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Disclaimer

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List of abbreviations

AAC: Adriatic Advisory Committee
AF - Application Form
AP - Associated Partner
AQ - Aquaculture
AS - Adriatic Sea
AO – Associated Organization
CM - Communication Manager
FM - Financial Manager
IAS - Invasive Alien Species
PSC - Project Steering Committee
LPMT – Lead Partner Project Management Team
MoU – Memorandum of Understanding
PCL - Project Communication Leader
PCM - Project Communication Manager
PFM - Project Financial Manager
PM - Project Manager
PP - Project Partner
RP - Reporting Period
QM - Quality Manager
QP - Quality Plan
SSF - Small Scale Fisheries
WP - Working Package
WPL - Work Package Leaders

Project executive summary

BRAVE is a European Territory Cooperation project funded under the 2nd call for Operations of Strategic Importance of the Interreg VIA Italy-Croatia 2021 – 2027 Programme, Priority 2 "Green and resilient shared environment", Specific Objective 2.2 "Enhancing protection and preservation of nature, biodiversity and green infrastructure, including in urban areas, and reducing all forms of pollution". The project duration is 36 months (01.07.2025-30.06.2028) and the overall objective is to enhance species knowledge by ensuring ecosystemic functionality and tackling biodiversity loss in the Adriatic Sea (AS), through monitoring activities, creation of a smart digital platform and innovative planning in response to environmental change.

BRAVE intends to address the following common challenges that can have strong environmental (competition for resources and substitution of native species), social (conversion of work activities and change in citizens' habits) and economic (fisheries and aquaculture sectors) impacts:

Invasive Alien Species (IAS): The proliferation of non-native species poses a significant threat to ecosystems, human health, and economic viability

Biodiversity Loss: The AS is experiencing a decline in biodiversity due to IAS, climate and environmental change, habitat degradation, pollution, and overexploitation

Data Fragmentation: Inconsistencies in existing databases hinder our ability to assess the overall health of the AS

Data Communication Gap: Difficulties in dissemination and use of environmental data by non-experts or those involved in monitoring and managing environmental data, increased by the challenging coordination between public bodies, research centres, business and citizens.

To achieve the goals, 13 project partners from the Italian and Adriatic Regions and 2 associated organizations will jointly implement strategic and operational actions

Introduction

Work Package 1 (WP1) defines the knowledge governance architecture of the BRAVE project. It establishes the strategic framework through which environmental information generated across the Adriatic Sea basin is organised, interpreted and mobilised to support coordinated cross-border action.

The Adriatic Sea is characterised by interconnected ecological systems and cumulative pressures that transcend administrative boundaries. However, environmental data are typically collected, managed and reported within national or sector-specific structures. WP1 addresses this structural fragmentation by creating the conditions for a shared transnational understanding of environmental status, trends and risks.

Rather than focusing solely on technical integration, WP1 strengthens the governance dimension of environmental knowledge. It promotes coherence between freshwater and marine assessments, reinforces alignment with EU regulatory frameworks such as the Water Framework Directive and the Marine Strategy Framework Directive, and enhances the science–policy interface across the project area.

A central component of WP1 is the development of the BRAVE Smart Digital Platform, conceived as a shared analytical environment supporting data visualisation, comparison and interpretation. However, WP1 extends beyond the creation of a digital tool. It ensures that environmental knowledge generated through pilot actions and existing monitoring systems contributes to long-term cooperation, adaptive management and evidence-based policy processes at Adriatic scale.

Through this strategic orientation, WP1 provides the enabling framework that connects data generation, analytical tools and mitigation measures, ultimately supporting the resilience and adaptive capacity of the Adriatic Sea ecosystem.

Within the broader framework established by WP1, Activity 1.1 focuses on the definition and validation of common data collection protocols supporting the development and effective functioning of the BRAVE Smart Digital Platform.

The activity responds to the need for harmonised, interoperable and operationally feasible data collection approaches capable of integrating traditions. By establishing

minimum data requirements, shared structures and standardisation principles, Action 1.1 enables diverse data heterogeneous datasets generated across different sectors, environmental contexts and monitoring streams—ranging from chemical status monitoring to biological, habitat-based and risk-oriented observations—to be structured in a comparable and compatible manner.

The protocol deliverables developed under this activity provide a shared methodological framework for data collection, ensuring consistency across pilot actions while allowing partner-specific adaptations reflecting different environmental settings and technical capacities. Each protocol defines essential variables, metadata standards and validation procedures necessary to ensure reliability, traceability and quality control of the collected information.

Validation is carried out through pilot actions implemented under real-world operational conditions, involving different types of operators, technologies and environmental contexts. This process ensures that the resulting framework functions not only as a project-specific instrument, but as a transferable and adaptable reference applicable to other Adriatic contexts beyond the pilot phase.

In this way, Action 1.1 operationalises the strategic objectives of WP1, translating the project's governance vision into concrete, tested methodologies that support transnational environmental assessment and coordinated mitigation measures.

