategy; identified and liaised with PRIDE stakeholders at all levels; developed and maintained an online bio and geodiversity data platform and provided training on biodiversity data standards and databases for partners and stakeholders.

Since August 2020 Aleksandre has served as a member of the operational board of the European Marine Science Educators Association (EMSEA). His role in EMSEA entails the promotion of sustainable growth in the marine and maritime sectors (blue growth) within the Black Sea Region. Since March 2021 Aleksandre is the faculty liaison at the faculty of science of Utrecht University. As a liaison, he acts as a connecting link between the faculty and the academic services of the university library promoting the transition from current publication culture towards more open access publishing.

Photo credit: Harold van de Kamp (photo editor, Utrecht University)

9

PUBLICATIONS

Peer reviewed

Gogaladze, A., N. Raes, J. C. Biesmeijer, C. Ionescu, A. B. Pavel, M. O. Son, N. Gozak, V. Anistratenko, and F. P. Wesselingh. 2020a. Social network analysis and the implications for Pontocaspian biodiversity conservation in Romania and Ukraine: A comparative study. PLoS ONE 15:740084.

Gogaladze, A., F. P. Wesselingh, K. Biesmeijer, V. Anistratenko, N. Gozak, M. O. Son, and N. Raes. 2020b. Using social network analysis to assess the Pontocaspian biodiversity conservation capacity in Ukraine. Ecology and Society 25 (2): 25.

Gogaladze, A., M. O. Son, M. Lattuada, V. V. Anistratenko, V. L. Syomin, A. B. Pavel, O. P. Popa, L. O. Popa, J.-J. t. Poorten, J. C. Biesmeijer, N. Raes, T. Wilke, A. F. Sands, T. Trichkova, Z. K. Hubenov, M. V. Vinarski, O. Y. Anistratenko, T. L. Alexenko, and F. P. Wesselingh. 2021. Decline of unique Pontocaspian biodiversity in the Black Sea Basin: a review. Ecology and Evolution 11(19): 12923-12947.

Wesselingh, F. P., T. A. Neubauer, V. V. Anistratenko, M. V. Vinarski, T. Yanina, J. J. ter Poorten, P. Kijashko, C. Albrecht, O. Y. Anistratenko, A. D'Hont, P. Frolov, A. M. Gandara, A. Gittenberger, **A. Gogaladze**, M. Karpinsky, M. Lattuada, L. Popa, A. F. Sands, S. v. d. Velde, J. Vandendorpe, and T. Wilke. 2019. Mollusc species from the Pontocaspian region – an expert opinion list. ZooKeys 827: 31-124.

Trommer, G., M. Poxleitner, P. Lorenz, E. Bitzilekis, **A. Gogaladze**, S. Schultes, and H. Stibor. 2017. Altered food-web dynamics under increased nitrogen load in phosphorus deficient lakes. Aquatic Sciences 79: 1009-1021.

Reports

Gogaladze, A., C. v. Impelen, N. Raes, S. Nandini, M. Lattuada and F. P. Wesselingh. 2019. Deliverable D1.1. Model input for the Pontocaspian-Information System (PC-IS). Dissemination level: "Confidential, only for members of the consortium (including the Commission Services)".

Gogaladze, A., C. v. Impelen, and F. P. Wesselingh. 2019. Deliverable D2.1. Taxonomic data delivery to PC-Tax system. Dissemination level: "Confidential, only for members of the consortium (including the Commission Services)".

Wesselingh, F. P., **A. Gogaladze**, C. v. Impelen and N. Raes. 2016. Deliverable D4.3. Outreach programme established and approved - Public version.

Other

Gogaladze, A., N. Raes. 2016. Scratchpads user manual for Pontocaspian Biodiversity Rise and Demise (PRIDE) taxonomic platform (PC-Tax). Public version.

Gogaladze, A., F. P. Wesselingh, and the PRIDE team. Discover the unique mollusk fauna of the Black Sea. A tool for citizen science.

10

References

Abrahamson, E., Rosenkopf, L., 1997. Social network effects on the extent of innovation diffusion: A computer simulation. Organization science 8, 289-309.

Adger, W.N., Brown, K., Tompkins, E.L., 2005. The political economy of cross-scale networks in resource co-management. Ecology and Society 10.

Akimov, I.A., 2009. Red Data Book of Ukraine. Animal World. Globalconsulting, Kiev, Ukraine. [in Ukrainian].

Alexandrov, B., Boltachev, A., Kharchenko, T., Lyashenko, A., Son, M., Tsarenko, P., Zhukinsky, V., 2007. Trends of aquatic alien species invasions in Ukraine. Aquatic Invasions 2, 215-242.

Alexenko, T.L., 2004. Mollusks of the Dnieper-Bug Estuary Region and Their Role in Feeding of Fish. Hydrobiological Journal 40, 56-62.

Alexenko, T.L., Kucheryava, A.N., 2019. Osoblyvosti rozselennya moluskiv roda Caspia (Gastropoda, Pectinibranchia, Pyrgulidae) u Dniprovsko-Buzkiy gyrloviy oblasti (Specificity of distribution of molluscs of the genus *Caspia* (Gastropoda, Pectinibranchia, Pyrgulidae) in the Dnieper-Bug estuary area). Naukovi chytannya, prysvyacheni Dnyu nauky. Ecologichni dislidzhennya Dniprovsko-Buzkogo rehionu 12, 28-33. [in Ukrainian].

Alexenko, T.L., Shevchenko, I.V., 2016. Strukturno-funkcionalni osoblyvosti formuvannya ugrupovan donnykh bezkhrebetnykh rusla Nyzhnoho Dnipra v suchasnykh umovakh (Structural-functional characteristics of formation of communities of the bottom invertebrates of the Lower Dnieper riverbed in modern conditions). Naukovi chytannya, prysvyacheni Dnyu nauky. Ecologichni dislidzhennya Dniprovsko-Buzkogo rehionu 9, 45-50. [in Ukrainian].

Alexenko, T.L., Starobogatov, Y.I., 1987. Vidy *Caspia* i *Turricaspia* (Gastropoda, Pectinibranchia, Pyrgulidae) Azovo-Chernomorskogo basseyna (Species of *Caspia* and *Turricaspia* (Gastropoda, Pectinibranchia, Pyrgulidae) of the Azov-Black Sea basin). Vestnik zoologii 21, 32-38. [in Ukrainian].

Aliyeva, G., Halsall, C., Alasgarova, K., Avazova, M., Ibrahimov, Y., Aghayeva, R., 2013. The legacy of persistent organic pollutants in Azerbaijan: an assessment of past use and current contamination. Environmental Science and Pollution Research 20, 1993-2008.

Amano, T., Sutherland, W.J., 2013. Four barriers to the global understanding of biodiversity conservation: wealth, language, geographical location and security. Proceedings of the Royal Society B: Biological Sciences 280, 20122649.

Andrussov, N., 1897. Fossil and living Dreissensidae of Eurasia. Trudy Sankt-Peterburgskogo obschestva estestvoispytatelej. Otdel geologii i mineralogii 25, 1–683. [in Russian].

Angelov, A., 2000. Mollusca (Gastropoda et Bivalvia) aquae dulcis, catalogus Faunae Bulgaicae. Pensoft & Backhuys Publ., Sofia, Leiden 54.

Anistratenko, O.Y., Starobogatov, Y.I., Anistratenko, V.V., 1999. Mollusks of the genus *Theodoxus* (Gastropoda, Pectinibranchia, Neritidae) from the Black and the Azov seas basin. Vestnik zoologii 33, 11-19.

Anistratenko, V.V., 1996. Bryukhonogiye mollyuski Chernomorskogo biosphernogo zapovednika (Gastropod Mollusks of the Black Sea Biosphere Nature Reserve). Vestnik zoologii 1/2, 9-15.

Anistratenko, V.V., 2007a. Finding of the extremely rare hydrobiid *Caspia logvinenkoi* (Mollusca: Gastropoda) in the estuary of the River Don and its zoogeographical significance. Mollusca 25, 23-26.

Anistratenko, V.V., 2007b. New data on the composition, structure, and genesis of the Ponto-Caspian Gastropod fauna in the Azov–Black Sea basin. Zoological Journal 86, 793-801.

Anistratenko, V.V., 2008. Evolutionary trends and relationships in hydrobiids (Mollusca, Caenogastropoda) of the Azov-Black Sea Basin in the light of their comparative morphology and paleozoogeography. Zoosystematics and Evolution 84, 129-142.

Anistratenko, V.V., 2009. *Turricaspia lincta* Milaschevitch, 1908, In Red Data Book of Ukraine. Animal World. ed. I.A. Akimov, p. 290. Globalconsulting, Kiev, Ukraine.

Anistratenko, V.V., 2013. On the taxonomic status of the highly endangered Ponto-Caspian gastropod genus *Caspia* (Gastropoda: Hydrobiidae: Caspiinae). Journal of Natural History 47, 51-64.

Anistratenko, V.V., Anistratenko, O.Y., 2018. New finds of "Red Data Book" molluscs of the Ponto-Caspian biogeographic complex. Materials to the Fourths Edition of the Red Data Book of Ukraine, Animal World, pp. 19-20, Kiev, Ukraine.

Anistratenko, V.V., Anistratenko, O.Y., Khaliman, I.A., 2014. Conchological variability of *Anadara inaequivalvis* (Bivalvia, Arcidae) in the Black–Azov sea basin. Vestnik zoologii 48, 457-466.

Anistratenko, V.V., Khaliman, I.A., 2006. Bivalve Mollusc *Anadara inaequivalvis* (Bivalvia, Arcidae) in the Northern Part of the Sea of Azov: Completion of Colonization of the Azov-Black Sea Basin. Vestnik zoologii 40, 505-511.

Anistratenko, V.V., Khaliman, I.A., Anistratenko, O.Y., 2011. The Molluscs of the Sea of Azov. Kyiv: Naukova dumka, 1-173. [in Russian].

Anistratenko, V.V., Sitnikova, T.Y., Kijashko, P.V., Vinarski, M.V., Anistratenko, O.Y., 2020. A review of species of the genus *Theodoxus* (Gastropoda: Neritidae) of the Ponto-Caspian region, with considerations on available type materials. Ruthenica 30, 115-134.

Anistratenko, V.V., Zettler, M.L., Anistratenko, O.Y., 2017. On the taxonomic relationship between *Theodoxus pallasi* and *T. astrachanicus* (Gastropoda: Neritidae) from the Ponto-Caspian region. Archiv für Molluskenkunde International Journal of Malacology 146, 213-226.

Audzijonyte, A., Baltrūnaitė, L., Väinölä, R., Arbačiauskas, K., 2017. Human-mediated lineage admixture in an expanding Ponto-Caspian crustacean species *Paramysis lacustris* created a novel genetic stock that now occupies European waters. Biological Invasions 19, 2443-2457.

Audzijonyte, A., Daneliya, M.E., Mugue, N., Väinölä, R., 2008. Phylogeny of Paramysis (Crustacea: Mysida) and the origin of Ponto-Caspian endemic diversity: resolving power from nuclear protein-coding genes. Molecular phylogenetics and evolution 46, 738-759.

Audzijonyte, A., Daneliya, M.E., Väinölä, R., 2006. Comparative phylogeography of Ponto-Caspian mysid crustaceans: isolation and exchange among dynamic inland sea basins. Molecular Ecology 15, 2969-2984.

Azam, C.S., Gigot, G., Witte, I., Schatz, B., 2016. National and subnational Red Lists in European and Mediterranean countries: current state and use for conservation. Endangered Species Research 30, 255-266.

Baboianu, G., 2016. Danube Delta: The Transboundary Wetlands (Romania and Ukraine). The Wetland Book: II: Distribution, Description and Conservation, 1-12.

Balashov, I.A., Son, M.O., Coadă, V., Welter-Schultes, F., 2013. An updated annotated checklist of the molluscs of the Republic of Moldova. Folia Malacologica 21, 175-181.

Ban, N.C., Mills, M., Tam, J., Hicks, C.C., Klain, S., Stoeckl, N., Bottrill, M.C., Levine, J., Pressey, R.L., Satterfield, T., 2013. A social–ecological approach to conservation planning: embedding social considerations. Frontiers in Ecology and the Environment 11, 194-202.

Barnes, M.L., Lynham, J., Kalberg, K., Leung, P., 2016. Social networks and environmental outcomes. Proceedings of the National Academy of Sciences 113, 6466-6471.

Barnes, R., 1989. What, if anything, is a brackish-water fauna? Earth and Environmental Science Transactions of The Royal Society of Edinburgh 80, 235-240.

Barnosky, A.D., Matzke, N., Tomiya, S., Wogan, G.O., Swartz, B., Quental, T.B., Marshall, C., McGuire, J.L., Lindsey, E.L., Maguire, K.C., 2011. Has the Earth/'s sixth mass extinction already arrived? Nature 471, 51-57.

Barrat, A., Barthélemy, M., Vespignani, A., 2004. Weighted evolving networks: coupling topology and weight dynamics. Physical review letters 92, 228701.

