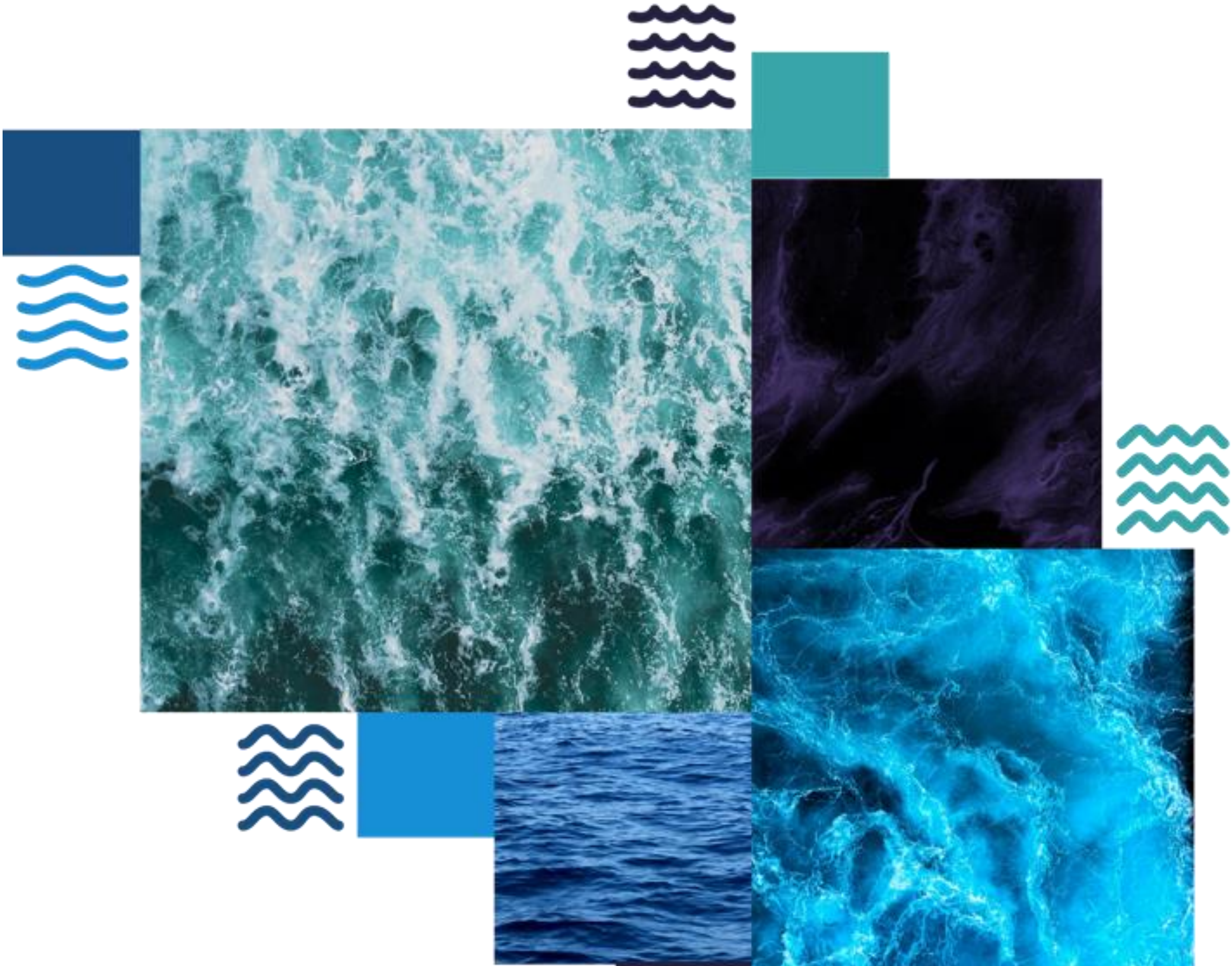
Framework and toolbox for assessment and analyses of CIA/CEA, GES status, Ecosystem Services and uncertainty

Deliverable 4.2



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1 GES4SEAS Project Summary

Human activities at sea (e.g., maritime transport, extraction of living and non-living resources, etc.) and in coastal areas (e.g., agriculture, leisure and recreation, etc.) have expanded considerably, leading to an increased level of pressures and subsequent degradation of ocean health and, ultimately, human health. Single and cumulative impacts of these activities are likely to increase, driven by human demands and enhanced by climate change.

Human activities evolve following socio-economic drivers leading to pressures, which often are studied in isolation from each other even though their impacts on marine ecosystems can interact, making the effects cumulative (e.g., synergistic, antagonistic or a combination). Knowledge on these interactions and their cumulative effects in the marine environment has increased in recent years, but huge challenges remain to be solved. Thus, there is little predictability to inform decision-making processes, especially regarding ecological tipping points, which, if exceeded, could lead to a point of no-return for the system. In this context, an ecosystem-based management (EBM) approach to the management of human activities at sea and on land should ensure that the combined pressure of such activities is kept within levels compatible with the achieving Good Environmental Status (GES) (requirements of the Marine Strategy Framework Directive – MSFD), against a background of climate change. This means that the capacity of marine and coastal ecosystems to respond to human-induced changes is not compromised, enabling the sustainable use of marine goods and services by present and future generations.

Thus, the main objective of GES4SEAS is to inform and guide marine governance in minimizing human pressures and their impacts on marine biodiversity and ecosystem functioning, while maintaining the sustainable delivery of ecosystem services. This will be achieved through developing an innovative and flexible toolbox, tested, validated, demonstrated and upscaled, in the context of adaptive EBM approach. The toolbox will allow competent authorities to assess and predict the effect of multiple stressors (including climate change) and pressures from human activities, at the national, sub-regional, regional and European level. Ultimately, this will enable GES achievement, and support different policies at national, European and global levels (e.g. Birds and Habitats Directives (BHD), Biodiversity Strategy 2030, United Nations Sustainable Development Goals (SDG)).