- To collect harmonized and strategically relevant data within the defined scope of the project area.
- To provide operational inputs supporting the development and implementation of the project platform.
- To validate the proposed protocols through pilot actions and platform simulation exercises.

Objectives of the Data Collection standard 4

The Data Collection Standards 4 final objective is to develop a scalable and transferable framework that can be extended to larger areas across the Adriatic Sea, supporting coordinated monitoring and management of alien species and their impacts.

Partner-specific objectives:

Friuli-Venezia Giulia Autonomous region (PP2): to characterize the distribution and abundance of the native lagoon cockle and to assess its interactions with the introduced Manila clam, within a context strongly influenced by predation pressure from the blue crab.

Emilia-Romagna region (PP3): to develop a practical and adaptable framework focused on the blue crab (*Callinectes sapidus*), based on the analysis of environmental drivers, monitoring data, and site-specific dynamics, supporting adaptive and evidence-based management of its spread and ecological impacts in the Adriatic Sea.

Confcooperative Veneto (PP6): to identify environmental patterns and conditions that favour the establishment and proliferation of non-indigenous species, with particular reference to the blue crab, supporting early detection and risk assessment.

Istria County (PP7): to identify and prioritise coastal areas in the Istria Region at risk from blue crab (Callinectes sapidus) based on environmental drivers, and to support the development of practical, site-specific monitoring and mitigation approaches through the integration of spatial data, field observations and stakeholder knowledge.

Zadar County (PP9): to assess the potential role of Croatian regulatory frameworks and marine protected areas (MPAs) in preventing and/or mitigating the spread of undesirable species (locally absent, non-native, and invasive) in the Adriatic Sea.

Development Agency of Šibenik-Knin County (PP12): to establish a standardized framework for monitoring and early detection of non-indigenous species (NIS) in the Krka River estuary.

Dubrovnik and Neretva County (PP13): to contribute to a common framework for biodiversity protection against alien species by developing economically feasible measures to mitigate the spread of non-native species associated with aquaculture activities at the farm level.

Importance of the Data collection standard 4 for the BRAVE Project

PP2 will investigate the interactions between the native lagoon cockle (*Cerastoderma glaucum*) and the introduced Manila clam (*Ruditapes philippinarum*) in the Marano Lagoon, within a context characterized by high predation pressure from the blue crab (*Callinectes sapidus*).

The activity aims to assess species distribution, relative abundance, and potential competitive or trophic interactions, providing a better understanding of how invasive predation pressure may influence local bivalve communities and associated traditional harvesting activities.

PP3 activity will focus on analysing the interconnections between biodiversity loss, alien species dynamics, and environmental conditions in the Adriatic Sea, with particular emphasis on the drivers facilitating the spread of invasive species such as the blue crab (*Callinectes sapidus*).

As a semi-enclosed basin, the Adriatic Sea is especially sensitive to climate change, anthropogenic pressures, and habitat modifications, all of which can accelerate biodiversity loss and favour biological invasions. The activity will implement an integrated and harmonized assessment of key environmental drivers, including temperature, salinity gradients, nutrient inputs, oxygen levels, hydrodynamics, and human activities, to better understand their role in shaping invasion processes.

Special attention will be given to the ecological behaviour, spatial and temporal distribution, and ecosystem impacts of the blue crab as a model invasive species. The objective is to identify high-risk areas and critical environmental conditions associated with species establishment and spread, while improving the understanding of links between environmental degradation and invasion success.

The results will support the development of evidence-based management strategies for fisheries, aquaculture, and coastal ecosystems, and will contribute to transboundary cooperation, shared monitoring approaches, and policy-oriented recommendations.

For **PP6**, this activity focuses on the development and validation of a participatory data collection framework to support the monitoring of environmental parameters related to the spread of invasive alien species (IAS), particularly in coastal and lagoon productive areas.

The activity builds on pilot actions by translating field observations and operational inputs from fisheries and aquaculture operators into standardized and structured datasets. The active involvement of cooperatives and local stakeholders is a key component, enabling the integration of practice-based knowledge with scientific monitoring approaches, while ensuring data quality and consistency.

Priority is given to simple, cost-effective, and replicable data collection methods that can be easily adopted by operators. At the same time, the framework ensures interoperability

with the BRAVE Smart Digital Platform and contributes to long-term monitoring and cross-border harmonization.

For **PP7**, Activity 1.1.6 focuses on the identification and monitoring of key environmental parameters influencing the distribution and spread of invasive alien species, with particular emphasis on the blue crab (*Callinectes sapidus*) in coastal and transitional ecosystems of the Istrian region.

The activity aims to establish a structured and operational framework for linking environmental conditions—such as salinity, temperature, habitat type and hydrodynamic features—with the presence and abundance of IAS. Special attention is given to lagoon systems, estuaries and shallow coastal areas, which represent highly suitable habitats for the establishment and expansion of the species.

The approach combines the use of existing environmental datasets (e.g. Copernicus Marine Service, EMODnet), remote sensing techniques and targeted field observations, complemented by local ecological knowledge from fisheries stakeholders.