Benson, A., Boydstun, C., 1995. Invasion of the zebra mussel into the United States. Our Living Resources: A Report to the Nation on the Distribution, Abundance, and Health of US Plants, Animals and Ecosystems, US Department of the Interior, National Biological Service, Washington, DC, 445-446.

Bespalaya, Y.V., Bolotov, I.N., Aksenova, O.V., Kondakov, A.V., Gofarov, M.Y., Laenko, T.M., Sokolova, S.E., Shevchenko, A.R., Travina, O.V., 2018. Aliens are moving to the Arctic frontiers: an integrative approach reveals selective expansion of androgenic hybrid *Corbicula* lineages towards the North of Russia. Biological Invasions 20, 2227-2243.

Bespalov, A., 2005. Landscape zoning of the Sea of Azov using elements of GIS technology, PhD thesis, Rostov State University, In Retrieved from: http://earthpapers.net/ [in Russian].

Bick, A., Bastrop, R., Kotta, J., MEIßNER, K., Meyer, M., Syomin, V., 2018. Description of a new species of Sabellidae (Polychaeta, Annelida) from fresh and brackish waters in Europe, with some remarks on the branchial crown of Laonome. Zootaxa 4483, 349-364.

Bij de Vaate, A., Jazdzewski, K., Ketelaars, H.A.M., Gollasch, S., Van der Velde, G., 2002. Geographical patterns in range extension of Ponto-Caspian macroinvertebrate species in Europe. Canadian Journal of Fisheries and Aquatic Sciences 59, 1159-1174.

Binning, C., Young, M., Cripps, E., 1999. Beyond Roads, Rates and Rubbish: Opportunities for local government to conserve native vegetation.

Birstein, V.J., Waldman, J.R., Bemis, W.E., 2006. Sturgeon biodiversity and conservation. Springer Science & Business Media.

Bláha, M., Uzhytchak, M., Bondarenko, V., Policar, T., 2017. The least known European native crayfish Astacus pachypus (Rathke, 1837) revealed its phylogenetic position. Zoologischer Anzeiger 267, 151-154.

Bloesch, J., Jones, T., Reinartz, R., Striebel, B., 2006. An action plan for the conservation of sturgeons (Acipenseridae) in the Danube River Basin. Österreichische Wasser-und Abfallwirtschaft 58, 81-88.

Bodin, Ö., Crona, B., Ernstson, H., 2006. Social networks in natural resource management: what is there to learn from a structural perspective? Ecology and Society 11.

Bodin, Ö., Crona, B.I., 2009. The role of social networks in natural resource governance: What relational patterns make a difference? Global Environmental Change 19, 366-374.

Bodin, Ö., Prell, C., 2011. Social networks and natural resource management: uncovering the social fabric of environmental governance. Cambridge University Press.

Boeters, H.D., Gloer, P., Georgiev, D., Dedov, I., 2015. A new species of *Caspia* Clessin et W. Dybowski, 1887 (Gastropoda: Truncatelloidea: Hydrobiidae) in the Danube of Bulgaria. Folia Malacologica 23, 177-186.

Bogdan, R., Taylor, S.J., 1975. Introduction to Qualitative Research Methods. John Wiley & Sons, New York.

Bogutskaya, N.G., Kijashko, P.V., Naseka, A.M., Orlova, M.I., 2013. Identification keys for fish and invertebrates. Volume 1: Fish and molluscs. KMK Scientific Publishers, Moscow. [in Russian].

Borcea, I., 1926a. Faune survivante de type caspien dans le liman d`eau douce de Roumanie. Note preliminaire. Ann Sc Univ Iassy 13, 207-232.

Borcea, I., 1926b. Quelques remarques sur les Adacnides et principalement sur les Adacnides des Lacs Razelm. Ann Sc Univ Iassy 13, 449-485.

Börzel, T., 2009. Coping with accession to the European Union: new modes of environmental governance. Springer.

Bradley, E.H., Curry, L.A., Devers, K.J., 2007. Qualitative data analysis for health services research: developing taxonomy, themes, and theory. Health services research 42, 1758-1772.

Brandes, U., 2001. A faster algorithm for betweenness centrality. Journal of mathematical sociology 25, 163-177.

Brechin, S.R., Wilshusen, P.R., Fortwangler, C.L., West, P.C., 2002. Beyond the square wheel: toward a more comprehensive understanding of biodiversity conservation as social and political process. Society &Natural Resources 15, 41-64.

Briggs, B.S.V., 2001. Linking ecological scales and institutional frameworks for landscape rehabilitation. Ecological Management & Restoration 2, 28-35.

Bulysheva, N.I., Glushchenko, G.Y., Kreneva, K.V., Kleschenkov, A.V., Varchenko, E.A., 2019. Settling of the fouling organisms at the metals in the delta of the Don River and in the estuarine zone of the Sea of Azov in winter. International Multidisciplinary Scientific GeoConference: SGEM 19, 521-526.

Burada, A., Ţopa, C.M., Georgescu, L.P., Teodorof, L., Năstase, C., Seceleanu-Odor, D., Negrea, B.M., Iticescu, C., 2014. Heavy metals accumulation in plankton and water of four aquatic complexes from Danube Delta area. Aquaculture, Aquarium, Conservation & Legislation 7, 301-310.

Burt, R.S., 1992. Structural Holes: The Social Structure of Competition. Harvard University Press, Cambridge, MA.

Burt, R.S., 2002. The social capital of structural holes. The new economic sociology: Developments in an emerging field 148, 190.

Burt, R.S., 2004. Structural holes and good ideas. American journal of sociology 110, 349-399.

Buzogány, A., 2015. Building governance on fragile grounds: lessonsfrom Romania. Environment and Planning C: Government and Policy 33, 901-918.

Cardoso, P., Erwin, T.L., Borges, P.A., New, T.R., 2011. The seven impediments in invertebrate conservation and how to overcome them. Biological conservation 144, 2647-2655.

Carmin, J., VanDeveer, S.D., 2004. Enlarging EU environments: Central and Eastern Europe from transition to accession. Environmental Politics 13, 3-24.

Caro, T., 2010. Conservation by proxy: indicator, umbrella, keystone, flagship, and other surrogate species. Island Press.

Cartea Roșie a Republicii Moldova, 2015. p. 492, Chișinău: Știința.

Cash, D.W., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N., Guston, D.H., Jäger, J., Mitchell, R.B., 2003. Knowledge systems for sustainable development. Proceedings of the National Academy of Sciences 100, 8086-8091.

Catianis, I., Secrieru, D., Pojar, I., Grosu, D., Scrieciu, A., Pavel, A.B., Vasiliu, D., 2018. Water quality, sediment characteristics and benthic status of the Razim-Sinoie lagoon system, Romania. Open Geosciences 10, 12-33.

CBD, 1992. Convention on Biological Diversity. U.N.T.S. vol. 1760, p. 79.

CBD, 1992. United Nations Conference on Environment and Development, Rio de Janeiro.

CBD, S.o.t., 2020. Global Biodiversity Outlook 5, Montreal.

CEP, 2002. Transboundary diagnostic analysis for the Caspian Sea, Baku, Azerbaijan.

Chang, H., Angelis, J., Nauwelaers, C., Posselt, T., Schuch, K., 2017. Peer Review of the Ukrainian Research and Innovation system. Horizon 2020 Policy Support Facility.

CITES, 1973. Convention on International Trade in Endangered Species of Wild Fauna and Flora. U.N.T.S. vol. 993, p. 243.

Cognetti, G., Maltagliati, F., 2000. Biodiversity and adaptive mechanisms in brackish water fauna. Marine pollution bulletin 40, 7-14.

Council of Europe, 1979. Convention on the Conservation of European Wildlife and Natural Habitats. European Treaty Series 104.

Cowling, R.M., Wilhelm-Rechmann, A., 2007. Social assessment as a key to conservation success. Cambridge Univ. Press 32 Avenue of the Americas, New York, NY 10013-2473 USA.

Crespo, D., Dolbeth, M., Leston, S., Sousa, R., Pardal, M.Â., 2015. Distribution of *Corbicula fluminea* (Müller, 1774) in the invaded range: a geographic approach with notes on species traits variability. Biological Invasions 17, 2087-2101.

Crona, B., Bodin, Ö., 2006. What you know is who you know? Communication patterns among resource users as a prerequisite for co-management. Ecology and Society 11.

Crona, B., Ernstson, H., Prell, C., Reed, M., Hubacek, K., 2011. Combining social network approaches with social theories to improve understanding of natural resource governance, pp. 44-71. Cambridge University Press: Cambridge.

Crutzen, P.J., 2016. Geology of mankind, In Paul J. Crutzen: A Pioneer on Atmospheric Chemistry and Climate Change in the Anthropocene. pp. 211-215. Springer.

Csardi, G., Nepusz, T., 2006. The igraph software package for complex network research. InterJournal, Complex Systems 1695, 1-9.

Cuttelod, A., Seddon, M., Neubert, E., 2011. European red list of non-marine molluscs. Publications office of the European Union Luxembourg.

Davis, J.A., Leinhardt, S., 1967. The structure of positive interpersonal relations in small groups.

De Klemm, C., Shine, C., 1993. Biological diversity conservation and the law: legal mechanisms for conserving species and ecosystems. IUCN.

Dean Jr, J.W., Brass, D.J., 1985. Social interaction and the perception of job characteristics in an organization. Human Relations 38, 571-582.

Delreux, T., Happaerts, S., 2016. Environmental policy and politics in the European Union. Macmillan International Higher Education.

Díaz, C.L., 2010. The Bern Convention: 30 years of nature conservation in Europe. Review of European Community & International Environmental Law 19, 185-196.

Díaz, S., Demissew, S., Carabias, J., Joly, C., Lonsdale, M., Ash, N., Larigauderie, A., Adhikari, J.R., Arico, S., Báldi, A., 2015. The IPBES Conceptual Framework—connecting nature and people. Current Opinion in Environmental Sustainability 14, 1-16.

Díaz, S., Settele, J., Brondízio, E., Ngo, H., Guèze, M., Agard, J., Arneth, A., Balvanera, P., Brauman, K., Butchart, S., Chan, K., Garibaldi, L., Ichii, K., Liu, J., Subramanian, S., Midgley, G., Miloslavich, P., Molnár, Z., Obura, D., Pfaff, A., Polasky, S., Purvis, A., Razzaque, J., Reyers, B., Chowdhury, R., Shin, Y., Visseren-Hamakers, I., Willis, K., Zayas, C., 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, p. 56, Bonn, Germany.

Dijkstra, E.W., 1959. A note on two problems in connexion with graphs. Numerische mathematik 1, 269-271.

Dimitrova, A., Buzogány, A., 2014. Post-Accession Policy-Making in B ulgaria and R omania: Can Non-state Actors Use EU Rules to Promote Better Governance? JCMS: Journal of Common Market Studies 52, 139-156.

Dmitrieva, L., Kondakov, A.A., Oleynikov, E., Kydyrmanov, A., Karamendin, K., Kasimbekov, Y., Baimukanov, M., Wilson, S., Goodman, S.J., 2013. Assessment of Caspian seal by-catch in an illegal fishery using an interview-based approach. PLoS ONE 8, e67074.

Dotsenko, S.F., Ivanov, V.A., 2010. Natural disasters in Azov–Black Sea Region. National Academy of Sciences of Ukraine, Marine Hydrophysical Institute. Sevastopol 174.

Drensky, P., 1947. Synopsis and distribution of freshwater Mollusca in Bulgaria. Godishnik na Sofiyskiya Ouniversitet, FMF, Kniga 43, 33-51. [in Bulgarian, English summary].

DRPC, 1994. Convention on cooperation for the protection and sustainable use of the river Danube. OJ L342, p. 19.

Dubinina, V., Zhukova, S., 2016. Assessment of the possible consequences of the construction of the Bagayevskiy waterworks facility for the Lower Don ecosystem. Rybnoye khozyaystvo [Fisheries] 4, 20-30. [in Russian].

Dudgeon, D., 2012. Threats to freshwater biodiversity globally and in the Indo-Burma Biodiversity Hotspot. The Status and Distribution of Freshwater Biodiversity in Indo-Burma, 1-28.

Dudgeon, D., Arthington, A.H., Gessner, M.O., Kawabata, Z.-I., Knowler, D.J., Lévêque, C., Naiman, R.J., Prieur-Richard, A.-H., Soto, D., Stiassny, M.L., 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. Biological Reviews 81, 163-182.

Dudley, N., 2008. Guidelines for applying protected area management categories. IUCN.

Dumont, H., Mamaev, V., Zaitsev, Y., 1999. Black Sea Red Data Book. United Nations Office for Project Services, 413.

Durham, E., Baker, H., Smith, M., Moore, E., Morgan, V., 2014. BiodivERsA Stakeholder Engagement Handbook. BiddivERsA: Paris, France.

Dzhurtubaev, Y.M., Dzhurtubaev, M., Zamorov, V., 2018. Macrozoobenthos of Danubian Lake Kugurluy (Odessa region, Ukraine). Ukrainian Journal of Ecology 8, 898-905. [in Russian].