Stakeholders and the key competent authorities (including national, regional and European levels) are integrated in a Practitioner Advisory Board (PAB) to co-create and validate the toolbox and the EBM approach. This will result on a real problem-solving approach with iterative and incremental development steps.

GES4SEAS will also rely on existing multi-actor networks to involve and engage with stakeholders. This multi-actor approach will ensure that the research and deliverables are relevant to marine managers all around the world. Lastly, it is important to highlight that the toolbox will be tested and demonstrated at 11 Learning Sites (LSs) covering all European regional seas as well as selected overseas territories. Thus, it is expected that GES4SEAS will achieve Technological and Societal Readiness Levels 6. This will be achieved by the participation of 20 partners, covering the four European regional seas and Canada.

It is expected that GES4SEAS will:

- Operationalize integrative and holistic solutions for EBM, based upon a software toolbox for analysing, assessing and mapping cumulative pressures, GES and ecosystem services.
- Provide evidence (and training) to key stakeholders of the benefits of using the toolbox that will be developed in GES4SEAS for assessing the environmental status of marine waters and the ecosystem services considering the effects of multiple pressures so opt for using it.
- Ensure the EBM approach and guidelines for the management of Invasive Alien Species (IAS), harmful algal blooms (HABs) and jellyfish, the approach for monitoring top predators are used by end-users.
- Investigate, using models, the best ways to obtain thresholds of GES/non-GES status and tipping points (system breaking points).
- Reach and engage a wider society, and specifically young people and educators, on key messages steaming from this project, so GES4SEAS contributes to societal ocean literacy and responsible behaviours.

2 Deliverable 4.2 Summary and objectives

The objective of this deliverable (D4.2) is to present the overall framework on which the GES4SEAS toolbox builds both in scientific and technical terms. The deliverable is tagged as type "Software" in the technical description of the project. It therefore includes the software in the current implementation status. In addition to the software deliverable itself, this document outlines the scientific foundation of the toolbox. The technical implementation and documentation are included as separate files. These are the actual GES4SEAS toolbox software in the current version 2.0.3 (released to the project partners 26 February 2025) with executables for Windows 10 (and later) and macOS 11 (and later, both for Intel and Apple Silicon machines) plus the draft software manual for this version. The fully documented and complete reference manual for the software will be part of Deliverable 4.3 (due in project month 44 which is in April 2026).

This deliverable is one step of achieving the overall objective of WP4 within the GES4SEAS project. This objective is to develop an innovative assessment framework and the corresponding toolbox (TRL-SRL6) to be used by Regional Seas Conventions (RSCs) and Member States for assessing the cumulative effects of pressures on state change and on the capacity to deliver ecosystem services in an integrative and holistic way, based on an evidence-driven model, including an assessment of uncertainties related to the assessment results.

At this point, the assessment framework is in place as both the scientific (see chapter 3) and the technical frameworks (see chapter 4) have been developed, and testing has begun within the Learning Sites. The software has, however, not yet fully implemented all the various features within the framework (see chapter 5). This will be part of the ongoing iterative learning process within the Learning Sites which will end in December 2025. Currently, the toolbox software has these three main components which together form the basic framework (more details in Appendix 1):

- **Datasets:** user data (both spatial and non-spatial)
- **Indicators:** practical indicators to implement analyses and assessment with
- **Analyses:** abstract definitions of some data processing workflows and their realization

3 Scientific framework of the toolbox

3.1 Background

The GES4SEAS toolbox is constructed upon a comprehensive array of existing instruments, including the Cumulative Impact Assessment/Combined Effect Assessment (CIA/CEA) method initially developed and published by Halpern et al. (2008), as well as a suite of indicator-based assessment tools and frameworks facilitated by the Nested Environmental status Assessment Tool (NEAT) originally developed by the DEVOTES project (Berg et al., 2016; Borja et al., 2016). The toolbox is grounded in multiple requirements for the assessment of the marine environment, particularly the EU Marine Strategy Framework Directive (MSFD; European Commission, 2008), both in relation to the so-called CIA/CEA and 'Good Environmental Status' (GES) for MSFD descriptors. **The two most important tools currently in the toolbox are**:

- Analysis and mapping of CIA/CEA, exploiting an improved version of the original Halpern approach (see section 3.1.1 below)
- Indicator-based assessments of GES using the NEAT tool (see section 3.1.2)

3.1.1 CIA/CEA – What are we building upon?

The publication by Halpern et al. (2008) has garnered significant attention and has become a seminal work accruing over 7,700 citations according to Google Scholar. The considerable interest in this study stems from its introduction of a novel research domain, namely, the mapping of cumulative effects of multiple anthropogenic stressors on marine ecosystems, as well as the accessibility and simplicity of the methodology employed. Subsequent studies have been conducted at various scales, including the global, continental, regional, and national levels (Korpinen & Andersen, 2016; Kallio et al., 2025) and have improved the method by dealing with some of the shortcomings of the initial approach. **¡Error! No se encuentra el origen de la referencia.** shows a conceptual model of the fundamental principle in the method.