The objective is to define a set of relevant environmental indicators and data collection methods that are scalable, cost-effective and interoperable with the BRAVE Smart Digital Platform, supporting risk assessment, early detection and adaptive management of IAS at regional and Adriatic scale.

The **PP9** activity addresses the role of the Croatian fisheries legislative framework and marine protected areas (MPAs) in influencing the spread and management of alien, locally absent, and invasive species in the Adriatic Sea.

Fisheries regulations are traditionally based on accumulated knowledge and established data collection systems; however, ongoing environmental changes require continuous adaptation of regulatory instruments. Within this pilot action, potential gaps and limitations in the current legislative framework will be analysed, particularly where unintended effects may facilitate the spread of undesirable species or reduce management effectiveness.

The activity will also assess how the designation of protected areas may influence the distribution and status of invasive species, providing insights into the effectiveness of spatial management tools in mitigating ecological impacts.

For **PP12**, this activity focuses on the feasibility and validation of monitoring approaches for the early detection of invasive alien species (IAS) and associated environmental pressures in the Krka River estuary.

Building on the strategic assessment conducted under D1.1.5, the activity introduces a more technical evaluation of monitoring systems, including data acquisition, data flow integration, and the suitability of indicators for real-time or near-real-time environmental monitoring.

Particular attention is given to scalable, cost-effective, and interoperable solutions that can support the BRAVE Smart Digital Platform and facilitate future cross-border harmonization of monitoring practices.

Aquaculture represents a significant pathway for the transfer of non-native species and associated pathogens between farming sites, particularly through the movement of bivalves.

The **PP13** activity addresses this risk by developing practical procedural and technical measures that can be implemented at the farm level to reduce the spread of invasive species linked to aquaculture practices.

The proposed measures will be evaluated in terms of feasibility, cost-effectiveness, and risk reduction potential, with the aim of identifying solutions that are both operationally viable and economically sustainable for stakeholders. The activity will contribute to strengthening biosecurity practices within the sector and reducing the ecological impact of species translocation.

Existing data

To support the implementation of the protocols described above, it is first necessary to review the environmental datasets and databases already available within the Adriatic context. The following chapter therefore provides an overview of existing data sources relevant to the BRAVE project.

Existing environmental datasets represent an essential foundation for the development and validation of the BRAVE data collection protocols. Reviewing these sources allows the partnership to identify available information, assess its relevance for the project objectives, and determine how it can be integrated into the BRAVE Smart Digital Platform.

At present, no specific and comprehensive datasets focused on the blue crab (Callinectes sapidus) are available within the pilot areas. Existing knowledge is mainly derived from scientific publications and academic theses, which provide useful reference information and allow comparisons with other regions of the Mediterranean. These sources will support the development of monitoring protocols and help contextualize pilot data within broader ecological patterns.

At the EU level, the Biodiversity Strategy for 2030 addresses the management of invasive alien species (IAS). Under the EU IAS Regulation, the European Alien Species Information Network (EASIN) has been established, containing records of more than 14,000 alien species across Europe. Member States are required to implement surveillance systems for IAS of Union concern.

At the Mediterranean scale, within the framework of the General Fisheries Commission for the Mediterranean (GFCM), a Pilot Study on Non-Indigenous Species in the Eastern Mediterranean is ongoing. Although it does not include the Adriatic Sea, it provides insights into species potentially relevant for the region. GFCM activities also address NIS through targeted measures (e.g. Blue Crab Control Strategy) and broader approaches such as Local Ecological Knowledge.

Within the Interreg MED Programme, the SHAREMED project (2019–2022) developed a system for exchanging data on environmental threats in the Mediterranean Sea. The project identified high levels of anthropogenic pressure (e.g. nautical tourism, ports) that hinder the achievement of Good Environmental Status (GES), highlighting the need for more restrictive maritime spatial planning measures.

Mandatory fisheries data collection under the GFCM Data Collection Reference Framework (DCRF) and the EU Data Collection Framework (DCF) (in Italy and Croatia) does not currently require the systematic collection of data on non-indigenous species catches. In Croatia, a mobile application for reporting invasive species has been developed by the competent Ministry; however, reporting remains voluntary and is not part of a mandatory monitoring system.

Italian projects and database

In the Italian Adriatic, available datasets are still fragmented and not fully exhaustive.

The presence and distribution of the lagoon cockle (*Cerastoderma glaucum*) were first evaluated in 2019 through a feasibility study funded under the EMFF 2014–2020 programme.

This resulted in a preliminary distribution map of the species in the Marano Lagoon, although the data remain incomplete and require further updating and integration.

BLUECRAB project (Interreg VI-A IT-SLO 2021–2027)

Within the Italian pilot areas, additional data have been generated through the BLUECRAB project, which implemented a monitoring system to support the understanding and management of the spread of *Callinectes sapidus* in the Northern Adriatic.