Dzhurtubaev, Y.M., Dzhutubaev, M., Zamorov, V., 2017. Macrozoobenthos of Danubian Lake Yalpug (Odessa region, Ukraine). Ukrainian Journal of Ecology 7, 160-168. [in Russian].

ECODIT LLC, 2017. Ukraine Biodiversity Analysis. United States Agency for International Development, Arlington, USA.

Ecological Atlas, 2019. The Black Sea and the Sea of Azov. In series: Ecological Atlases of the Russian Seas. . Moscow, “NIR” Foundation, 464. [in Russian].

Ernoul, L., Wardell-Johnson, A., 2013. Governance in integrated coastal zone management: a social networks analysis of cross-scale collaboration. Environmental Conservation 40, 231-240.

Ernstson, H., Sörlin, S., Elmqvist, T., 2008. Social movements and ecosystem services—The role of social network structure in protecting and managing urban green areas in Stockholm. Ecology and Society 13.

Eschmeyer, W.N., Bailey, R.M., 1990. Catalog of the genera of recent fishes. California Academy of Sciences.

EU, 1992. Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora, ed. O.J.o.t.E. Union, pp. 7-50.

EU, 1996. Council Regulation (EC) No 338/97 of 9 December 1996 on the protection of species of wild fauna and flora by regulating trade therein, p. 1.

EU, 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, ed. O.J.o.t.E. Union, pp. 1-73.

EU, 2009. Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds, ed. O.J.o.t.E. Union, pp. 7-25.

European Commission, 2018. Burgas Vision Paper. A Blue Growth Initiative for Research and Innovation in the Black Sea, Burgas, Bulgaria.

European Commission, 2019. The EU Environmental Implementation Review 2019, Country Report - Romania, Brussels, Belgium.

European Commission, 2020. EU Biodiversity Strategy for 2030, Brussels.

Evans, D., 2012. Building the European union’s Natura 2000 network. Nature conservation 1, 11.

Favreau, J.M., Drew, C.A., Hess, G.R., Rubino, M.J., Koch, F.H., Eschelbach, K.A., 2006. Recommendations for assessing the effectiveness of surrogate species approaches. Biodiversity & Conservation 15, 3949-3969.

Fazey, I., Evely, A.C., Reed, M.S., Stringer, L.C., Kruijsen, J., White, P.C., Newsham, A., Jin, L., Cortazzi, M., Phillipson, J., 2013. Knowledge exchange: a review and research agenda for environmental management. Environmental Conservation 40, 19-36.

Filipenko, S., 2011. The current state of the benthic communities of the Kuchurgan Reservoir – the cooler of the Moldavian GRES // Vestnik Pridnestrovskogo Universiteta. SER.: MEDIKO-BIOLOGICHESKIE I HIMICHESKIE NAUKI 2, 83-90.

Francis, R.A., Goodman, M.K., 2010. Post-normal science and the art of nature conservation. Journal for nature conservation 18, 89-105.

Freeman, L.C., 1977. A set of measures of centrality based on betweenness. Sociometry, 35-41.

Freeman, L.C., 1978. Centrality in social networks conceptual clarification. Social networks 1, 215-239.

Freeman, L.C., Roeder, D., Mulholland, R.R., 1979. Centrality in social networks: II. Experimental results. Social networks 2, 119-141.

Freyhof, J., Brooks, E., 2011. European Red List of Freshwater Fishes (Publications Office of the European Union, Luxembourg).

Fuhse, J., Mützel, S., 2011. Tackling connections, structure, and meaning in networks: quantitative and qualitative methods in sociological network research. Quality & quantity 45, 1067-1089.

Gastescu, P., 2009. The Danube Delta biosphere reserve. Geography, biodiversity, protection, management. Rev Roum Géogr 53, 139-152.

Genov, I., Peychev, V., 2001. Holocene sediments from West part of Black Sea. Works of the Institute of Oceanology, Varna 3, 29–42.

Georgiev, D., Hubenov, Z., 2013. Freshwater snails (Mollusca: Gastropoda) of Bulgaria: an updated annotated checklist. Folia Malacologica 21, 237-263.

Giosan, L., Bokuniewicz, H., Panin, N., Postolache, I., 1999. Longshore sediment transport pattern along the Romanian Danube delta coast. Journal of Coastal Research, 859-871.

Giurca, A., Metz, T., 2017. A social network analysis of Germany's wood-based bioeconomy: Social capital and shared beliefs. Environmental Innovation and Societal Transitions.

Glaser, B.G., Strauss, A.L., Strutzel, E., 1967. The Discovery of Grounded Theory: Strategies for Qualitative Research New York Aldine De Gruyter. Inc.

Glowka, L., Shine, C., Santos, O.R., Phārūka, M., Gündling, L., 1998. A guide to undertaking biodiversity legal and institutional profiles. IUCN-The World Conservation Union.

Gogaladze, A., Raes, N., Biesmeijer, J.C., Ionescu, C., Pavel, A.B., Son, M.O., Gozak, N., Anistratenko, V., Wesselingh, F.P., 2020a. Social network analysis and the implications for Pontocaspian biodiversity conservation in Romania and Ukraine: A comparative study, In PLoS ONE. p. 740084.

Gogaladze, A., Son, M.O., Lattuada, M., Anistratenko, V.V., Syomin, V.L., pavel, A.B., popa, O.P., popa, L.O., Poorten, J.-J.t., Biesmeijer, J.C., Raes, N., Wilke, T., Sands, A.F., Trichkova, T., Hubenov, Z.K., Vinarski, M.V., Anistratenko, O.Y., Alexenko, T.L., P, W.F., Submitted. Decline of unique Pontocaspian biodiversity in the Black Sea Basin: a review. Diversity and Distributions.

Gogaladze, A., Wesselingh, F.P., Biesmeijer, K., Anistratenko, V., Gozak, N., Son, M.O., Raes, N., 2020b. Using social network analysis to assess the Pontocaspian biodiversity conservation capacity in Ukraine. Ecology and Society 25.

Golikov, A.N., Starobogatov, Y.I., 1966. Ponto-kaspiyskiy bryukhonogiye mollyuski v Azovo-Chernomorskom basseyne. Zoological Journal 45, 352-362.

Golikov, A.N., Starobogatov, Y.I., 1972. Molliuski–Klass Briukhonogie [Mollusca-Gastropoda]. Opredeliteli Fauny Chernogo i Azovskogo Morei [Identification key to the fauna of the Black and Azov Seas, free living invertebrates: Arthropoda (besides Crustacea), Mollusca, Echinodermata, Chaetognatha, Chordata] 3, 65-166.

Gomar, J.O.V., Stringer, L.C., Paavola, J., 2014. Regime complexes and national policy coherence: Experiences in the biodiversity cluster. Global Governance: A Review of Multilateralism and International Organizations 20, 119-145.

Gomoiu, M., Skolka, M., 1996. Changements recents dans la biodiversite de la Mer Noire dus aux immigrants. Geo-eco-marina 1, 34-48.

Gomoiu, M., Skolka, M., 1998. Cresterea biodiversitatii prin imigrare-noi specii in fauna Romaniei. Increase of biodiversity by immigration-new species for the Romanian fauna. "Ovidius" University Annals of Natural Science, Biology-Ecology series 2, 181-202.

Granovetter, M.S., 1973. The strength of weak ties. American journal of sociology 78, 1360-1380.

Grigorovich, I.A., Therriault, T.W., MacIsaac, H.J., 2003. History of aquatic invertebrate invasions in the Caspian Sea, In Marine bioinvasions: Patterns, processes and perspectives. pp. 103-115. Springer.

Grilli, G., Garegnani, G., Poljanec, A., Ficko, A., Vettorato, D., De Meo, I., Paletto, A., 2015. Stakeholder analysis in the biomass energy development based on the experts' opinions: the example of Triglav National Park in Slovenia. Folia Forestalia Polonica 57, 173-186.

Grinbart, S.B., 1953a. Bentos Dnestrovskovo limana i nizoviev Dnestra, ego kormovaia otsenka // Materiali po gidrobiologii i rybolovstvu limanov severno-zapadnogo Prichernomoria (Benthos of the Dniester estuary and the lower reaches of the Dniester, assessment of its nutritional value // Materials on hydrobiology and fishing in the limans of the northwestern Black Sea). Odessa University, 7-17.

Grinbart, S.B., 1953b. K izucheniu zoobentosa Tiligulskogo limana i ego kormovykh resursov (On the study of zoobenthos of the Tiligul estuary, and its feeding resources). Odessa University, 85-106. [in Russian].

Grinbart, S.B., 1955. Materials for studying the zoobenthos of the Berezan Liman. Trudy Odesskogo Gosudarstvennogo Universiteta im. I. I. Mechnikova. Ser. Biol. 145, 3–180.

Grinevetsky, S.R., Zonn, I.S., Zhiltsov, S.S., Kosarev, A.N., Kostianoy, A.G., 2016. The Black Sea Encyclopedia. Springer.

Grossu, A.V., 1956. Fauna Republicii Populare Romîne. Mollusca, 3 (2). Gastropoda, Prosobranchia si Opisthobranchia. Academiei Republicii Populare Romine, Bucureşti.

Grossu, A.V., 1962. Fauna Republicii Populare Romîne Molusca. Editura Academiei Republicii Populare Romîne, București 3, 426. [in Romanian].

Grossu, A.V., 1973. Les Limnocardiides actuelles du bassin Ponto-Caspique. Informations de la Société belge Belge de malacologieMalacologie.

Grossu, A.V., 1986. Gastropoda Romaniae. Editura Litera.

Groves, C., Valutis, L., Vosick, D., Neely, B., Wheaton, K., Touval, J., Runnels, B., 2000. Designing a geography of hope: A practitioner's handbook for ecoregional conservation planning. Volumen 1 y 2. The Nature Conservancy, Virginia (EUA).

Gubbay, S., Sanders, N., Haynes, T., Janssen, J., Rodwell, J., Nieto, A., Criado, M.G., Beal, S., Borg, J., 2016. European red list of habitats, part 1: marine habitats. European Union.

Hauck, J., Schmidt, J., Werner, A., 2016. Using social network analysis to identify key stakeholders in agricultural biodiversity governance and related land-use decisions at regional and local level. Ecology and Society 21.

Hauck, J., Stein, C., Schiffer, E., Vandewalle, M., 2015. Seeing the forest and the trees: facilitating participatory network planning in environmental governance. Global environmental change 35, 400-410.

Haythornthwaite, C., 1996. Social network analysis: An approach and technique for the study of information exchange. Library & information science research 18, 323-342.

He berling, J.M., Miller, J.T., Noesgaard, D., Weingart, S.B., Schigel, D., 2021. Data integration enables global biodiversity synthesis. Proceedings of the National Academy of Sciences 118.

Hermoso, V., Clavero, M., Villero, D., Brotons, L., 2017. EU's conservation efforts need more strategic investment to meet continental commitments. Conservation Letters 10, 231-237.

Herz, A., Peters, L., Truschkat, I., 2015. How to do qualitative strukturale Analyse? The qualitative interpretation of network maps and narrative interviews, In Forum Qualitative Sozialforschung/Forum: Qualitative Social Research.

Hortal, J., de Bello, F., Diniz-Filho, J.A.F., Lewinsohn, T.M., Lobo, J.M., Ladle, R.J., 2015. Seven shortfalls that beset large-scale knowledge of biodiversity. Annual Review of Ecology, Evolution, and Systematics 46, 523-549.

Hubenov, Z., 2001. Corbiculidae: a new family to the Bulgarian recent Malacofauna (Mollusca: Bivalvia). Acta zoologica bulgarica 53, 61-66.

Hubenov, Z., 2006. *Anodonta* (*Sinanodonta*) *woodiana* (Lea, 1834)(Mollusca: Bivalvia: Unionidae)–a new invasive species for the Bulgarian malacofauna. Acta zoologica bulgarica 58, 35-40.

Hubenov, Z., 2007. Fauna and zoogeography of marine, freshwater, and terrestrial mollusks (Mollusca) in Bulgaria, In Biogeography and ecology of Bulgaria. pp. 141-198. Springer.

Hubenov, Z., 2015. Species composition of the free living multicellular invertebrate animals (Metazoa: Invertebrata) from the Bulgarian sector of the Black Sea and the coastal brackish basins. Historia naturalis bulgarica 21, 49-168.

Hubenov, Z., Trichkova, T., 2007. *Dreissena bugensis* (Mollusca: Bivalvia: Dreissenidae): New invasive species to the Bulgarian malacofauna. Acta zoologica bulgarica 59, 203-209.

Hubenov, Z., Trichkova, T., Kenderov, L., Kozuharov, D., 2012. Recent distribution of invasive alien mussels *Anodonta woodiana* and *Corbicula fluminea* (Mollusca: Bivalvia: Unionidae & Corbiculidae) in Bulgaria. Journal of International Scientific Publications: Ecology & Safety 6, 269-284.