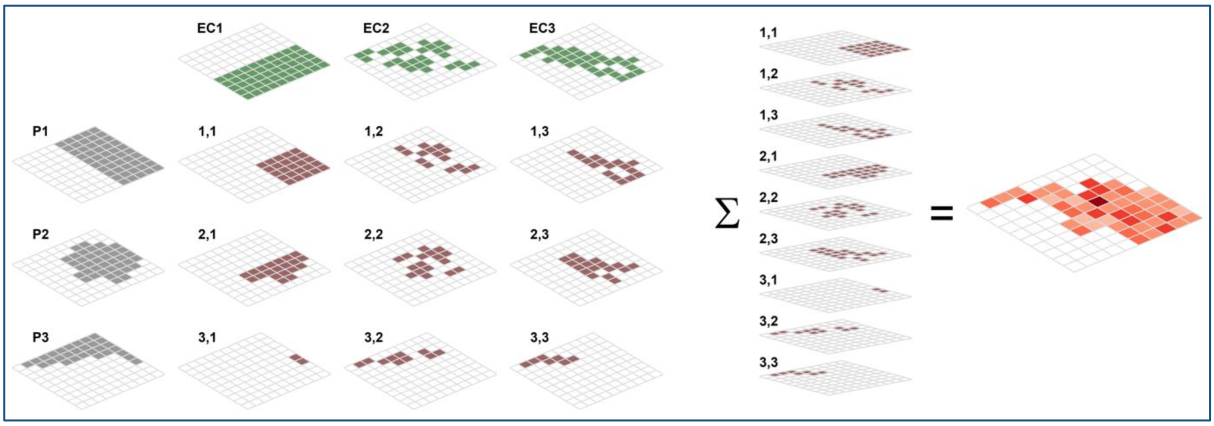

Figure 1. Conceptual illustration of the Cumulative Impactct Assessment/Combined Effect Assessment (CIA/CEA) method originally developed and published by Halpern et al. (2008), and subsequently used world-wide cf. Korpinen & Andersen (2016) and Kallio et al. (2025). Effects are calculated for each combination of a pressure dataset (P) with an ecosystem component dataset (EC). The overall estimated combined effect is obtained from the aggregated (here summed) combination of all individual effects.

In the European context, the initial HELCOM HOLAS assessment not only evaluated cumulative effects, but also represented the first regional downscaling of the Halpern approach (HELCOM, 2010; Korpinen et al., 2012). This regional downscaling has generated significant interest in the methodology. Despite its relative simplicity, several projects and studies have been based on both HELCOM's first HOLAS assessment and methodology:

- in the North Sea, the HARMONY project (Andersen & Stock, 2013; Stock, 2016)
- subsequent studies in the Baltic Sea (HOLAS 2; HELCOM, 2018 and HOLAS 3; HELCOM, 2023)
- in the Mediterranean Sea (Coll et al., 2012), and in the Adriatic Sea (Furlan et al., 2019)

Moreover, two European studies have mapped and analysed CIA/CEA, namely the 'Multiple Pressures' assessment by Korpinen et al. (2019 and 2021) and 'Multiple pressures 2' by Stock et al. (2025). Several national studies in EU Member States have also applied the Halpern approach and mapped and analysed CIA/CEA, including those in Denmark (RALAHA, Andersen et al., 2020a) and ECOMAR (Andersen et al., 2020b), in Sweden (Symphony; Hammar et al., 2020) and in Estonia (Kotta et al., 2020).

In GES4SEAS, a specific focus is on enhancing elements in this CIA/CEA method that have been subject to criticism (Halpern & Fujita, 2013) but developed in close alignment with a global CIA/CEA standard. These enhancements are predicated on sound scientific principles and are amenable to testing, specifically addressing the following:

- the implementation of a hierarchical structure for ecosystem components in lieu of the currently employed flat structure
- the utilisation of dose-response relationships or analogous models (such as change points or thresholds) to replace the presently used linear relations
- the substitution of interview-based sensitivity scores with alternative methods, namely data- and literature-based scoring systems.

The toolbox is anticipated to be of utility to a diverse range of professionals, including other scientists and developers, national competent authorities responsible for monitoring and assessment, RSCs, and the European Environment Agency (EEA). The latter will utilise the toolbox to support the CIA/CEA assessment in the future 'Marine Messages III' synthesis assessment.

3.1.2 NEAT – a multi-metric indicator-based assessment tool

Both the EU Water Framework Directive and MSFD (European Commission, 2000, 2008) have necessitated the development of multi-metric indicator-based assessment tools or frameworks for the evaluation of 'good ecological status' and 'good environmental status' (Birk et al., 2012). However, none of the Common Implementation Strategy (CIS) processes for the directive has addressed such tools, methods or frameworks. Despite the lack of support through the CIS process, HELCOM made a substantial contribution with their 'Ecosystem health of the Baltic Sea – an initial holistic assessment' (HELCOM, 2010). This study mapped both CIA/CEA and environmental status for the Baltic Sea by employing the method established by Halpern et al. (2008) and an extensive array of newly developed multi-metric indicator-based assessment instruments. These tools were subsequently applied thematically to evaluate 'eutrophication' (HEAT; Andersen et al., 2011), 'biodiversity' (BEAT; Andersen et al., 2014), 'contaminants' (CHASE; Andersen et al., 2016), and 'ecosystem health' (HOLAS; HELCOM, 2010).

Whilst their methodology was sound, the initial generation of multi-metric indicator-based assessment tools were not ideally suited to large scale studies, with classifications conducted in Excel templates. A substantial advancement was facilitated by the EU FP9 DEVOTES project, wherein a state-of-the-art and user-friendly biodiversity assessment tool was developed and evaluated in 10 case study sites (see Berg et al., 2016 and Uusitalo et al., 2016, for further details). NEAT or NEAT-based assessment tools have been implemented in a European-wide context, as exemplified by the 'Yes, We Can!' study by Borja et al. (2019) and 'Marine Messages II', a pan-European tool-based synthesis assessment by Reker et al. (2020). The coming EEA synthesis Assessment 'Marine Messages III' is intended to anchor its thematic identification of 'problem areas' and 'non-problem areas' in the GES4SEAS toolbox – themes to be addressed will cover 'biodiversity', 'ecosystem health', 'eutrophication', 'contaminants', and 'marine litter'.