Data collection activities included:

- spatial and temporal distribution of blue crab populations
- abundance and catch trends
- biological parameters (size, sex, reproductive status, growth patterns)
- environmental conditions (habitat characteristics, water conditions, ecosystem pressures)
- fishing-related data (gear selectivity and effectiveness of capture practices)
- socio-economic impacts on fisheries and aquaculture

Data were collected through field sampling, pilot monitoring activities, and digital tools (apps and IT systems), enabling systematic and harmonized reporting across Italy and Slovenia. The resulting dataset supported the establishment of a cross-border observatory integrating scientific and operational knowledge.

Croatian projects and database

Alongside the Italian datasets, several national data sources are available on the Croatian side of the Adriatic basin, providing complementary information on water quality monitoring and environmental status assessments.

MARBLE project (Horizon, 2023–2025)

In the Croatian pilot area (e.g. Šibenik), activities under the MARBLE project support the integration of maritime robotics and sensor-based technologies for environmental monitoring, including real-time data acquisition systems applied to aquaculture contexts (e.g. Smart Mussel Farm).

Additional projects have contributed to the current knowledge base:

CASCADE (2020–2023, Interreg IT-HR)

Development of integrated monitoring systems for ecosystem protection and restoration. In the Krka Estuary, significant concentrations of copper (Cu) and zinc (Zn) in sediments were identified, mainly linked to antifouling paints and nautical activities.

InnovaMare (2020–2023, Interreg IT-HR)

Development of a cross-border innovation ecosystem for underwater robotics and sensors, including real-time monitoring prototypes and a Blue Growth strategic roadmap.

In addition, a **mariculture assessment study in Mali Ston Bay (Pećarević et al., 2020)** provided a comprehensive overview of aquaculture activities in the area and proposed guidelines for future management.

Furthermore, national databases such as the **Nature Protection Information System portal** (https://www.haop.hr/hr/baze-i-portali/interni-portal-informacijskog-sustava-zastite-prirode) contribute to environmental data availability.

Despite these resources, monitoring systems in Croatia are generally characterized by:

- low temporal resolution
- limited real-time capability
- fragmented institutional ownership
- weak interoperability with digital platforms

In areas such as the Krka estuary, important baseline knowledge exists; however, an operational early-warning monitoring framework for invasive species is still lacking.

Common projects and database (IT+HR)

Several initiatives and databases operate across both sides of the Adriatic Sea, contributing to a shared knowledge base required for transnational environmental assessments.

ALIENA (Interreg Italy–Croatia Programme 2021–2027)

Within the Interreg Italy–Croatia Programme, projects such as ALIENA focus on selected non-indigenous species across multiple pilot areas, supporting the development of shared monitoring approaches.

ARGOS (2020–2023, Interreg IT-HR)

Establishment of a common institutional framework for sustainable fisheries and aquaculture management, including the Adriatic Advisory Council (AAC) and standardized protocols for environmental and stock assessment.

The ARGOS project (Interreg IT-HR) also contributed to a socio-economic analysis of pilot areas and to the preliminary characterization of bivalve production sites along the Croatian Adriatic, particularly in relation to the risk of transferring non-native species and pathogens through aquaculture practices.

Additional cross-border research includes studies on invasive taxa affecting aquaculture systems, such as the **project on alien Polydora species** (Annelida: Spionidae), conducted by Italian and Croatian research institutions, which investigated their impact on oyster farming along both coasts of the Adriatic Sea.

Overall, while several cross-border initiatives exist, data integration remains limited, and differences in monitoring approaches, data formats, and reporting systems continue to constrain the development of a fully harmonized Adriatic-wide dataset.

New Data

While existing datasets provide an important baseline for understanding environmental conditions in the Adriatic Sea basin, the BRAVE project also generates additional data through pilot actions implemented by project partners. These new datasets complement existing monitoring systems and support the validation of the common data collection protocols developed under Activity 1.1, contributing to the development of the BRAVE Smart Digital Platform.

Pilot Sites: Description, Context & Justification

This section describes the selected pilot sites and their relevance for the project objectives. These areas represent diverse ecological, environmental, and socio-economic conditions across the Adriatic Sea and are used as real-world testing environments for validating data collection protocols. Their variability ensures that the developed framework is robust, scalable, and transferable to broader regional contexts.

PP2: The Marano Lagoon (Italy) is a Natura 2000 site and represents a historically important area characterized by extensive tidal flats previously dedicated to mollusc aquaculture and intensively managed production systems. Currently, the area is no longer productive, as intensive mussel farming has ceased. This makes it a suitable case study to investigate the ecological dynamics influencing the presence of commercially important molluscs, with particular reference to native species and their interactions with non-native species, within a context increasingly affected by predation pressure from the blue crab (*Callinectes sapidus*).