Hubenov, Z., Trichkova, T., Kenderov, L., Kozuharov, D., 2013. Distribution of *Corbicula fluminea* (Mollusca: Corbiculidae) over an eleven-year period of its invasion in Bulgaria. Acta zoologica bulgarica 65, 315-326.

Huisman, M., 2009. Imputation of missing network data: some simple procedures. Journal of Social Structure 10, 1-29.

ICPDR, 2008. Joint Danube Survey 2, Final Scientific Report, In ICPDR Secretariat, Vienna International Centre. Vienna, Austria.

ICPDR, 2015a. The Danube river basin district management plan. ICPDR-Internat. Commission for the Protection of the Danube River Secretariat.

ICPDR, 2015b. Joint Danube Survey 3. A comprehensive analysis of Danube water quality, Vienna.

ICPDR, 2018. Sturgeon Strategy.

ICPDR, 2020. Sturgeon 2020. A program for the protection and rehabilitation of Danube sturgeons ed. D.S.T.F. (DSTF).

Ignat, G., Cristofor, S., Angheluță, V., Rîșnoveanu, G., Nafornița, G., Florescu, C., 1997. Structure and dynamics of benthic fauna in Danube Danube and Danube Delta, Scientific Annals of the Danube Delta Research and Design Institute. IV, 133-142.

Isaac, M.E., 2012. Agricultural information exchange and organizational ties: The effect of network topology on managing agrodiversity. Agricultural systems 109, 9-15.

Iwanski, T., 2011. Ukraine-Romania: a sustained deadlock. OSW Centre for Eastern Studies 30.

Janssen, J., Rodwell, J., Criado, M., 2016. European red list of habitats, part 2: terrestrial and freshwater habitats. European Union.

Jarvis, R.M., 2015. Putting people back in the picture: a social research agenda for a social-ecological approach to conservation planning. Auckland University of Technology.

Jordan, R.C., Ballard, H.L., Phillips, T.B., 2012. Key issues and new approaches for evaluating citizen-science learning outcomes. Frontiers in Ecology and the Environment 10, 307-309.

Kaneva-Abadjieva, V., 1957. Mollusca and Malacostraca im Varnasee. Arbeiten aus der Biologischen Meeresstation, Varna 19, 127–154. [in Bulgarian, Russian and German summaries].

Kantor, Y.I., Sysoev, A., 2006. Marine and Brackish water Gastropoda of Russia and adjacent countries: an illustrated catalogue. KMK Scientific Press, Moscow, 371 + plates pp.

Ketelaars, H.A., 2004. Range extensions of Ponto-Caspian aquatic invertebrates in continental Europe, In Aquatic invasions in the Black, Caspian, and Mediterranean seas. pp. 209-236. Springer.

Khalaim, A., Son, M., 2016. Biologo-ekologicheskaia kharakteristika *Hypanis laeviuscula fragilis* (Milachevitch, 1908) (Mollusca, Cardiidae) vodokhranilisha Sasyk. Uzhgorod University Scientific Bulletin: Series: Biology, 59-63. [in Russian].

Khlebovich, V.V., 1974. The critical salinity of biological processes. Nauka, Leningrad, 235 pp. [in Russian].

Kijashko, P., 2013. Chapter 5. Mollusca of the Caspian Sea. In: Bogutskaya, N.G., P.V. Kijashko, A.M. Naseka & M.I. Orlova. Identification keys for fish and invertebrates of the Caspian Sea. 1 Fish and Molluscs, St. Petersburg/ Moscow.

Kiseleva, M.I., 2004. Polychaetes (Polychaeta) of the Azov and Black Seas [Mnogoshetinkovie chervil (polychaeta) Chernogo i Azovskogo morey]. Russian Academy of Science, Murmansk Marine Biological Institute, Apatity, Kola Science Centre, pp. 409. [in Russian].

Kittinger, W., 1997. The Danube River Protection Convention, In Protecting Danube River Basin Resources. pp. 43-47. Springer.

Kleinberg, J.M., 1998. Authoritative sources in a hyperlinked environment, In In Proceedings of the ACM-SIAM Symposium on Discrete Algorithms. Citeseer.

Kluvankova-Oravska, T., Chobotová, V., Banaszak, I., Slavikova, L., Trifunovova, S., 2009. From government to governance for biodiversity: the perspective of central and Eastern European transition countries. Environmental Policy and Governance 19, 186-196.

Knoke, D., Kuklinski, J.H., 1991. Network analysis: basic concepts. Markets, hierarchies and networks: the coordination of social life, 173-182.

Koester, V., 2002. The five global biodiversity-related conventions: a stocktaking. Rev. Eur. Comp. & Int'l Envtl. L. 11, 96.

Korpakova, I., Afanasyev, D., Barabashin, T., Tsybulsky, I., Belova, L., Naletova, L., Bychkova, M., 2007. Hydrobiological features of the estuary area of the Temryuk Bay of the Sea of Azov. Environmental Protection in the Oil and Gas Complex 9, 69-75. [in Russian].

Korpakova, I., Afanasyev, D., Tsybulsky, I., Barabashin, T., Belova, L., Naletova, L., Bychkova, M., 2010. Benthic and planktonic communities of estuaries of the Kuban River delta. News of higher educational institutions. North Caucasus region. Natural sciences 2, 78-81. [in Russian].

Korpakova, I., Tsybulsky, I., Afanasyev, D., Barabashin, T., Belova, L., Naletova, L., Bychkova, M., 2008. Hydrobiological characteristics of the south-eastern part of the Sea of Azov. Environmental Protection in the Oil and Gas Complex 11, 70-80. [in Russian].

Kostianoy, A.G., Kosarev, A.N., 2005. The Caspian Sea Environment. Springer Science & Business Media.

Kotiaho, J.S., Halme, P., 2018. The IPBES assessment report on land degradation and restoration.

Kovachev, S., Stoichev, S., Hainadjieva, V., 1999. The zoobenthos of several lakes along the Northern Bulgarian Black Sea Coast. Lauterbornia 35, 33-38.

Kovalenko, E.P., 2009. Donnyye bespozvonochnyye krupnykh vodotokov del'ty Dona (Bottom invertebrates of large watercourses of the Don delta), In VI International Scientific and Practical Conference of Young Scientists, dedicated to the ecological problems of aquatic ecosystems. p. 55. [in Russian], Sevastopol.

Kowalski, A.A., Jenkins, L.D., 2015. The role of bridging organizations in environmental management: examining social networks in working groups. Ecology and Society 20.

Koyano, M., 2008. The significance of the Convention on Environmental Impact Assessment in a Transboundary Context (Espoo Convention) in international environmental law: examining the implications of the Danube Delta case. Impact Assessment and Project Appraisal 26, 299-314.

Krapal, A.M., Popa, O.P., Levarda, A., Iorgu, E.I., Popa, L.O., Costache, M., Crocetta, F., 2015. Molecular Confirmation on the Presence of *Anadara kagoshimensis* (Tokunaga, 1906)(Mollusca: Bivalvia: Arcidae) in the Black Sea/ Confirmarea moleculară a prezenţei speciei *Anadara kagoshimensis* (Tokunaga, 1906)(Mollusca: Bivalvia: Arcidae) în Marea Neagră. Travaux du Muséum National d'Histoire Naturelle "Grigore Antipa" 57, 9-12.

Kreneva, S., Kreneva, K., Golovko, G., 2013. Assessment of the biocenoses' state in the Mius Liman of the Sea of Azov. Bulletin of the Southern Scientific Centre, 9 (4), 9, 71–77 [in Russian].

Krijgsman, W., Tesakov, A., Yanina, T., Lazarev, S., Danukalova, G., Van Baak, C.G., Agustí, J., Alçiçek, M., Aliyeva, E., Bista, D., 2019. Quaternary time scales for the Pontocaspian domain: Interbasinal connectivity and faunal evolution. Earth-science reviews 188, 1-40.

Krivoshey, V., 2016. On the project of the Bagayevskiy waterworks facility. Astrakhanskiy vestnik ekologicheskogo obrazovaniya [Astrakhan Bulletin of Environmental Education] 2, 76-80. [in Russian].

Landman, T., 2002. Issues and methods in comparative politics: an introduction. Routledge.

Lattuada, M., Albrecht, C., Wesselingh, F.P., Klinkenbuß, D., Vinarski, M.V., Kijashko, P., Raes, N., Wilke, T., 2020. Endemic Caspian Sea mollusks in hotspot and non-hotspot areas differentially affected by anthropogenic pressures. Journal of Great Lakes Research.

Lattuada, M., Albrecht, C., Wilke, T., 2019. Differential impact of anthropogenic pressures on Caspian Sea ecoregions. Marine pollution bulletin 142, 274-281.

Latypov, Y.Y., 2015. The Bivalve Mollusc Abra ovata: role in succession of soft bottom communities on newly flooded area of the Caspian Sea. American Journal of Climate Change 4, 239.

Lazega, E., Quintane, E., Casenaz, S., 2017. Collegial oligarchy and networks of normative alignments in transnational institution building. Social networks 48, 10-22.

Leavitt, H.J., 1951. Some effects of certain communication patterns on group performance. The Journal of Abnormal and Social Psychology 46, 38.

Lee, K.N., 1999. Appraising adaptive management. Conservation ecology 3.

Lindholm, W.A., 1908. Materialien zur Molluskenfauena [sic] von Südwestrussland, Polen und der Krim. Zapiski Novorossijskago Obshchestva Estestvoispytatelej 31, 199–232.

Lundberg, J.G., Kottelat, M., Smith, G.R., Stiassny, M.L., Gill, A.C., 2000. So many fishes, so little time: an overview of recent ichthyological discovery in continental waters. Annals of the Missouri Botanical Garden, 26-62.

Lyashenko, A., Zorina-Sakharova, Y.Y., Makovskiy, V., Sanzhak, Y.O., 2012. Modern state of the Ponto-Caspian complex of the macrofauna of invertebrates in the Lower Reaches of the Danube River within the territory of Ukraine. Hydrobiological Journal 48.

Makarov, A.K., 1938. Rasprostraneniye nekotorykh rakoobraznykh (Mysidacea, Cumacea) i limannykh mollyuskov v ust'yakh i otkrytykh limanakh Severnogo Prichernomor'ya [Distribution of some crustaceans (Mysidacea, Cumacea) and liman mollusks in estuaries and open limans of the northern Black Sea region]. Zoological Journal 17, 1055-1062. [in Russian].

Male, T.D., Bean, M.J., 2005. Measuring progress in US endangered species conservation. Ecology Letters 8, 986-992.

Manolache, S., Ciocanea, C.M., Rozylowicz, L., Nita, A., 2017. Natura 2000 in Romania–a decade of governance challenges. Eur. J. Geogr 8, 24-34.

Manolache, S., Nita, A., Ciocanea, C.M., Popescu, V.D., Rozylowicz, L., 2018. Power, influence and structure in Natura 2000 governance networks. A comparative analysis of two protected areas in Romania. Journal of Environmental Management 212, 54-64.

Marinov, T., 1990. The zoobenthos from the Bulgarian sector of the Black Sea. 195 pp. Sofia (BAN).[in Bulgarian, with Russian and English summary].

Markovsky, B., Willer, D., Patton, T., 1988. Power relations in exchange networks. American Sociological Review, 220-236.

Markovsky, Y.M., 1953. Fauna bespozvonochnykh nizov'ev rek Ukrainy, usloviya sushchestvo vaniya i puti ispol'zovaniya. Chast' 1. Vodoemy delty Dnestra i Dnestrovskii liman [Fauna of invertebrates of the lower river streams of Ukraine, life conditions and ways of utilization. Part 1. The basin of the Dniester delta and Dniester lagoon.]. AN USSR, Kiev, 1-207. [in Russian].

Markovsky, Y.M., 1954a. Fauna bespozvonochnykh nizov'ev rek Ukrainy, usloviya sushchestvovaniya i puti ispol'zovaniya. Chast' 2. Dneprovsko-Bugskii liman [Fauna of invertebrates of the lower river streams of Ukraine, life conditions and ways of utilization. Part 2. Dnieper-Bug lagoon.]. AN USSR, Kiev, 1-207. [in Russian].

Markovsky, Y.M., 1954b. Rezultaty raboty Instituta gidrobiologii Akademii Nauk USSR po pereseleniyu nekotorykh kormovykh bespozvonochnykh. [The work results of the Hydrobiological Institute of USSR Academy of Sciences on the resettlement of some forage invertebrates]. Trudy soveshchanii ikhtiologicheskoi komissii AN SSSR 3, 151-158. [in Russian].

Markovsky, Y.M., 1955. Fauna bespozvonochnykh nizov'ev rek Ukrainy, usloviya sushchestvovaniya i puti ispol'zovaniya. Chast' 3. Vodoemy Kilijskoi deity Dunaya [The fauna of invertebrates of the lower river streams of Ukraine, life conditions and ways of utilization. Part 3. The basin of the Kilian delta of the Danube]. AN USSR, Kiev, 1-275. [in Russian].