3.2 Ecosystem services

The framework for integrating ecosystem services is based on the work done in WP3. Task 3.1 identified CIA/CEA as the key tool to assess the capacity to supply ecosystem services and achieve GES (Coll et al., 2023). As such, the ecosystem services are being integrated into the toolbox as part of this tool (see section 3.1.1).

The work in WP3 involved the development of a so-called linkage framework between ecosystem components and ecosystem services. It is based on previous work on North Sea biodiversity (Knights et al., 2015; Piet et al., 2015; 2017; Borgwardt et al., 2019) has been extended with ecosystem services by Culhane et al. (2018; 2019a,b) and the work in WP3 (Piet et al., 2024).

The aim of the linkage framework is to connect (link) ecosystem components to their capacity to supply ecosystem services. This capacity is a result of the function the ecosystem component has within the ecosystem, e.g., biota such as phytoplankton produce oxygen as part of the photosynthesis, they are doing to produce energy for themselves to survive (simply speaking). This ecosystem process helps maintaining the physical and chemical conditions in the ecosystem. It has the capacity to provide several ecosystem services. So, the biotic ecosystem components determine through their functioning the capacity to supply ecosystem services (Culhane et al., 2018; 2019a, b).

For more details, see deliverable D3.1 (Coll et al., 2023).

3.3 Uncertainty

The assessment methods implemented into the toolbox are typically simple linear models connecting pressures/indicators with ecosystem components through weights or sensitivity scores. However, WP4 will further develop the assessment methodology to include non-linear relationships (Task 4.3), potentially also different approaches to sensitivity scores (Task 4.4) and different ways of aggregation (Task 4.5). The implication of this is that the assessment machineries will include both linear and non-linear relationships where it is not always possible to state explicit formulas for calculation of standard deviations. Hence, the pragmatic solution for assessing the confidence of assessments is through uncertainty propagation by Monte Carlo simulation.

This involves defining a specific amount of uncertainty around the input datasets for an assessment. These uncertainties can be parameterised based on analysis of available data (e.g. Carstensen et al. 2024) or if this is not possible, expert knowledge. Applying the uncertainty to the datasets results in a new number of derived datasets that use the probability distribution resulting from the uncertainty.

The simulation thus repeatedly adds random errors to the specific input datasets (pressure and ecosystem component data layers as well as sensitivity scores) and calculates the CIA/CEA assessment as well as other relevant statistics. For each data set, a link function is chosen (see below) to ensure that simulations are within the expected sample space. This results in a large number of assessment results (typically 1,000 or more) that are subsequently summarized to describe the distributions of the relevant statistics. An average outcome can be calculated and the associated uncertainty visualized based on the variations of the simulation outcome.

In a CIA/CEA based on the Halpern method (Halpern et al., 2008), the cumulative effect in each grid cell of a spatial assessment is found by aggregating across all combinations of pressures and ecosystem components. This method is strictly linear in the pressure and ecosystem component data although the log-transformation of the pressure variable introduces a non-linearity such that the effect of the pressure on the ecosystem component is exponential, i.e. the effect increases progressively with the pressure level. However, this transformation is not very flexible for describing all possible pressure-ecosystem effects. A more general approach is to assume that the combined effect of a pressure on an ecosystem component can be described by a function. In most cases, this function is monotonic (increasing or decreasing) but it is also possible to formulate more complex relationships. The only requirement is that the function is parametric.

The Halpern method is one possible functional relationship out of many following this formulation. In this general approach, ecosystem components are not represented as either present or absent but as probability of presence (the mutually exclusive presence/absence represents a special case where the probability of presence/absence is either 0 or 1). This general method can be formulated as a stochastic equation, where all stochastic variables that can be described through a normal distribution and a link function. The functions log(), logit(), and id() are typical link functions that are adequate for different types of data. The link functions translate the sample space of the input data to a scale of real numbers, appropriate for simulating with the normal distribution (they are transformed into a normal distribution). For simplicity, the parameters involved in the functional relationship would typically be assumed normal distributed, i.e. using the identify link function unless they have a restricted sample space.

With this general uncertainty framework, it is possible to propagate the original uncertainty to the assessment result and thus to simulate the resulting uncertainty on the predicted cumulative effect score, provided that distributions for pressures, ecosystem components and parameters connecting them to an impact score are known.

In practice, this means that each pressure dataset (both pressures and ecosystem components) in the WP4 toolbox should include a variance (or alternatively, standard deviation) for each grid cell and that the link function should be specified as part of the metadata for the dataset. The parameter variances should also be described as part of the definition of the functional relationship between pressures and ecosystem components. With this parameterization, it will be possible to assess the standard deviation of the predicted cumulative impact score as well as all other derivative metrics such as the impact of a particular pressure and the cumulative effect of all pressures on a particular ecosystem component.

However, the complicated part is to provide variances for all datasets and parameters linking them together. The following approaches in ranked order are considered:

1. If the dataset describes fixed features (e.g. harbours, offshore wind farms, ship traffic) where the entire population is known, there is no uncertainty associated with the dataset
2. If the dataset has been produced with methods that explicitly supply prediction variance or standard deviation (e.g. GAMs, MaxEnt) then use the results from the method
3. If the dataset has been produced by a model that does not supply an uncertainty estimate and that is calibrated for a number of discrete observation points, then the variance of the dataset can be produced by the variogram of the prediction errors
4. If none of the methods above applies, a qualified variance estimate can be supplied – typically using a relative standard deviation. This could be a 'pedigree solution' with e.g. high = 5 %, medium = 10 % and low = 20 % standard deviation.