PP3: Additional Italian pilot areas include the Valli di Comacchio (Po Delta Park), specifically the Stazione Foce, and/or the mouth of the Reno River. These sites represent key transitional and coastal environments characterized by gradients in salinity, hydrodynamics, nutrient loads, and habitat structure, as well as varying levels of anthropogenic pressure, including fishing, aquaculture, and coastal modifications. Monitoring activities in these areas integrate traditional biological sampling, environmental DNA (eDNA), multiparametric sensors, and stakeholder-based data collection, ensuring the generation of comprehensive and harmonized datasets. Their representativeness of Adriatic transitional systems, combined with dynamic environmental conditions, makes them particularly suitable for investigating the drivers of invasive species spread—especially the blue crab—and associated biodiversity changes.

In addition, a multi-site monitoring approach is implemented across coastal and lagoon areas, where structured and multi-dimensional datasets are collected to support the assessment of invasive alien species. Data collection includes species distribution and abundance, environmental parameters (e.g. temperature, salinity, dissolved oxygen, chlorophyll, substrate type), pressure indicators such as fishing effort and tourism intensity, socio-economic variables related to fisheries and aquaculture, and model-derived outputs such as habitat suitability and vulnerability. Data are collected at different spatial and temporal scales (monthly and annual), combining grid-based and area-based approaches. This structure allows the integration of field observations, operator inputs, and model outputs, ensuring consistency and direct usability within the BRAVE Smart Digital Platform, as well as supporting scenario analysis and cross-border comparability.

At a broader scale, the analysis of the regulatory framework governing marine fisheries in Croatia, aligned with EU legislation and GFCM recommendations, provides an additional context for the pilot activities. This framework reflects conditions across the Adriatic Sea and allows the evaluation of how existing regulations and data collection systems influence the management of non-indigenous and invasive species. The results are intended to support potential improvements in both regulatory instruments and monitoring systems, enhancing the effectiveness of management measures.

PP7: The pilot sites selected for PP7 include representative coastal and transitional environments along the Istrian coast, such as estuaries, semi-enclosed bays and lagoon systems (e.g. Raša Bay, Mirna estuary, Lim Bay and other Natura 2000 sites).

These areas are characterised by strong environmental gradients, particularly in salinity, temperature and nutrient inputs, as well as significant interactions between marine and freshwater systems. Such conditions create favourable habitats for invasive species such as the blue crab, which has already been recorded across multiple locations in the region.

These sites are particularly relevant for testing monitoring approaches due to their ecological importance, vulnerability to biological invasions and relevance for fisheries and aquaculture activities.

The selection of pilot sites ensures that the developed methodologies are tested under diverse but representative environmental conditions, supporting their transferability to other areas of the Adriatic Sea.

PP12: The Krka River estuary (Croatia) represents a particularly relevant pilot site due to its unique environmental characteristics. The estuary extends over 22 km from Skradin to the port of Šibenik and is characterized by strong stratification between freshwater and seawater, with depth increasing from approximately 2 m at the head to 42 m at the mouth. This stratification creates a highly productive ecosystem with a high proportion of filter feeders and supports shellfish and fish farming activities. The area includes 54 shellfish farming fields and 6 fish farming sites, involving approximately nine active farmers, and is protected as a significant landscape.

The estuarine system is particularly vulnerable to biological invasions. The halocline layer acts as an ecological trap, accumulating organic material and favouring the establishment of invasive species introduced through ballast water or marine currents. The geomorphology of the system allows the penetration of saline water upstream, enabling marine predators such as the blue crab (*Callinectes sapidus*) to reach inland areas and impact native freshwater species. In addition, the Port of Šibenik represents a key entry point for invasive species through ballast water discharge and hull fouling, increasing pressure on the ecosystem. Despite favourable conditions for aquaculture, production has declined in recent years, highlighting the need for improved monitoring and management.

PP13: Mali Ston Bay (Croatia) represents another key pilot site. It is a 28 km long mildly eutrophic coastal ecosystem influenced by freshwater inputs from submarine springs and the Neretva River. The area is both a Natura 2000 site and a special marine reserve designated for oyster farming. It is of major economic and cultural importance, hosting over 85% of the Mediterranean aquaculture production of the European flat oyster (*Ostrea edulis*), marketed under the Protected Designation of Origin “Malostonska kamenica”, and representing the main production area for Mediterranean mussel (*Mytilus galloprovincialis*) in Croatia.

However, aquaculture production in the bay is highly sensitive to environmental variability and extreme events, as demonstrated by recent mass mortality episodes. To compensate for production losses, farmers often translocate bivalves between sites, sometimes across long distances and between different ecosystems. This practice involves the transfer of entire culture units, including associated biofouling communities, and represents a significant pathway for the spread of non-native and invasive species. Due to its ecological sensitivity, economic importance, and exposure to these risks, Mali Ston Bay provides an ideal setting for testing mitigation strategies and improving biosecurity practices.

Pilot Actions: Execution & Tech Stack

Following the description of the testing locations, the next section outlines how pilot actions are implemented in practice, including operational procedures, technological tools and data structures used for the collection and processing of information.

PP2 – Marano Lagoon (Italy)

Operations: Field activities focus on evaluating the distribution and abundance of the lagoon cockle (*Cerastoderma glaucum*) and its interactions with the introduced Manila clam (*Ruditapes philippinarum*), within a context strongly influenced by predation pressure from the blue crab (*Callinectes sapidus*).