Marret, F., Leroy, S., Chalié, F., Françoise, F., 2004. New organic-walled dinoflagellate cysts from recent sediments of Central Asian seas. Review of Palaeobotany and Palynology 129, 1-20.

Martín-López, B., Montes, C., Benayas, J., 2007. The non-economic motives behind the willingness to pay for biodiversity conservation. Biological conservation 139, 67-82.

Martín-López, B., Montes, C., Ramírez, L., Benayas, J., 2009. What drives policy decision-making related to species conservation? Biological conservation 142, 1370-1380.

Matishov, G., 2005. System approach to the water quality and bioproductivity of the Azov Sea basin. WIT Transactions on Ecology and the Environment 83.

Matishov, G.G., Grigorenko, K.S., 2017. Causes of salinization of the Gulf of Taganrog. Doklady Earth Sciences 477, 1311-1315. [in Russian].

Matishov, G.G., Grigorenko, K.S., Moskovets, A.Y., 2017. The salinization mechanisms in the Taganrog Bay under the conditions of the Don River extremely low runoff. Science in the South of Russia 13, 35–43. [in Russian].

Matthews, G.V.T., 1993. The Ramsar Convention on Wetlands: its history and development. Ramsar Convention Bureau Gland.

Mihailova-Neikova, M., 1961. Hydrobiological research of the Mandra Lake with regard to its importance as a fishing ground. Godishnik na Sofiyskiya Ouniversitet, BGGF, Kniga 53 (1. Zoology), 57-123. [in Bulgarian].

Mikhailov, V., Gorin, S., 2012. New definitions, regionalization, and typification of river mouth areas and estuaries as their parts. Water Resources 39, 247-260.

Milaschewitsch, K.O., 1916. Mollyuski russkikh morey. Tom 1. Mollyuski Chernago i Azovs¬kago morey [Molluscs of the seas of Russia. Tome 1. Molluscs of the Black Sea and the Sea of Azov]. Fauna Rossii i sopredelnykh stran. Imperatorskaya Akademiya Nauk, Zoologicheskiy Muzey, Petrograd, 1-312.

Mills, M., Álvarez-Romero, J.G., Vance-Borland, K., Cohen, P., Pressey, R.L., Guerrero, A.M., Ernstson, H., 2014. Linking regional planning and local action: Towards using social network analysis in systematic conservation planning. Biological conservation 169, 6-13.

Ministry of Ecology and Natural Resources of Ukraine, 2015. Fifth national report of Ukraine to the Convention on Biological Diversity.

Ministry of Ecology and Natural Resources of Ukraine, 2018. Sixth National Report of Ukraine on the Implementation of the Convention on Biological Diversity, Kiev.

Ministry of Environment and Climate Change of Romania, 2014. Fifth National Report of Romania to the Convention on Biological Diversity.

Mizruchi, M.S., Galaskiewicz, J., 1993. Networks of interorganizational relations. Sociological Methods & Research 22, 46-70.

Monchenko, V.I., 2003. Free-living cyclopoid copepods of Ponto-Caspian basin. Kiev: Naukova dumka, 1-350. [in Russian].

Monge, P.R., Edwards, J.A., Kirste, K.K., 1983. Determinants of communication network involvement: Connectedness and integration. Group & Organization Studies 8, 83-111.

Mordukhay-Boltovskoy, F., 1960. Kaspiyskaya fauna v Azovo-Chernomorskom basseyne. Izdatel'stvo Akademii Nauk SSSR, Leningrad, 228 pp.

Moreno, J.L., 1953. Who shall survive? Foundations of sociometry, group psychotherapy and socio-drama.

Moroz, T.G., Alexenko, T.L., 1983. Benthos of the Dnieper-Bug Liman following the regulation of the Dnieper River run-off. Gidrobiologicheskiy Zhurnal 19, 33-40.

Moroz, T.G., Alexenko, T.L., Bortkevich, L.V., Sobolenko, A.Z., 1986. Benthos des lagunes saumâtres de la Tiligule. Hydrobiological Journal 22, 31-35.

Moses, W.J., Gitelson, A.A., Berdnikov, S., Saprygin, V., Povazhnyi, V., 2012. Operational MERIS-based NIR-red algorithms for estimating chlorophyll-a concentrations in coastal waters—The Azov Sea case study. Remote Sensing of Environment 121, 118-124.

Munasypova-Motyash, I.A., 2006. O sovremennoi faune dvustvorchatix molluskov podsemeistva Limnocardiinae (Bivalvia, Cardiidae) Severno-Zapadnogo Prichernomoria [On the recent fauna of subfamily Limnocardiinae (Bivalvia, Cardiidae) in North-Western shore of Black Sea]. Vestnik zoologii 40, 41-48.

Munasypova-Motyash, I.A., 2009a. *Hypanis laeviuscula* (Milachevitch, 1916), In Red Data Book of Ukraine. Animal World. ed. I.A. Akimov, p. 306. Globalconsulting, Kiev, Ukraine.

Munasypova-Motyash, I.A., 2009b. *Hypanis plicata* (Milashevitch, 1916), In Red Data Book of Ukraine. Animal World. ed. I.A. Akimov, p. 307. Globalconsulting, Kiev, Ukraine.

Munjiu, O., 2012. The modern species composition of freshwater mollusks from Moldova, In Geoecological and bioecological problems of the north Black Sea coast. pp. 205–207. [in Russian]. Tiraspol.

Munteanu, A., Ehlinger, T., Golumbeanu, M., Tofan, L., 2013. Network environmental governance in the EU as a framework for trans-boundary sturgeon protection and cross-border sustainable management. Journal of Environmental Protection and Ecology 14, 685-692.

N'Guyen, A., 2016. Non-native goby species in Switzerland: impacts and management. University_of_Basel.

Nabozhenko, M.V., 2005. Distribution of the genus *Hypanis* Pander in Ménétriés, 1832 (Bivalvia, Cardioidea: Limnocardiidae) in the Taganrog Gulf (The Sea of Azov). Ekologiya Morya, 44.

Nabozhenko, M.V., 2008. Distribution of Molllusks of the Subfamily Lymnocardiinae (Bivalvia, Cardiidae) in the Basin of the Azov Sea. Vestnik. YuNTs RAN 4, 78-82.

Nabozhenko, M.V., Kovalenko, E.P., 2011. Contemporary distribution of macrozoobenthic communities of the Yeisk estuary (Taganrog Bay of the Sea of Azov). Oceanology 51, 626-631.

Nagalevsky, Y., Lobko, N., 2017. Specially Protected Natural Territories of the Kuban River Delta. Regional Geographical Studies 1, 11-16. [in Russian].

Nagalevsky, Y., Nagalevsky, E., 2013. Geographic and hydrological zoning of the Kuban delta estuaries. Classification schemes. Environmental Protection in the Oil and Gas Complex 12, 69-74. [in Russian].

National Research Council, 2000. Clean coastal waters: understanding and reducing the effects of nutrient pollution. National Academies Press.

Nekrasova, M.Y., 1972. Zoobenthos of the Azov Sea after the control of the Don River. Zoological Journal 51, 789-798. [in Russian].

Newman, L., Dale, A., 2005. Network structure, diversity, and proactive resilience building: a response to Tompkins and Adger. Ecology and Society 10.

Newman, L., Dale, A., 2007. Homophily and agency: creating effective sustainable development networks. Environment, Development and Sustainability 9, 79-90.

Newman, M.E., 2003. The structure and function of complex networks. SIAM review 45, 167-256.

Newman, M.E., 2004. Analysis of weighted networks. Physical review E 70, 056131.

Newman, M.E., Girvan, M., 2004. Finding and evaluating community structure in networks. Physical review E 69, 026113.

Nita, A., Rozylowicz, L., Manolache, S., Ciocănea, C.M., Miu, I.V., Popescu, V.D., 2016. Collaboration networks in applied conservation projects across Europe. PLoS ONE 11, e0164503.

OECD, 2019. Biodiversity: Finance and the Economic and Business Case for Action, report prepared for the G7 Environment Ministers' Meeting, 5-6 May 2019.

Olivari, G., 1953. Benthos of the Lower Dnieper. Trudy Instituta Gidrobioogii AN USSR 31, 35-61. [in Russian].

Olsson, P., Folke, C., Hahn, T., 2004. Social-ecological transformation for ecosystem management: the development of adaptive co-management of a wetland landscape in southern Sweden. Ecology and Society 9.

Opsahl, T., 2009. Structure and evolution of weighted networks. Queen Mary, University of London.

Opsahl, T., Agneessens, F., Skvoretz, J., 2010. Node centrality in weighted networks: Generalizing degree and shortest paths. Social networks 32, 245-251.

Opsahl, T., Colizza, V., Panzarasa, P., Ramasco, J.J., 2008. Prominence and control: the weighted rich-club effect. Physical review letters 101, 168702.

Orlova, M., 1987. Differences in salinity tolerance of *Dreissena* in the lower Dnieper River and the Dnieper-Bug Liman, In Abstracts of the 8th meeting on the investigation of molluscs. Nauka Press, Leningrad. pp. 261-263.

Orlova, M.I., Khlebovich, V.V., Komendantov, A.Y., 1998. Potential euryhalinity of *Dreissena polymorpha* (Pallas) and *Dreissena bugensis* (Andr.). Russ. J. Aquat. Ecol 7, 17-28.

Orlova, M.I., Therriault, T.W., Antonov, P.I., Shcherbina, G.K., 2005. Invasion ecology of quagga mussels (*Dreissena rostriformis Bugensis*): a review of evolutionary and phylogenetic impacts. Aquatic Ecology 39, 401-418.

Ostrom, E., Burger, J., Field, C.B., Norgaard, R.B., Policansky, D., 1999. Revisiting the commons: local lessons, global challenges. Science 284, 278-282.

Ostroumov, A.A., 1898. Brief report on hydrobiological studies in 1897. Izvestiya Peterburgskoy AN 7, 78-91.

Paletto, A., Hamunen, K., De Meo, I., 2015. Social network analysis to support stakeholder analysis in participatory forest planning. Society & natural resources 28, 1108-1125.

Pandourski, I., 2001. Recherches hydrobiologiques des zones humides de la côte bulgare de la Mer Noire. I. Le lac de Vaja. Riv. Idrobiol 40, 321-334.

Paraschiv, G.-M., Begun, T., Teaca, A., Bucur, M., Tofan, L., 2010a. New data about benthal populations of the Golovita and Zmeica lakes. Journal of Environmental Protection and Ecology 11, 253-260.

Paraschiv, G.-M., Tofan, L., Schroder, V., Bucur, M., 2010b. Analysis of zoobenthal communities from the Razim-sinoe lagoon complex. Journal of Environmental Protection and Ecology 11, 261-268.

Paunović, M., Csányi, B., 2018. Guidance document on Invasive Alien Species (IAS) in the Danube River Basin. Version March 2018. ICPDR – International Commission for the Protection of the Danube River, p. 61 pp.

Pavel, A., Dutui, L., Patriche, N., 2017. The benthic fauna associations from the meanders are of Danube –Sfantu Gheorghe branch, in the period 2016-2017. Geo-Eco-Marina 23/2017, 233-244.

Pavel, A.B., MENABIT, S., Mânzală, D., LUPAȘCU, N., Pop, I.C., Catianis, I., 2019. Benthic community structure characterization of the bed-sediment layer composition in the Musura Bay and Sakhalin area. Geo-eco-marina 25, 15-29.

Pebesma, E.J., 2018. Simple features for R: Standardized support for spatial vector data. R J. 10, 439.

Pimentel, D., Zuniga, R., Morrison, D., 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological economics 52, 273-288.

Policar, T., Bondarenko, V., Bezusyj, O., Stejskal, V., Kristan, J., Malinovskyi, O., Imentai, A., Blecha, M., Pylypenko, Y., 2018. Crayfish in central and southern Ukraine with special focus on populations of indigenous crayfish *Astacus pachypus* (Rathke, 1837) and their conservation needs. Aquatic Conservation: Marine and Freshwater Ecosystems 28, 6-16.

Poorbagher, H., Hosseini, S.V., Hosseini, S.M., Aflaki, F., Regenstein, J.M., 2017. Metal accumulation in Caspian sturgeons with different feeding niches, condition factor, body size and age. Microchemical Journal 132, 43-48.

Popa, O.P., Iorgu, E.I., Krapal, A.M., Kelemen, B.S., Murariu, D., Popa, L.O., 2011. Isolation and characterization of the first microsatellite markers for the endangered relict mussel *Hypanis colorata* (Mollusca: Bivalvia: Cardiidae). International journal of molecular sciences 12, 456-461.

Popa, O.P., Murariu, D., 2009. Freshwater bivalve molluscs invasive in Romania. Biological Invasions: Towards a Synthesis. Neobiota 8, 123-133.

Popa, O.P., Sarkany-Kiss, A., Kelemen, B.S., Iorgu, E.I., Murariu, D., Popa, L.O., 2009. Contributions to the knowledge of the present Limnocardiidae fauna (Mollusca: Bivalvia) from Romania. Travaux du Muséum National d'Histoire Naturelle "Grigore Antipa 52, 7-15.