Uncertainty in the individual input datasets included in the assessment is propagated through the assessment algorithms to the results of the estimated effect index, using the methods outlined.

4 Technical framework of the toolbox

The toolbox aims to implement the scientific framework in a flexible way to be open for any changes and enhancements to the scientific foundation and to allow for tailored custom analyses and assessments done by users within the toolbox.

As such, the toolbox has been designed to be as generic as possible. The toolbox is therefore in principle not restricted to the application field that is the objective of this project, namely the assessment of marine-biological datasets in conjunction with data on human activities leading to pressures in the marine environment. The toolbox can also be applied to freshwater and terrestrial ecosystem, even to domains outside of biology. Only the kind of metadata needed would need to change. This is ensured by the general-purpose foundation and framework of the toolbox implementation.

The toolbox currently operates around three different main components:

- **Datasets =** spatial datasets as geographical maps, non-spatial datasets as tables and matrices. The toolbox has functions to import such external data and visualize them including the storage of associated metadata
- **Indicators =** a practical measure able to represent (indicate) a certain situation (e.g. "status") or aspect of a dataset using one or more quantitative or qualitative parameters, simplifying a complex reality. A comprehensive set of 619 indicators updated from the DEVOTES project (only metadata) and supplemented with indicators for CIA/CEA and status assessment are currently included. Some of the indicators already have implementations (in the form of data processing workflows) in the toolbox enabling the user to apply these indicators to their datasets.
- **Analyses =** a general framework to define dataset processing workflows for the datasets imported into the toolbox (so-called analysis templates). These are visual, graph-like representations of some numeric processing of datasets which can encompass multiple steps and outputs which in turn are visualized in the form of (geographical) maps, tables or individual numeric results.

These components are bundled into projects so user can have multiple separate project files to work with different datasets and goals.

The main components are built on top of several background data in the toolbox. These include e.g. hierarchical lists and definitions of activities, pressures and state as part of the DAPSI(W)R(M) framework (Elliott et al., 2017) in order to be able to use commonly agreed terminology and classifications such as the one laid down in the annexes of the MSFD (Annex III Table 2 in 2017/845/EU on activities and pressures) and the corresponding Commission Decision (2017/848/EU; European Commission, 2017).

As part of the background data, also the Common International Classification of Ecosystem Services (CICES) classification of ecosystem services (https://cices.eu) is already included in the software. This is one of the important classifications to use when applying the assessments with ecosystem services as their target point. Datasets on specific ecosystem components can flexibly be assigned to one or more of the individual elements of all these classifications.

Technically, this is implemented as an embedded relational database which is used for every new project created within the toolbox. This ensures that all projects use the same basic information. With every update of the software, changes to this database will be merged into older project files, thus keeping them in sync across versions as the requirements and frameworks change. The other advantage is that the project files, being single database files, always can be shared among users and will work out of the box on another computer running the toolbox.

For more details, especially on the various tools and functionality of the toolbox, see the draft software manual accompanying this document, as well as the manual in Appendix 1.

5 Current status and next steps of the framework implementation

The development of the toolbox software is a continuous effort. During the project, the toolbox has been prototyped (version 0.2 on 2023-04-30 as Deliverable D4.1) and then developed further to an initial version that could be used by the partners in the project (version 1.0 on 2024-03-11). Experiences from the Learning Sites have been fed back into the development and through an iterative process, this resulted in version 1.3 being released on 2024-08-05.

Based on these experiences, the framework of the toolbox has been revisited during summer and autumn 2024 to allow the integration of the remaining features, especially indicators, confidence assessment and indicator aggregation. This work led to the release of version 2.0 on 2025-02-03 and their subsequent bugfix releases 2.0.1 (2025-02-12), 2.0.2 (2025-02-18) and 2.0.3 (2025-02-26). The latter version is the current one at the time of writing. A detailed version history with a list of changes from version to version is included in the software manual (Appendix 1).

Development and enhancements will continue throughout the project lifetime. Feedback from the Learning Sites, the Practitioners Advisory Board (PAB) and the public will be used to make the toolbox a versatile software. The following list indicates the important features still missing:

- More basic analysis functions (including functions to apply threshold values for classification of results, e.g. according to the EU (European Commission, 2024)
- The possibility to add and work with custom classifications (basic data)
- Hierarchical CIA/CEA, expanding on the current CIA/CEA indicators
- Uncertainty assessment for CIA/CEA indicators
- Speed improvements for larger spatial datasets (above approx. 1000 x 1000 grid cells)

These will be implemented with the highest priority as they are needed for the work in the Learning Sites. Especially the implementation of the uncertainty calculations is challenging. These calculations come with a computational constraint. Since the toolbox is doing the assessment on a spatial grid that can potentially have a high number of grid cells, the uncertainty calculation will scale up the computational effort by factor of 100 and more. This implies that the confidence assessment should not be a standard calculation for each assessment as this will drastically slow down the responsiveness of the toolbox. Therefore, it will be implemented as a post hoc analysis to the assessment, i.e. an option that can be turned on when specifically requested by the user.

NEAT is already implemented into the toolbox including the uncertainty analysis using the method outlined in section 3.3. Only the option to turn it off and on during analysis is missing. Currently, it is always on. For the CIA/CEA implementation, it will be supplied in one of the next versions. Further it will be investigated whether it is feasible that the basic building blocks of this kind of uncertainty analysis are exposed to the user not only as integral parts of the indicators (CIA/CEA and NEAT) but also as independent actions that can be used in any analysis template (or indicator implementation) where users want to apply them.