*Technology***:** Hydraulic dredges authorized for clam collection are used to monitor mollusc distribution and abundance. Dedicated traps are deployed to capture blue crabs and assess their population structure and predation impact.

Data Profiles:

- Mollusc species presence and abundance, used to generate sensitivity maps
- Blue crab presence and population structure
- Mollusc landing data as a reference framework

PP3 – Transitional coastal systems (Italy)

Operations: Pilot actions involve field monitoring of the blue crab (*Callinectes sapidus*) in the Valli di Comacchio (Stazione Foce) and/or the mouth of the Reno River. Activities include biological sampling, environmental assessments, and analysis of ecological interactions, supporting the validation of monitoring protocols and the assessment of species distribution patterns.

Technology: Integrated monitoring tools are used, including environmental DNA (eDNA) analysis and smart multiparametric sensors, to automate sampling, monitor species presence, and improve the temporal resolution of environmental observations.

Data Profiles:

- Raw sensor data
- Validated ecological datasets (species abundance, distribution, reproductive parameters)
- Associated metadata (environmental conditions, sampling protocols, anthropogenic pressures)

All data are harmonized and integrated into the BRAVE Smart Digital Platform to support visualization, analysis, and decision-making.

PP6 – Multi-site participatory monitoring

Operations: The pilot action collects structured, multi-dimensional datasets across multiple coastal and lagoon sites to support the monitoring of invasive alien species, with a focus on the blue crab. Activities include the involvement of fisheries and aquaculture operators in data collection processes.

Technology: Data collection relies on a combination of field-based tools, including underwater probes, remote sensing, and satellite data, enabling the detection of environmental parameters linked to the spread of alien species.

Data Profiles:

- Species distribution and abundance data
- Environmental parameters (temperature, salinity, oxygen, chlorophyll, substrate)
- Pressure indicators (fishing effort, tourism-related pressure)
- Socio-economic data
- Model-derived outputs (habitat suitability and vulnerability scores)

These datasets support cross-border comparability and integration within the BRAVE platform.

PP7 – Stakeholder-based data collection (Istria sites)

Operations: The pilot action focuses on the collection and integration of environmental and ecological data to assess the drivers influencing the distribution of invasive species, particularly the blue crab (*Callinectes sapidus*). Activities include:

- identification of high-risk areas based on environmental suitability
- targeted field observations and validation of species presence
- integration of environmental datasets with local ecological knowledge from fishers

Technology: The monitoring approach combines:

- remote sensing data (e.g. sea surface temperature, salinity proxies, chlorophyll concentration)
- existing environmental databases (Copernicus Marine Service, EMODnet)
- GIS-based spatial analysis
- simple field verification tools and stakeholder reporting

This approach prioritises cost-effective and scalable methods that can be replicated across different Adriatic regions.

Data Profiles: Collected data include:

- environmental parameters (temperature, salinity, habitat type, depth, hydrodynamics)
- species presence/absence and relative abundance (blue crab)
- spatial data (georeferenced observations and habitat mapping)
- qualitative inputs from fisheries stakeholders

The integration of these datasets supports the development of habitat suitability assessments and risk mapping, enabling improved understanding of IAS dynamics and supporting decision-making within the BRAVE Smart Digital Platform.

PP9 – Regulatory framework analysis (Adriatic Sea)

Operations: A critical analysis of the fisheries regulatory framework and data collection systems is conducted to identify weaknesses and gaps in the assessment of Non-Indigenous Species (NIS), with particular emphasis on marine protected areas.

Technology: Scenario-based analytical approaches are applied, including a hypothetical case study focusing on the lionfish (*Pterois miles*) to explore potential future invasion dynamics and habitat suitability.

Data Profiles:

- Regulatory datasets and policy frameworks
- Qualitative and quantitative indicators related to NIS management
- Outputs supporting recommendations for improving monitoring and governance

PP12 – Krka River Estuary (Croatia)

Operations: Two complementary activities are implemented:

1. Feasibility study of monitoring technologies: Evaluation of existing monitoring systems for early detection of invasive species, including technical screening and suitability assessment.
2. Environmental data analysis and validation: Integration and reinterpretation of existing datasets to assess environmental changes and invasive species dynamics.

Field activities include targeted verification measurements using portable equipment and expert-based assessments, supported by stakeholder consultation.

Technology: A modular, low-cost monitoring approach is adopted, based on portable multiparametric probes and data loggers measuring key physico-chemical parameters. Emphasis is placed on cost-efficiency, robustness in stratified estuarine conditions, and compatibility with the BRAVE Smart Digital Platform.

Data Profiles:

- Technology performance matrices
- Monitoring suitability scores
- Environmental datasets derived from existing sources
- Metadata templates aligned with BRAVE requirements

PP13 – Mali Ston Bay (Croatia)

Operations: The pilot action focuses on developing and assessing mitigation measures to reduce the risk of spreading non-native species and pathogens through bivalve translocation in aquaculture systems. The approach relies on external expertise and aims to remain aligned with current practices to ensure feasibility.