Prell, C., Hubacek, K., Reed, M., 2009. Stakeholder analysis and social network analysis in natural resource management. Society and Natural Resources 22, 501-518.

Protasov, A., Sylayeva, A., Yarmoshenko, L., Novoselova, T., Primak, A., Savitskiy, A., 2013. Hydrobiological studies on the techno-ecosystem of the Zaporozhye nuclear power station. Hydrobiological Journal 49.

Pullin, A.S., Knight, T.M., 2001. Effectiveness in conservation practice: pointers from medicine and public health. Conservation Biology 15, 50-54.

Pullin, A.S., Knight, T.M., Stone, D.A., Charman, K., 2004. Do conservation managers use scientific evidence to support their decision-making? Biological conservation 119, 245-252.

Rahel, F.J., Olden, J.D., 2008. Assessing the effects of climate change on aquatic invasive species. Conservation Biology 22, 521-533.

Reed, M., Fazey, I., Stringer, L., Raymond, C., Akhtar-Schuster, M., Begni, G., Bigas, H., Brehm, S., Briggs, J., Bryce, R., 2013. Knowledge management for land degradation monitoring and assessment: an analysis of contemporary thinking. Land Degradation & Development 24, 307-322.

Reed, M., Stringer, L., Fazey, I., Evely, A., Kruijsen, J., 2014. Five principles for the practice of knowledge exchange in environmental management. Journal of Environmental Management 146, 337-345.

Reed, M.S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., Prell, C., Quinn, C.H., Stringer, L.C., 2009. Who's in and why? A typology of stakeholder analysis methods for natural resource management. Journal of Environmental Management 90, 1933-1949.

Reid, A.J., Carlson, A.K., Creed, I.F., Eliason, E.J., Gell, P.A., Johnson, P.T., Kidd, K.A., MacCormack, T.J., Olden, J.D., Ormerod, S.J., 2019. Emerging threats and persistent conservation challenges for freshwater biodiversity. Biological Reviews 94, 849-873.

Reid, D.F., Orlova, M.I., 2002. Geological and evolutionary underpinnings for the success of Ponto-Caspian species invasions in the Baltic Sea and North American Great Lakes. Canadian Journal of Fisheries and Aquatic Sciences 59, 1144-1158.

Reinartz, R., Bloesch, J., Sandu, C., Suciu, R., Lenhardt, M., Guti, G., Jahrl, J., 2012. Sturgeon conservation in the Danube River Basin: how to implement the Sturgeon Action Plan 2005, In Proc. 39. IAD conf., Szentendre, Hungary. pp. 21-24.

Ricciardi, A., MacIsaac, H.J., 2000. Recent mass invasion of the North American Great Lakes by Ponto–Caspian species. Trends in Ecology & Evolution 15, 62-65.

Roberge, J.M., Angelstam, P., 2004. Usefulness of the umbrella species concept as a conservation tool. Conservation Biology 18, 76-85.

Romanenko, V., 1987. Priroda Ukrainskoj SSR. Morya i vnutrennie vody. [Nature of the Ukrainian SSR. Seas and inland waters]. Kiev: Naukova dumka, 1-223. [in Russian].

Rosenberg, G., Ludyanskiy, M.L., 1994. A nomenclatural review of *Dreissena* (Bivalvia: Dreissenidae), with identification of the quagga mussel as *Dreissena bugensis*. Canadian Journal of Fisheries and Aquatic Sciences 51, 1474-1484.

Russev, B.K., 1966. The zoobenthos of Danube River between 845th and 375th river kilometer. I. Diversity, distribution and ecology. Izv. Zool. Inst. Muz. Sofia 20, 55-131.

Russev, B.K., Naidenow, W.T., 1978. Limnology of the Bulgarian part of the Danube section. Sofia, Bulgarian Academy of Sciences, 308 pp. [in Bulgarian].

Ryan, G.W., Bernard, H.R., 2003. Techniques to identify themes. Field methods 15, 85-109.

Sala, O.E., Chapin, F.S., Armesto, J.J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L.F., Jackson, R.B., Kinzig, A., 2000. Global biodiversity scenarios for the year 2100. Science 287, 1770-1774.

Salafsky, N., Margoluis, R., Redford, K.H., Robinson, J.G., 2002. Improving the practice of conservation: a conceptual framework and research agenda for conservation science. Conservation Biology 16, 1469-1479.

Sands, A.F., Glöer, P., Gürlek, M.E., Albrecht, C., Neubauer, T.A., 2020. A revision of the extant species of *Theodoxus* (Gastropoda, Neritidae) in Asia, with the description of three new species. Zoosystematics and Evolution 96, 25-66.

Sands, A.F., Sereda, S.V., Stelbrink, B., Neubauer, T.A., Lazarev, S., Wilke, T., Albrecht, C., 2019. Contributions of biogeographical functions to species accumulation may change over time in refugial regions. Journal of Biogeography 46, 1274-1286.

Sandström, A., Carlsson, L., 2008. The performance of policy networks: the relation between network structure and network performance. Policy Studies Journal 36, 497-524.

Sandström, A., Rova, C., 2010. Adaptive co-management networks: a comparative analysis of two fishery conservation areas in Sweden. Ecology and Society 15.

Scarlato, O., Starobogatov, Y.I., 1972a. Class Bivalvia. Guide for identification of the fauna of the Black and Azov Seas. Vol. 3. Freeliving invertebrates. Arthropods (other than crustaceans), mollusks, echinodermatans, chaetognathans, chordatans, 178-270.

Scarlato, O.A., Starobogatov, Y.I., 1972b. Class Bivalvia. Guide for identification of the fauna of the Black and Azov Seas. Vol. 3. Free-living invertebrates. Arthropods (other than crustaceans), mollusks, echinodermatans, chaetognathans, chordatans, 178-270.

Schmutz, S., Sendzimir, J., 2018. Riverine Ecosystem Management: Science for Governing Towards a Sustainable Future. Springer Nature.

Scott, J., 1991. Social network analysis: A handbook.

Semenchenko, V., Son, M., Novitsky, R.A., Kvach, Y., Panov, V.E., 2016. Checklist of non-native benthic macroinvertebrates and fish in the Dnieper River basin. BioInvasions Records 5, 185–187.

Semenchenko, V.P., Son, M.O., Novitsky, R.A., Kvatch, Y.V., Panov, V.E., 2015. Alien macroinvertebrates and fish in the Dnieper River basin. Russian Journal of Bbiological Invasions 6, 51-64.

Shannon, C.E., Weaver, W., 1949. The mathematical theory of communication. Urbana, IL: University of Illinois Press.

Shatova, O., Khmara, T., Slepchuk, K., Yastreb, V., 2009. Interannual variability of salinity in the Dnieper-Bug estuary. Ekologicheskaja Bezopasnost' Pribrezhnoj I Shel'fovoj Zon i Kompleksnoe Ispol'zovanie Resursov Shel'fa 20, 185-194. [in Russian].

Shevtsova, L., 2000. Hydrobiological research of the Dniester: results, problems and Ways of their solving. Hydrobiological Journal 36.

Shiganova, T., 2011. Pontocaspian invasion, In Encyclopedia of Biological Invasions. ed. M.R. Daniel Simberloff, pp. 549-557. University of California Press.

Shokhin, I.V., Nabozhenko, M.V., Sarvilina, S.V., Titova, E.P., 2006. The present-day condition and regularities of the distribution of the bottom communities in Taganrog Bay. Oceanology 46, 401-410.

Simonov, A., Altman, E., 1991. Hydrometeorology and Hydrochemistry of the USSR seas. Vol. IV. The Black Sea. Gidrometeoizdat, Moscow.

Singh, J., 1999. Study on the development of transboundary natural resource management areas in Southern Africa: global review; lessons learned. Biodiversity Support Program, Washington, DC (EUA).

Sitnikova, T.Y., Starobogatov, Y.I., 1999. A new genus of the family Pyrgulidae (Gastropoda, Pectinibranchia) from the fresh water Azov-Black Sea Basin (Related to the problem on Ponto-Caspian species). Зоологический журнал 78.

Skjærseth, J.B., Wettestad, J., 2002. Understanding the effectiveness of EU environmental policy: how can regime analysis contribute? Environmental Politics 11, 99-120.

Son, M.O., 2007a. Invasive molluscs in fresh and brackish waters of the Northern Black Sea Region. Druk, Odessa, 1-131.

Son, M.O., 2007b. Native range of the zebra mussel and quagga mussel and new data on their invasions within the Ponto-Caspian Region. Aquatic Invasions 2, 174-184.

Son, M.O., 2008. Rapid expansion of the New Zealand mud snail *Potamopyrgus antipodarum* (Gray, 1843) in the Azov-Black Sea Region. Aquatic Invasions 3, 335-340.

Son, M.O., 2011a. *Caspia gmelinii*. The IUCN Red List of Threatened Species 2011: e.T155474A4782113. http://dx.doi.org/10.2305/IUCN.UK.2011-1.RLTS.T155474A4782113.en. [accessed on 05 December 2018].

Son, M.O., 2011b. *Caspia knipowitchi*. The IUCN Red List of Threatened Species 2011: e.T156116A4900657. http://dx.doi.org/10.2305/IUCN.UK.2011-1.RLTS.T156116A4900657.en. [accessed on 05 December 2018].

Son, M.O., 2011c. *Caspia makarovi*. The IUCN Red List of Threatened Species 2011: e.T155680A4822960. http://dx.doi.org/10.2305/IUCN.UK.2011-1.RLTS.T155680A4822960.en. [accessed on 05 December 2018].

Son, M.O., 2011d. *Turricaspia chersonica*. The IUCN Red List of Threatened Species 2011: e.T155738A4835520. http://dx.doi.org/10.2305/IUCN.UK.2011-1.RLTS.T155738A4835520.en. Downloaded on 05 December 2018.

Son, M.O., 2011e. *Turricaspia ismailensis*. The IUCN Red List of Threatened Species 2011: e.T155600A4806726. http://dx.doi.org/10.2305/IUCN.UK.2011-1.RLTS.T155600A4806726.en. [accessed on 05 December 2018].

Son, M.O., 2011f. *Turricaspia lincta*. The IUCN Red List of Threatened Species 2011: e.T155627A4811075. http://dx.doi.org/10.2305/IUCN.UK.2011-1.RLTS.T155627A4811075.en. [accessed on 05 December 2018].

Son, M.O., Cioboiu, O., 2011. *Turricaspia ismailensis*. Te IUCN Red List of Treatened Species 2011:e.T155600A4806726. https://doi.org/10.2305/IUCN.UK.2011-1.RLTS.T155600A4806726.en [Accessed on 05 December 2018].

Son, M.O., Novitsky, R.A., Dyadichko, V.G., 2013. Recent state and mechanisms of invasions of exotic Decapods in Ukrainian rivers. Vestnik zoologii 47, 59-64.

Son, M.O., Prokin, A.A., Dubov, P.G., Konopacka, A., Grabowski, M., MacNeil, C., Panov, V.E., 2020. Caspian invaders vs. Ponto-Caspian locals – range expansion of invasive macroinvertebrates from the Volga Basin results in high biological pollution of the Lower Don River. Management of Biological Invasions 11, 178-200.

Sowinsky, V.K., 1904. An introduction to the study of the fauna of the Ponto-Caspian-Aral marine basin, considered as independent zoogeographical province. Zapiski Kievskogo obschestva estestvoispytatelej 18, 1-487. [in Russian].

Stanica, A., Dan, S., Ungureanu, V.G., 2007. Coastal changes at the Sulina mouth of the Danube River as a result of human activities. Marine pollution bulletin 55, 555-563.

Stark, I., 1960. Bentos Taganrogskogo zaliva. [Benthos of the Taganrog Bay] Trudy Azovskogo Nauchno-Issledovatel'skogo Instituta Rybnogo Khozyaystva (AZNIIRKH) 1, 210-216. [in Russian].

Starobogatov, Y.I., 1970. Molluscan fauna and zoogeographical division of the continental waterbodies of the globe. Nauka, Leningrad.

Stoica, C., Gheorghe, S., Petre, J., Lucaciu, I., Nita-Lazar, M., 2014. Tools for assessing Danube Delta systems with macro invertebrates. Environmental Engineering & Management Journal (EEMJ) 13.

Stoica, C., Lucaciu, I., Nicolau, M., Vosniakos, F., 2012. Monitoring the ecological diversity of the aquatic Danube Delta systems in terms of spatial-temporal relationship.

Stoica, C., Stanescu, E., Lucaciu, I., Gheorghe, S., Nicolau, M., 2013. Influence of global change on biological assemblages in the Danube Delta.

Stork, D., Richards, W.D., 1992. Nonrespondents in communication network studies: Problems and possibilities. Group & Organization Management 17, 193-209.

Strat, D., Mihăilescu, S., Sandu, C.S., Sahlean, T.C., 2017. Conservation status of species and habitats of community importance on the Romanian Black Sea coast, In Sabotinov N.(Ed-in-Chief), Book of Abstracts, First European Symposium Research, conservation and management of biodiversity in the European seashores-RCMBES. p. 69.