Other important features to be implemented include:

- More indicator implementations such as SEAS4GES, CIMPAL, SCAIRM
- Enable analyses of datasets via scripts written in Tcl and R

The current plan is to implement these as the next priority. However, depending on the work in the Learning Sites during 2025 (testing, validation, scientific evaluation), other features might turn out to be more important.

The software manual (Appendix 1) includes a list the above-mentioned features to be implemented. In addition, the software manual lists many other features. Most of these can be described as “convenience functions”. They make it easier for users to preprocess and postprocess their data including some numerical statistics on the output of analyses. Although these functions are not essential for the work at hand (it can be done with external tools such as GIS or statistical software), having these in the software will result in a much smoother experience. It will also help to lower the barrier for using the toolbox, especially by people not having a good knowledge of how to handle and process spatial data. These functions are important for the toolbox staying alive also after the end of the GES4SEAS project.

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7 Appendix: GES4SEAS toolbox – Software manual, Version 2.0.3.

8 Introduction

8.1 Philosophy

Tools such as spreadsheet or statistical software (R, Primer, Excel, …) and specialised software for biologists wanting to conduct some sort of environmental assessments (such as GIS systems, ECOSIM, …) are the digital ages's equivalent of pen and paper and calculating devices. All those tools do specific jobs well but often you have to import data into one tool, process it there, then export it again and put it into the next tool and so forth. Although software packages such as R are capable of integrating all these tasks, they are difficult to use and require the knowledge of programming.

Making the task of conducting an environmental assessment (or other kinds of data analysis) easy to learn and to perform in an integrated toolbox is the vision of the GES4SEAS toolbox. You should be able to import and store your data, flexibly work with them and put them into an analysis of your choice and also view and assess the output – all inside the same user interface.

The GES4SEAS toolbox is a software application developed as part of the GES4SEAS project, an effort to create an integrated toolbox for assessing cumulative pressures, impacts on ecosystem components, ecosystem health/status and effects on ecosystem services in the marine environment. The toolbox aims to support the implementation of the European Marine Strategy Framework Directive (MSFD), Habitats Directive, Biodiversity Directive and other legal frameworks that are in need for spatial assessments. For this, the toolbox offers standardized, reproducible assessments.

Environmental impact assessment is an inherently complex task, involving consideration of interactions between multiple human activities, pressures exerted on the environment, responses of diverse ecosystem components, and consequences for ecosystem services provision. The MSFD specifically requires an ecosystem-based approach that combines these elements across sectors, rather than sector-by-sector assessments. However, fully implementing this integrated, cumulative effects assessment is challenging due to:

- Complexity of combining disparate spatial data sources
- Lack of standardized, transparent assessment processes
- Need for specialized multidisciplinary expertise
- Limitations in current models to capture all relevant factors and interactions
- Resource constraints for comprehensive assessments

The GES4SEAS toolbox aims to address these challenges by providing a versatile, user-friendly platform for cumulative impact and status assessments, following an integrated approach. As such, the toolbox allows users to bring together diverse spatial data sources, apply various assessment methods and generate outputs to support environmental monitoring, management, and reporting needs. The toolbox emphasizes flexibility and versatility to handle data-rich and data-poor regions, different ecosystem types and a range of use cases for researchers, stakeholders, advisors and competent authorities.

The key features include:

Data integration

- Supports a wide range of spatial data formats
- Includes pre-loaded core datasets for Europe (activities, pressures, habitats, ecosystem components, etc.)
- Facilitates linking environmental data to MSFD criteria, descriptors and reporting needs
- Comprehensive metadata documentation of imported datasets

Visual assessment workflow

- Visual workflow setup using blocks representing data and algorithms
- Ability to chain together data processing/transformation steps
- Library of indicators, partly with built-in implementations
- Flexibility to customize templates and create new assessment workflows

Cumulative Impact and Status Assessment Models

- Linear models based on impact/sensitivity scores
- Advanced models capturing non-linear ecosystem responses
- Aggregation methods (e.g. one-out-all-out, decision trees)
- Ability to weight and integrate across parameters
- Scenario testing by modifying input datasets or weights

Outputs and Reporting

- Map visualizations of cumulative impacts, pressure distributions, ecosystem component status
- Tabular outputs with integrated assessment results
- Comprehensive metadata on analysis parameters and methods

Note, that the toolbox is not restricted to this specific kind of analysis. In theory, you can use the toolbox on any kind of spatial data as long as you can classify them in terms of the available metadata elements.

8.2 About this manual

8.2.1 Terms and conventions

…

8.2.2 Referring to the user interface and menus

When the manual refers to a toolbox interface element that can be interacted with (such as a button or an item in the navigation bar), the visible name for that element is formatted in blue, such as "Click on the Compute button to start the calculations". Button labels, keyboard shortcuts and menu items are displayed in this fashion.

Menus are referred to by showing their hierarchy using the "‣" character to separate top-level, submenus, and commands. Here's an example: "Choose File ‣ Open project … to open an existing project from your computer".

Keyboard shortcuts such as Ctrl use the same styling. The following keys are used in the manual:

- list here (different for Windows/macOS/Linux)

8.2.3 Found an error or have a suggestion?

Should you find an error in the manual or have a suggestion to make a specific description better, we would like to hear from you. Just write to …

8.3 Installation and updating

8.3.1 Installing the software

No special installation procedure is needed.

The toolbox is built and available for the Windows (64bit) and macOS (64bit, Intel and M1/M2 processor) operating systems. A Linux version will be coming.