Technology: Cost and feasibility assessments are conducted through surveys involving supply chain operators (farmers, transporters, equipment providers), combined with small-scale proof-of-concept tests to evaluate risk reduction measures.

Data Profiles:

- Qualitative data from stakeholder surveys
- Quantitative data from pilot tests
- Risk assessment outputs related to biosecurity measures

Data Checklist

In order to ensure consistency across pilot actions and facilitate data integration within the BRAVE Smart Digital Platform, a common set of minimum data requirements has been defined. The following section presents the data checklist applicable to the different protocols.

The definition of the minimum dataset will be carried out in collaboration with the partnership, including members of the Adriatic Advisory Council (AAC), to ensure alignment with stakeholder needs. In addition, targeted questionnaires will be developed to verify the relevance and usability of the proposed data categories, in coordination with other data input activities.

The following macro-categories represent the core structure of the data checklist:

- Species data
- Environmental parameters
- Anthropogenic pressures
- Monitoring metadata
- Technology-derived data (e.g. sensors, eDNA)
- Socio-economic data and management indicators

PP2 – Mollusc and blue crab interaction data

- Number of mollusc species
- Density (individuals/m²) for each species
- Number of individuals per age class
- Quantity of molluscs landed (kg)

These data support the assessment of species distribution, population structure, and resource exploitation, and contribute to sensitivity mapping.

PP3 – Blue crab monitoring and environmental drivers

- Species data
  Presence/absence of the blue crab (*Callinectes sapidus*), abundance estimates, life stages, reproductive success
- Environmental parameters
  Water temperature, salinity, oxygen concentration, nutrient levels, hydrodynamic conditions (currents, residence times)

- Anthropogenic pressures
  Fishing activity, aquaculture intensity
- Monitoring metadata
  Sampling date and time, sampling method, geographic coordinates, equipment used, data collector
- eDNA and sensor data
  Raw and processed outputs from eDNA analyses and multiparametric sensors, including quality control and validation procedures

PP6 – Environmental and pressure-related data

- Environmental parameters (temperature, salinity, oxygen, chlorophyll, substrate)
- Species occurrence and abundance
- Pressure indicators (fishing effort, tourism intensity)
- Socio-economic variables related to fisheries and aquaculture

PP7 – Stakeholder-derived data and integrated data

- Observational data on species presence and distribution, collected through stakeholder engagement (fisheries, aquaculture operators and local users), providing valuable insights into spatial and temporal patterns of invasive species.
- Operational data from fisheries and aquaculture activities, supporting the understanding of interactions between species, habitats and human activities.
- Qualitative information contributing to the interpretation of local ecological dynamics, including seasonal occurrence, habitat use and perceived impacts.
- These data are complemented by spatial and environmental datasets (e.g. habitat maps, salinity and temperature data), allowing integration of stakeholder knowledge with environmental drivers and supporting site prioritisation and risk assessment.

PP9 – Regulatory and governance data

- Elements of the regulatory framework relevant to invasive species management
- Data Collection System (DCS) components and identified gaps
- Indicators supporting qualitative and quantitative assessment of Non-Indigenous Species

The analysis is expected to identify aspects requiring improvement to enable verifiable measures for mitigating the spread of invasive species, including scenario-based

considerations (e.g. lionfish). Data will be standardized for integration into the Smart Digital Platform.

PP12 – Early detection and environmental monitoring (Krka estuary)

For the PP12 pilot, the minimum dataset prioritises variables relevant for early detection of invasive species and environmental anomalies in stratified estuarine systems.

- Environmental parameters (temperature, salinity, oxygen, nutrient load, chlorophyll)
- Indicators of hydrological variability
- Data supporting detection of invasive species presence and inflow
- Metadata aligned with monitoring conditions and data sources

PP13 – Aquaculture-related risk and mitigation data

- Price per kg of bivalve species, including additional costs associated with modified translocation procedures
- Effectiveness of biofouling control measures on translocated bivalves, expressed as percentage of remaining organisms (total and per taxonomic group)

These data are interpreted within a broader qualitative framework, as their significance depends on integration into cost and risk assessments, which represent the main output of this activity.

Data Standardisation

The data standardisation framework is designed to ensure a high level of coherence, comparability, and interoperability across all pilot actions, while preserving the necessary flexibility to account for local ecological, operational, and methodological specificities. At its core, the process focuses on aligning data collection methodologies, formats, and metadata structures through a set of shared principles, including the harmonisation of measurement units, the temporal alignment of sampling efforts and reference periods, the adoption of standardised geospatial coordinate systems and spatial grids, and the enforcement of comprehensive metadata requirements describing sampling protocols, environmental conditions, and data provenance. These foundational elements enable the integration of heterogeneous datasets originating from field surveys, legacy databases, remote sensing, and stakeholder observations, supporting a coherent analytical framework at the Adriatic basin scale.