Stringer, L.C., Dougill, A.J., 2013. Channelling science into policy: Enabling best practices from research on land degradation and sustainable land management in dryland Africa. Journal of Environmental Management 114, 328-335.

Stringer, L.C., Paavola, J., 2013. Participation in environmental conservation and protected area management in Romania: a review of three case studies. Environmental Conservation 40, 138-146.

Sutherland, W.J., Pullin, A.S., Dolman, P.M., Knight, T.M., 2004. The need for evidence-based conservation. Trends in Ecology & Evolution 19, 305-308.

Syomin, V., Kolyuchkina, G., Grigorenko, K., Savikin, A., Oleinikov, E., Moskovets, A., Glebova, M., 2020. Changes in the bottom fauna of the Sea of Azov under the conditions of abnormal salinization, In Proceedings of the VIII International Scientific and Practical Conference "Marine Research and Education (MARESEDU-2019)" Volume II (III): [collection]. Tver: LLC "PolyPRESS". pp. 490-493.

Syomin, V., Sikorski, A., Bastrop, R., Köhler, N., Stradomsky, B., Fomina, E., Matishov, D., 2017. The invasion of the genus *Marenzelleria* (Polychaeta: Spionidae) into the Don River mouth and the Taganrog Bay: morphological and genetic study. Journal of the Marine Biological Association of the United Kingdom 97, 975-984.

Szarek-Mason, P., 2010. The European Union's fight against corruption: the evolving policy towards Member States and candidate countries. Cambridge University Press.

Teampău, P., 2020. Trouble in paradise: Competing discourses and complex governance in the Romanian danube delta. Marine Policy 112, 103522.

Teodorescu-Leonte, R., 1966. Rezultatele Cercetărilor asupra bazei trofice a complexului Razelm şi perspectivele producţiei piscicole din acest complex prin dirijarea popularii. Bul. Inst. Cerc. Project. Piscicole 25, 38-47.

Teodorescu-Leonte, R., 1977. Le complexe Razelm–Sinoie un sistem typiquement saumatre. MAMBO Constanta. In „Biologie des eauxsaumatre de la Mer Noire", 213-234.

Teodorescu-Leonte, R., Leonte, V., 1969. Variation des biocenoses benthiques du Complexe Razelm, en fonction des conditions de salinité, In Rapports de la Commission Internationale pour l'Étude Scientifique de la Mer Méditerranée. CIESM, Monaco 19 (5).

Teodorescu-Leonte, R., Leonte, V., Dumitru, M., Soileanu, B., 1956. Observations on the Razelm–Sinoie complex during 1950–1952. The Annals of the Romanian Research Institute of Fisheries 1, 1-50.

The Government of Romania, 2014. National strategy and Action plan for biodiversity conservation, Romania.

The World Bank study team, 2014. Draft Danube Delta Integrated Sustainable Development Strategy (2030), Report 2.2.

The World Bank study team, 2015. Report on Strategic Environmental Assessment in Danube Delta.

Therriault, T.W., Docker, M.F., Orlova, M.I., Heath, D.D., MacIsaac, H.J., 2004. Molecular resolution of the family Dreissenidae (Mollusca: Bivalvia) with emphasis on Ponto-Caspian species, including first report of *Mytilopsis leucophaeata* in the Black Sea basin. Molecular phylogenetics and evolution 30, 479-489.

Trichkova, T., 2007. Zoobenthos of non-lotic Bulgarian wetlands. Pp. 185–195. In: Michev, T., & Stoyneva, M. (Eds.), Inventory of Bulgarian Wetlands and their Biodiversity. Part 1: Non-Lotic Wetlands. Sofia: Publishing House Elsi-M, 364 pp.

Trichkova, T., Todorov, M., Georgiev, D., Hubenov, Z., 2019. Species composition and distribution of Mollusca (Gastropoda and Bivalvia) in the Bulgarian Sector of the Danube River and the adjacent wetlands. Chapter 2. Pp. 29–71. In: Shurulinkov, P. S., Hubenov, Z., Beshkov, S., & Popgeorgiev, G. (Eds.), Biodiversity of the Bulgarian-Romanian Section of the Lower Danube. New York: Nova Science Publishers.

Tudor, M.-I., Tudor, M., David, C., Teodorof, L., Tudor, D., Ibram, O., 2006. Heavy metals concentrations in aquatic environment and living organisms in the Danube Delta, Romania, In Chemicals as Intentional and Accidental Global Environmental Threats. pp. 435-442. Springer.

UNECE, U.N.E.C.f.E., 1991. Convention on Environmental Impact Assessment in a Transboundary Context. U.N.T.S. vol. 1989, p. 309. UNECE Geneva.

UNESCO, 1971. Convention on Wetlands of International Importance Especially as Waterfowl Habitat. U.N.T.S. vol. 996, p. 245.

UNESCO, 1972. Convention for the Protection of the World Cultural and Natural Heritage. U.N.T.S. vol. 1037.

Vadineanu, A., Cristofor, S., Ignat, G., Ciubuc, C., Rîşnoveanu, G., Bodescu, F., Botnariuc, N., 2000. Structural and functional changes within the benthic communities of Danube Delta lakes. Internationale Vereinigung für theoretische und angewandte Limnologie: Verhandlungen 27, 2571-2576.

Valkanov, A., 1941. Our coastal lakes and marshes in Dobrudzha. Fishery Review [Ribarski Pregled] 6. [in Bulgarian].

Valkanov, A., 1957a. Katalog unserer Schwarzmeerfauna. Arbeiten aus der Biologischen Meeresstation in Varna 19, 1–62. [in Bulgarian].

Valkanov, A., 1957b. Katalog unserer Schwarzmeerfauna. Arbeiten aus der Biologischen Meeresstation in Varna, Bulgarien, 19: 1-62. 19, 1-62. [in Bulgarian, German summary].

Varbanov, M., 2002. Lakes and marshes. Pp. 237–242. In: Kopralev, I., Yordanova, M., & Mladenov, C. (Eds.), Geography of Bulgaria. Physical Geography. Socio-Economic Geography. Sofia: ForCom Publishing House, 760 pp.

Varnosfaderany, M.N., Bakhtiari, A.R., Gu, Z., Chu, G., 2015. Distribution and characteristic of PAHs in sediments from the southwest Caspian Sea, Guilan Province, Iran. Water Science and Technology 71, 1587-1596.

Vasile, V., 2013. Romania: A country under permanent public sector reform. Public Sector Shock, 449.

Vassilev, M., 2006. Lower Danube–the last refuge for surviving of sturgeon fishes in the Black Sea Region, In Water Observation and Information System for Decision Support. Conference Proceedings, Balwois, Ohrid, Macedonia [http://balwois. org–Accessed on 15th April 2009].

Velde, S.v.d., Jorissen, E.L., Neubauer, T.A., Radan, S., Pavel, A.B., Stoica, M., Van Baak, C.G., Martínez Gándara, A., Popa, L., Stigter, H.d., 2019. A conservation palaeobiological approach to assess faunal response of threatened biota under natural and anthropogenic environmental change. Biogeosciences 16, 2423-2442.

Verissimo, D., MacMillan, D.C., Smith, R.J., 2011. Toward a systematic approach for identifying conservation flagships. Conservation Letters 4, 1-8.

Vidinova, Y., Tyufekchieva, V., Varadinova, E., Stoichev, S., Kenderov, L., Dedov, I., Uzunov, Y., 2016. Taxonomic list of benthic macroinvertebrate communities of inland standing water bodies in Bulgaria. Acta zoologica bulgarica 68, 147-158.

Vinogradov, A.K., Bogatova, Y.I., Sinegub, I.A., 2014. Ecology of the sea ports (Black Sea and Azov Sea basin). Astroprint, Odessa, 568 pp.

Vishnevetskiy, V., Popruzhniy, V., 2018. Some features of the ecological situation of The Miussky estuary. Engineering Journal of Don 4.

Visseren-Hamakers, I.J., 2015. Integrative environmental governance: enhancing governance in the era of synergies. Current Opinion in Environmental Sustainability 14, 136-143.

Visseren-Hamakers, I.J., 2018. Integrative Governance: The relationships between governance instruments taking center stage. SAGE Publications Sage UK: London, England.

Vitousek, P., 1997. Human domination of earth ecosystems (vol 277, Pg 494, 1997). Science 278, 21-21.

Vorobyev, V.P., 1949. Benthos of the Sea of Azov. Proceedings of the Azov-Black Sea Institute of Marine Fisheries and Oceanography 13, 1-196.

Waldron, A., Mooers, A.O., Miller, D.C., Nibbelink, N., Redding, D., Kuhn, T.S., Roberts, J.T., Gittleman, J.L., 2013. Targeting global conservation funding to limit immediate biodiversity declines. Proceedings of the National Academy of Sciences 110, 12144-12148.

Wasserman, S., Faust, K., 1994. Social network analysis: Methods and applications. Cambridge university press.

Weimann, G., 1982. On the importance of marginality: One more step into the two-step flow of communication. American Sociological Review, 764-773.

Wesselingh, F., Gogaladze, A., van Impelen, C., Raes, N., 2016. PRIDE Outreach Policy Plan. Naturalis Biodiversity Center, Leiden, the Netherlands.

Wesselingh, F.P., Neubauer, T.A., Anistratenko, V.V., Vinarski, M.V., Yanina, T., ter Poorten, J.J., Kijashko, P., Albrecht, C., Anistratenko, O.Y., D'Hont, A., Frolov, P., Gandara, A.M., Gittenberger, A., Gogaladze, A., Karpinsky, M., Lattuada, M., Popa, L., Sands, A.F., Velde, S.v.d., Vandendorpe, J., Wilke, T., 2019. Mollusc species from the Pontocaspian region – an expert opinion list. ZooKeys 827, 31-124.

Wesselink, A., Paavola, J., Fritsch, O., Renn, O., 2011. Rationales for public participation in environmental policy and governance: practitioners' perspectives. Environment and Planning A 43, 2688-2704.

Wilke, T., Albrecht, C., Anistratenko, V.V., Şahin, S.K., Yildirim, M.Z., 2007. Testing biogeographical hypotheses in space and time: faunal relationships of the putative ancient Lake Egirdir in Asia Minor. Journal of Biogeography 34, 1807-1821.

Wohlberedt, O., 1911. Zur Molluskenfauna von Bulgarien. Abhandlungen der Naturforschenden Gesellschaft zu Gorlitz 27, 167-234.

World Economic Forum, 2020. The Global Risks Report, ed. 15.

WWF, 2007. Danube Delta: a natural gateway to Europe Ecology and Economy in Harmony, ed. D.-C.P. WWF International, Vienna.

WWF, 2020. Living Planet Report 2020 - Bending the curve of biodiversity loss. Almond, R.E.A., Grooten M. and Petersen, T. (Eds). WWF, Gland, Switzerland.

Yamaki, K., 2017. Applying social network analysis to stakeholder analysis in Japan's natural resource governance: two endangered species conservation activity cases. Journal of Forest Research 22, 83-90.

Zakonnov, V., Timchenko, V., Zakonnova, A., 2019. Silt Accumulation in Large Plain Reservoirs. Hydrobiological Journal 55, 93-102.

Zenkevitch, L., 1963. Biology of the Seas of the USSR. New York: Interscience Publishers.

Zhadin, V., 1931. Die Mollusken des Bassins des südlichen Bugs. Trudy Prirodnico-Technicnogo Viddilu 13, 13–53.

Zhadin, V., 1952. Mollyuski presnykh i solonovatykh vod SSSR. Izdatel'stvo Akademii Nauk SSSR, Moskva, Leningrad, 376 pp.

Zhidkova, A.Y., Gusakova, N.V., Petrov, V.V., 2018. The Research of Waters Eutrophication of the Gulf of Taganrog of the Sea of Azov For Ecological Monitoring Purposes. Exploration and Monitoring of the Continental Shelf Underwater Environment 235, 235.

Zhivoglyadova, L., Revkov, N., Kovalev, E., 2018. Extension of the bivalve *Corbicula fluminea* (O. F. Müller, 1774) areal in the Lower Don river system. Marine Biological Journal 3, 73-75. [in Russian].

Zhivoglyadova, L.A., Frolenko, L.N., 2017. Kharakteristika kormovoi bazi rib-bentofagov nijnego Dona [Characteristics of the food supply for benthophagous fish in the Lower Don]. Izvestiya TINRO (Transactions of the Pacific Research Institute of Fisheries and Oceanography) 189. [in Russian].

Zhulidov, A.V., Kozhara, A.V., van der Velde, G., Leuven, R.S., Son, M.O., Gurtovaya, T.Y., Zhulidov, D.A., Nalepa, T.F., 2018. Status of the invasive brackish water bivalve *Mytilopsis leucophaeata* (Conrad, 1831)(Dreissenidae) in the Ponto-Caspian region. BioInvasions Records 7, 111–120.