8.3.1.1 Windows

The toolbox has been tested and runs on Windows 10 and later. It is unknown whether it runs on Windows 7. Earlier versions are likely to not work.

To install the software, get the corresponding zipped file from the GES4SEAS SharePoint site and unzip it into any suitable directory on your computer. Then just start the resulting executable (double-click in it) after unpacking the zip file.

You can put the executable file wherever you want, on the desktop, in the program folder or elsewhere. At a later stage, we might distribute the toolbox with a proper Windows installer.

You may experience that a message appears after trying to open the software saying that *Microsoft Defender SmartScreen prevented an unrecognised app from starting*. Microsoft Defender SmartScreen is enabled by default in Windows and provides a reputation-based protection against malicious apps and websites. However, it can be disabled unless your organisation hasn't disallowed to change the security setting on your computer:

1 Click on *More info* in the blue window that warned your

2 Click on *Run anyway*

If you want to check your security settings as a whole:

1 Open the Windows settings

2 Click on *Update & Security*

3 Click on *Windows Security* (in older version called *Windows Defender Security Center*) in the left pane

4 Click on *App & browser control*

5 Go to *Reputation-based protection settings*

6 Do what you need to do here

If your system prevents you from making these changes, you can still run the toolbox. You then need to start the Windows "Command line" program (also called "command prompt" or "CMD"). You will need to know how to start a program from this command line program and you will then be able to launch the toolbox from here. However, you need to do this every time you want to use the toolbox. So, the better solution is to ask your IT department to enable launching the toolbox the "normal way".

8.3.1.2 macOS

The toolbox needs macOS 11 ("Big Sur") or later. It has been tested on macOS 12 ("Monterey"), 13 ("Ventura") and 15 ("Sequioa").

To install the software, get the right DMG file for your Mac from the GES4SEAS SharePoint site. As there are currently two types of Macs, there are also two different versions of the toolbox:

- g4s-toolbox-mac-x86-v2.x.dmg (for (older) Mac computers running on an Intel x86 chip)
- g4s-toolbox-mac-arm-v2.x.dmg (for (newer) Mac computers running on an M1/M2 arm chip)

You then just double click on the DMG file. A window opens where you can drag the toolbox into your 'Applications' folder. (Don't forget to un-mount the DMG afterwards.)

When you open the application for the first time, you may get the message that the application cannot be opened because it is not verified and macOS cannot inspect it for malware. In this case, you just need to open the application with a right mouse click instead to open the context menu, then select "Open" to confirm you trust it (macOS will remember this setting and don't ask again next time so you can just open it normally onwards).

8.3.1.3 Linux

(nothing here yet)

8.3.2 Updating the software

Currently, updating the software means to download a newer version and trash the older one. Later, we will provide online updates so you get notified about new releases and can install them right out of the box. If you have projects that were created with an older version and you open them in the updated software, you will get a notification. You can then either abort or let the toolbox update your project file accordingly.

8.3.3 Known issues with version 2.0

This is an (incomplete) list of known issues/limitations in the current version. If you run into this, you do not need to report it to us. We are aware of them and are working on a solution.

Apart from the missing functionality of the next versions, these few issues are the ones you will most likely encounter:

- There is a setting for the program language in the "Preferences" window but that setting only works when we have provided translations for a program strings
- Analyses can have separate isolated chains of blocks (with different input and end result, i.e. multiple terminal blocks) while only one chain should be allowed. (When this is the case, running the analysis will lead to all initial blocks showing up in the dialog window where the user chooses the set of input data. Only when a data block is not connected to another block, it will not be shown).
- When updating a project database, the metadata can sometimes not be transferred completely. The information from the metadata field "character set" (Category "Format", Subcategory "Specifications") will not be transferred if it does not match the pre-defined values. You may need to check this field for your datasets after the update has completed.
- When updating an old project file to version 2.0, sources you might have added are automatically transferred. However, this only happens when the source is used by a dataset. Sources present and otherwise not used/references, are ignored.
- Sometimes buttons in dialogs may be disabled although they should not. Often, this can be worked-around by clicking into another field in the window of clicking the buttons "Previous" and "Next" once more.

8.3.4 Version history

Notable changes …

- Version 0.2 "prototype" released 2023-04-30
- Version 0.8 released 2024-01-25
- Version 0.9 released 2024-02-11

8.3.4.1 Version 1.0 (released 2024-03-11):

- fix: dataset import has been enhanced and some errors were corrected
- completed: the metadata editor is now complete and you can (and should) enter metadata when importing datasets
- new: you can now create analysis templates and start using them in analyses
- new: in freshly created projects, you will have one example of a pre-defined analysis template (CEA based on Halpern et al. 2008)
- enhanced: a few speed improvements for map display
- changed: a more compact format of the error messages you send us as feedback when you encounter errors
- added: included a section in the quick guide about planned features

8.3.4.2 Version 1.1 (released 2024-04-21):

- new: copy analysis templates
- new: edit metadata after import
- new: show the validity of an analysis, eventually specifying the reason why an analysis is not valid anymore
- new: mark analyses as invalid when a dataset was deleted that had been used in the evaluation
- added: various analysis actions (minimum, arithmetic mean, median, logarithm, rescaling to 0..1, presence/absence)

8.3.4.3 Version 1.1.1 (released 2024-05-05):

- numerous bug fixes for data import and analysis

8.3.4.4 Version 1.1.2 (released 2024-05-07):

- fix: make sure that relevant background data are available for all text based dataset formats
- fix: made sure that not only the last column was used in matrix data import
- fix: no more shifted column headers in Excel import when cells are empty in the input data
- enhanced: speed up import code for Excel files by only reading the user-selected Excel sheet or the first one, not all ones every time
- fix: potential problem when importing text data containing single quotes