Across the various pilot projects (PP2, PP3, PP6, PP7, PP9, PP12, and PP13), these standardisation principles are operationalised within different thematic contexts. In ecological monitoring activities, such as those focusing on mollusc populations and the invasive blue crab *Callinectes sapidus*, standardisation ensures consistency in species distribution assessments, abundance estimates, and density metrics, while also enabling the systematic evaluation of key pressure factors, particularly predation dynamics. Similarly, in pilots addressing environmental drivers and anthropogenic pressures, clear and shared protocols are defined to guarantee the comparability of physical, chemical, and biological parameters, as well as human-induced stressors across sites.

Particular attention is given to the harmonisation of environmental and pressure-related datasets collected through multiple sources, including in situ measurements, remote sensing products, and operator-generated inputs, ensuring that differences in data origin do not compromise analytical consistency. In parallel, stakeholder-based data integration represents a crucial component of the framework, whereby observational and operational data collected by fishers and aquaculture operators are structured through simplified templates, standardised variable definitions, and minimum metadata requirements. This approach enables the effective integration of qualitative knowledge with quantitative environmental datasets, such as habitat mapping, salinity, and temperature, supporting the identification of spatial patterns, environmental drivers, and priority areas for intervention.

From a governance and regulatory perspective, standardisation efforts also address the alignment of data collection frameworks with monitoring requirements for Non-Indigenous Species (NIS), identifying existing gaps and defining harmonised data structures capable of supporting both qualitative and quantitative assessments. In estuarine environments, such as the Krka estuary, the application of these principles demonstrates how interoperability between field measurements, historical datasets, and spatial planning layers can be achieved, providing a model for scalable and transferable monitoring approaches across the Adriatic region. Furthermore, in the context of aquaculture and biosecurity, standardisation supports the structuring of data related to mitigation measures, cost-efficiency, and risk assessment outputs, ensuring their comparability and integration within broader analytical workflows.

A critical cross-cutting component of the process is the integration with the BRAVE Smart Digital Platform. All partners collaborate closely with ICT teams to define shared data structures, standardised templates, validation rules, and data management workflows, ensuring that all standardised datasets can be seamlessly uploaded, accessed, and analysed within a unified digital environment. This guarantees not only interoperability and long-term usability, but also the capacity to support advanced, evidence-based management and decision-making processes.

Ultimately, the outcome of this comprehensive standardisation effort is the development of a robust, scalable, and transferable framework for data collection and management. This framework enables comparability across pilot sites, facilitates the integration of diverse and heterogeneous datasets, and strengthens the capacity for cross-border analysis, thereby supporting coordinated, science-based management strategies and policy development throughout the Adriatic region.

Conclusions

This deliverable establishes a common and operational framework for data collection within the BRAVE project, with the specific aim of supporting the monitoring, assessment, and management of non-indigenous and invasive species across the Adriatic Sea. By defining shared methodological principles, minimum data requirements, and standardisation criteria, the document provides the foundation for the generation of harmonised, interoperable, and policy-relevant datasets across a wide range of environmental, ecological, and socio-economic contexts.

A key strength of this deliverable lies in its capacity to bring together highly diverse pilot actions under a single coherent framework. Although the participating partners operate in different ecological settings and address different thematic priorities—from mollusc–blue crab interactions, environmental drivers and stakeholder-based observations, to regulatory analysis, estuarine monitoring, and aquaculture-related biosecurity—the document ensures that all activities contribute to a common data architecture. This approach is essential for reducing fragmentation, improving comparability among pilot sites, and enabling the integration of data collected through field observations, remote sensing, sensors, legacy datasets, and stakeholder inputs.

The deliverable also highlights the importance of grounding data collection within the specific environmental and operational conditions of each pilot area. By describing the ecological relevance, pressures, and monitoring needs of the selected sites, it ensures that the proposed protocols are not merely theoretical standards, but practical and adaptable tools tested in real-world conditions. In this sense, the pilot actions play a dual role: they generate new knowledge on invasive species dynamics and environmental pressures, while simultaneously validating the feasibility, scalability, and transferability of the proposed data collection framework.

Particular importance is given to the link between data generation and governance. The framework developed here is not limited to scientific monitoring, but is conceived as a support mechanism for coordinated management, adaptive decision-making, and long-term cross-border cooperation. Through the integration of standardised datasets into the BRAVE Smart Digital Platform, the deliverable contributes to the creation of a shared analytical environment where information can be visualised, compared, interpreted, and mobilised to support both technical assessments and strategic planning.

In conclusion, this deliverable represents a fundamental step in the implementation of WP1 and in the broader scientific and operational strategy of the BRAVE project. It lays the groundwork for a robust, scalable, and transferable data collection system capable of supporting a more integrated understanding of biodiversity loss, invasive species spread, and environmental change in the Adriatic Sea. By enhancing data quality, interoperability, and cross-border usability, it strengthens the basis for evidence-based management actions and contributes to the long-term resilience and adaptive capacity of Adriatic marine and coastal ecosystems.

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ANNEXES

- ANNEX 1 – Data collection Tables - standard 4