Zhulidov, A.V., Kozhara, A.V., van der Velde, G., Leuven, R.S., Zhulidov, D.A., Gurtovaya, T.Y., Nalepa, T.F., Santiago-Fandino, V.J., 2015. New records from the Ponto-Azov region demonstrate the invasive potential of *Mytilopsis leucophaeata* (Conrad, 1831)(Bivalvia: Dreissenidae). Journal of Molluscan Studies 81, 412-416.


0
ROMÂNIA
Km. 0
BUCUREȘTI
Piața
Universității
LIBERTATE
ZONA LIBERA
Mai bine haimana,
Mai bine huligan,
decât dictator
Mai bine golan,
decât activist
Mai bine mort,
decât comunist
CRISTIAN
PAȚURCĂ
1964-2011

I

General Summary

Fresh water and brackish water ecosystems are arguably the most vulnerable ecosystems on earth, due to concentrated human developments in and around them. The Pontocaspian (PC) region located at the border of Europe and Asia contains a variety of brackish water ecosystems and unique inhabitants, the PC biota. Globally, biodiversity levels in brackish water ecosystems are low due to the lack of longevity of these dynamic habitats. However, PC biota contains many unique endemic species resulting in biodiversity hotspot in brackish settings in the PC region. Current status and trends in PC biodiversity are poorly known, however severe deterioration of PC habitats is evident in the Black Sea and Caspian Sea Basins. Furthermore, knowledge on current socio-political systems that govern the PC biodiversity management and conservation is lacking. Finally, we have little understanding on the awareness of PC biodiversity by different stakeholders. This does affect PC biodiversity conservation, but we don't know how and how much.

This thesis aims to support an effective PC biodiversity conservation regime. I use the Black Sea Basin (BSB), including the Sea of Azov as a study system and outline current status and trends in PC biodiversity and assess direct anthropogenic drivers of the PC biodiversity change. Furthermore, I investigate how legal framework and stakeholder landscape are organized to deal with PC biodiversity conservation and what major obstacles are to establish effective conservation regimes.

PC biodiversity is severely declining as a result of human action. Identified direct drivers of decline include a) damming of rivers, b) habitat modifications affecting salinity gradients, c) pollution and eutrophication, d) invasive alien species and e) climate change. Indirect drivers of PC biodiversity decline include current legal arrangements; institutional design of environmental stakeholder organizations and the governance systems, as well as the additional social variables such as funding availability for PC biodiversity conservation, institutional stability and the recognition of the need for PC biodiversity conservation. Largely, conservation measures to address PC biodiversity crisis are hampered by a) lack of knowledge on different aspects of PC biota by the public, policy makers, conservation practitioners and scientists; and b) complex socio-political landscape within which the PC biodiversity management is embedded. Specifically, knowledge on PC species identities and taxonomy, distribution, abundances, population trends, life history traits, functional roles and sensitivity to changes in the environment need to be improved. Such knowledge is urgent for informing PC biodiversity conservation planning and the relevant policy and for incentivizing conservation practitioners to participate in PC biodiversity related conservation actions.

Threatened PC biota can greatly benefit from inclusion in the existing projects, initiatives and collaboration frameworks in the Black Sea Basin. Recent developments in molecular techniques, e.g., environmental DNA (eDNA) approaches can elucidate aspects of PC biodiversity such as the trends in rare species with patchy occurrences. Molecular techniques can also greatly benefit and inform the traditional morphology-based species recognition and are absolutely necessary for solving prevailing taxonomic uncertainties. Sustainable management of the BSB, including the coastal riverine ecosystems, has a high priority for the European Union and the Black Sea neighboring countries. Many of the initiatives and projects recognize major knowledge gaps in the BSB region, habitats and biota. They intend to improve the scientific basis to understand vulnerability of these habitats. This landscape of ongoing, large-scale collaboration frameworks provides an unprecedented opportunity for integrating the assessment of PC biodiversity on national and cross-country scales. Recognition of conservation needs of Pontocaspian taxa, combined with improved financial and legal conditions are necessary preconditions for such integration initiatives.

II

Samenvatting

Zoetwater- en brakwaterecosystemen behoren tot de meest kwetsbare ecosystemen op aarde, veelal vanwege de grootschalige menselijk bewoning en activiteiten. De Zwarte Zee- Kaspische Zee (Pontokaspische: PK) regio op de grens van Europa en Azië omvat een verscheidenheid aan zoet- en brakwater ecosystemen met een unieke biota, de zogenaamde Pontokaspische biota. Globaal is de soortenrijkdom in brakwaterecosystemen laag vanwege de gemiddeld korte levensduur van deze dynamische habitats. Pontokaspische biota bevatten echter veel endemische soorten, waardoor dergelijke brakwater milieus in de regio biodiversiteit hotspots vormen. De precieze status van PK soorten zijn onvoldoende bekend, maar de ernstige achteruitgang van habitats en biota in de Zwarte Zee en de Kaspische Zee en aanliggende gebieden is overduidelijk. Daarnaast ontbreekt het aan kennis over de huidige sociaal-politieke systemen die het beheer en behoud van de PK biodiversiteit mogelijk zouden kunnen maken. Ten slotte weten we nog maar weinig over het bewustzijn over de PK biodiversiteit van de verschillende belanghebbenden. Dit heeft invloed op effectief management van PK biodiversiteit, al weten we niet hoe.

Dit proefschrift heeft tot doel het systeem van Pontokaspische biodiversiteitsbeheer en behoud te verkennen en ondersteunen. Ik gebruik het Zwarte Zeebekken, inclusief de Zee van Azov, als locatie van mijn studie en schets daar de huidige status en trends in de PK biodiversiteit. Ik beoordeel hoe menselijk handelen direct effect heeft op PK biodiversiteit. Verder onderzoek ik hoe het wettelijk kader en het (institutioneel) landschap van belanghebbenden zijn georganiseerd en hoe zij omgaan met het behoud van PK biodiversiteit en welke obstakels er bestaan om effectieve beschermingsregimes op te zetten.

De Pontokaspische biodiversiteit neemt ernstig af als gevolg van menselijk handelen. Geïdentificeerde directe oorzaken van achteruitgang zijn onder meer a) afdamming van rivieren, b) aanpassingen van habitats die invloed hebben op saliniteitsgradiënten, c) vervuiling en eutrofiëring, d) invasieve uitheemse soorten en e) klimaatverandering. Indirecte oorzaken van de achteruitgang van de PK biodiversiteit omvatten de huidige wettelijke regelingen; het institutioneel ontwerp van belanghebbende organisaties op milieugebied en de bestuurssystemen, evenals de aanvullende sociale variabelen zoals de beschikbaarheid van financiering voor het behoud van de PK biodiversiteit, de institutionele stabiliteit en erkenning van de noodzaak tot het beschermen van PK biodiversiteit. Instandhoudingsmaatregelen worden grotendeels belemmerd door a) een gebrek aan kennis over de PK biota onder het algemeen publiek, beleidsmakers, natuurbeschermers en wetenschappers; en b) een complex sociaal-politiek landschap waarin het PK biodiversiteitsbeheer is ingebed. Specifiek moet de kennis over soorten, verspreiding, populatietrends, autecologie, functionele rollen en gevoeligheid voor veranderingen in de omgeving worden verbeterd. Dergelijke kennis is dringend nodig voor het ontwikkelen van relevante beleid voor het behoud van PK biodiversiteit, en voor het vergroten van de rol van natuurbeschermers.

Bedreigde PK-biota kunnen enorm profiteren van opname in de bestaande projecten, initiatieven en samenwerkingskaders in het Zwarte Zeebekken. Recente ontwikkelingen in moleculaire technieken, bijv. ”environmental”-DNA (eDNA), kunnen aspecten van PK-biodiversiteit ophelderen, zoals de trends in zeldzame soorten met fragmentarische voorkomens. Moleculaire technieken zijn een belangrijke toevoeging op de traditionele, op morfologie gebaseerde soortherkenning en zijn noodzakelijk voor het oplossen van heersende taxonomische onzekerheden. Duurzaam beheer van het Zwarte Zeebekken, inclusief de rivierecosystemen langs de kust, heeft een hoge prioriteit voor de Europese Unie en de landen aan de Zwarte Zee. Veel van de initiatieven en projecten erkennen grote kennislacunes in de regio, habitats en biota. Ze zijn van plan de wetenschappelijke basis te verbeteren om de kwetsbaarheid van deze habitats te begrijpen. Dit landschap van doorlopende, grootschalige samenwerkingskaders biedt een ongekende kans om de beoordeling van PK-biodiversiteit op nationale schaal en op grensoverschrijdende schaal te integreren. Erkenning van de instandhoudingsbehoeften van PK taxa, gecombineerd met verbeterde financiële en juridische voorwaarden, zijn noodzakelijke voorwaarden voor dergelijke integratie-initiatieven.

Translated by S. van de Velde

III

Аннотация

Пресноводные и солоноватоводные экосистемы являются одними из самых уязвимых на Земле из-за большого сосредоточения человеческой деятельности вокруг них. Понтокаспийский (ПК) регион, охватывающий бассейны Черного и Каспийского морей и расположенный на границе Европы и Азии, содержит множество солоноватоводных экосистем и уникальных обитателей – Понто-Каспийская биота. В глобальном масштабе, уровни биоразнообразия в солоноватоводных экосистемах низки из-за недолговечности этих динамичных местообитаний. Однако содержание в Понто-Каспийской биоте множества уникальных эндемичных видов делает регион Черного и Каспийского морей очагом солоноватоводного биоразнообразия. Текущее состояние и тенденции в биоразнообразии Понто-Каспия плохо изучены, несмотря на серьезное ухудшение экологической обстановки в регионе. Кроме того, отсутствуют знания о текущих социально-политических организациях, которые занимаются управлением и сохранением Понто-Каспийского биоразнообразия. Наконец, остается непонтным, насколько разные заинтересованные стороны осведомлены о биоразнообразии ПК. Все эти факты, в совокупости, оказывают влияние на сохранение Понто-Каспийски экосистем, но мы не знаем, насколько сильно и как.

Эта диссертация направлена на поддержку эффективного режима сохранения биоразнообразия ПК. Я использую бассейн Черного моря (ЧБ), включая Азовское море, в качестве системы исследования и описываю текущее состояние и тенденции в биоразнообразии ПК, а также оцениваю прямо влияющие на него антропогенные факторы. Кроме того, в данной работе исследуются организация правовой базы и возможности заинтересованных сторон для решения проблемы сохранения биоразнообразия ПК, а также описываются основные препятствия на пути создания эффективного режима сохранения.

Биоразнообразие ПК резко сокращается в результате деятельности человека. Выявленные прямые факторы сокращения включают: а) перекрытие рек; б) изменение среды обитания, влияющие на градиенты солености; в) загрязнение и эвтрофикация; г) инвазивные чужеродные виды; д) изменение климата. Среди косвенных факторов снижения биоразнообразия ПК можно отметить несовершенство существующей правовой базы и институциональный дизайна экологических организаций и систем управления, а также дополнительные социальные переменные, такие как доступность финансирования для сохранения биоразнообразия ПК, институциональная стабильность и признание необходимости сохранения биоразнообразия ПК. В основном, меры по сохранению, направленные на преодоление кризиса биоразнообразия ПК, затруднены из-за: а) недостатка знаний о различных аспектах биоты ПК у общественности, политиков, специалистов по охране природы и ученых и б) сложный социально-политический ландшафт, в который встроено управление биоразнообразием ПК. В частности, необходимо улучшить знания об идентичности и таксономии видов ПК, распространении, численности, тенденциях популяций, особенностях жизненного цикла, функциональных ролях и чувствительности к изменениям в окружающей среде. Такие знания необходимы при разработке плана и соответствующей политики по сохранению биоразнообразия ПК, а также для стимулирования практикующих экологов к участию в действиях по сохранению биоразнообразия Понто-Каспия.

Находящаяся под угрозой Понто-Каспийская биота может получить большую выгоду от включения в существующие проекты, инициативы и механизмы сотрудничества в бассейне Черного моря. Недавние разработки в области молекулярных методов, например, подходы к использованию ДНК окружающей среды (eDNA), могут пролить свет на такие аспекты биоразнообразия ПК, как динамика редких видов с ограниченным распространением. Молекулярные методы также могут внести большой вклад в решение проблем таксономии и определения видов, которые традиционно основываются на морфологиии таксонов. Устойчивое управление черноморским бассейном, включая прибрежные речные экосистемы, имеет высокий приоритет для Европейского Союза и черноморских стран. Многие инициативы и проекты признают серьезные пробелы в знаниях о регионе ЧБ, местообитаниях и биоте. Они намерены улучшить научную основу для понимания уязвимости этих местообитаний. Эта совокупность структур с крупномасштабным сотрудничеством предоставляет беспрецедентную возможность для интеграции оценки биоразнообразия ПК в национальном и межгосударственном масштабах. Признание потребностей в сохранении понтокаспийских таксонов в сочетании с улучшенными финансовыми и правовыми условиями являются необходимыми предпосылками для таких интеграционных инициатив.

Translated by Sergei Lazarev

Naturalis Biodiversity Center

Universiteit Leiden
The Netherlands