8.3.4.5 Version 1.1.3 “dove” (released 2024-05-20):

- fix: Excel import is no longer failing to read the last column and row of the data
- fix: in the ‘Origin’ metadata category a source will no longer get lost when editing metadata
- fix: the auto-corrected bounding box does no longer fail to be stored when importing text/Excel data

8.3.4.6 Version 1.2 “Levant” (released 2024-05-26):

- new: ability to load metadata from an existing dataset when importing a new dataset
- new: added support for importing datasets in Esri ASCII GRID format
- new: added support for exporting maps as Esri ASCII GRID format (user data and analysis evaluations; currently without metadata)
- new: added “edit” button to each view catalogue to edit metadata of datasets and titles of assessment templates and evaluations

- new: added a menu entry in the main menu to apply hotfixes to the toolbox (when serious bugs need to be applied immediately instead of releasing a new version)
- changed: removed the "…" button in the metadata panel for user data, use edit button below catalogue from now on
- changed: view of matrix data now only includes non-ignored columns and also shows mapped class names of all user items
- enhanced: error reporting and fixing during import

8.3.4.7 Version 1.3 "summer edition" (released 2024-08-05):

- completed: Halpern-style CEA is now working consistently with a default setting thought to be the most appropriate
- changed: the metadata editor now only shows the fields of one metadata category at a time (no more extensive scrolling needed)
- changed: the metadata editor now shows in the category list on the left for which metadata categories all mandatory fields have been filled
- new: the metadata editor now has a "summary" view listing all entered data in one page for a nice overview
- new: show size of maps in the metadata panel in terms of the number of cells
- new: a 'Transformation' analysis action to rescale values to a maximum of 1 (not rescaling the minimum as well)
- enhanced: documentation of the different analysis algorithms
- changed: moved some analysis algorithms in the "Calculation" category to the "Transformation" category for more consistency
- changed: the preview of non-text based datasets now also used the pre-defined colour for NO DATA (instead of grey) and shades of grey for the data values instead of shades of red (consistent with the map display of user data and analyses)
- fix: no error anymore when importing spatial data in text formats with an inconsistent bounding box
- fix: it is again possible to create a new analysis from the template section
- fix: exporting a map no longer crashes when hitting the "…" button to choose a file
- fix: corrected a corner-case in the update code for project files when they have inconsistent/empty analysis properties
- fix: made sure maps can only be exported when they are actually existing, as otherwise the export leads to an error

- fix: deleting a dataset used in an analysis now properly sets the invalid flag for that analysis, not causing the code to show the analysis to crash anymore
- fix: make bounding box and NO DATA values show up correctly at all times in maps
- fix: prevent crash during the preview when importing a tiff/geotiff/geopackage dataset containing only zeros- fix: prevent "Run analysis …" dialog from being kept open when hitting the "Cancel" button

8.3.4.8 Version 1.3.1 "dawn" (released 2024-11-06):

This is a bugfix release. The following features and enhancements should have been in version 1.3 already but were not included by accident. This is made up for here.

- new: another variant of the Halpern style CEA using an averaging approach on top of the cumulative sum (based on Halpern et al. 2009)
- new: additional option to Halpern style CEA templates to treat NO DATA values as zero (caution: this is a dangerous setting!)
- enhanced: unified the Halpern style CEA action blocks (based on Halpern et al. …) to the most sensible algorithms
- fix: inconsistent behaviour of the importer which could lead to crashes

8.3.4.9 Version 2.0 "novus" (released 2025-02-03):

- new: a "join" action for analyses templates allowing to transfer values from tabular datasets to maps
- new: allow users to assign a specific classification or spatial unit to pixel values of raster maps
- new: analyses can have more than one action block as the final block of the analysis (leafs in the template)
- new: analyses can have more than one result in the last action block, these are now shown individually
- new: tabular data can now be imported with custom assignment of table columns to specific "meanings"
- new: indicator section, pre-filled with 619 indicators and their metadata (an updated version of the DEVOTool indicators)
- new: provided indicator implementations for CEA and NEAT within the indicator section
- new: NEAT status assessment tool integrated into indicator section
- new: indicators and their metadata from DEVOTES integrated into the indicator section
- new: folder structure for analyses templates (soon coming to other sections as well)

- new: implemented the necessary infrastructure to soon allow user-defined scripts as analysis templates, system scripts already implemented and useable
- changed: nearly complete re-write of the importing and metadata tools for easier and quicker workflow and much more flexibility
- changed: redesign of the inner working of the toolbox for more consistency and flexibility of user features
- changed: pre-defined CEA assessment templates are now available from the new indicator section
- changed: new layout of the navigation bar in the left panel
- fix: corrected last inconsistencies in the Halpern-style CEAs
- fix: many, many bugs removed
- enhanced: toolbox now also tested on macOS Sequoia (macOS 15.2)
- incompatibility: data blocks in analysis templates using “Classification > Management stage > State” together with some other definitions might not preserve the “State” definition properly. This is due to the “State” classification having changed

8.3.4.10 Version 2.0.1 (released 2025-02-12):

This is a bugfix release. Notable fixes are:

- fix: an error when processing preconditional-mandatory elements
- fix: scrambled entries for metadata: contributor/metadata creator
- fix: metadata showed wrong sources for datasets
- fix: an existing Halpern CEA would not work anymore after update
- fix: removed superfluous old classification metadata items on updated existing datasets
- fix: sum of products analysis action was broken
- fix: enables implemented Halper CEA variants that were wrongly reported as not implemented
- fix: repaired system script indicators (settings were not transferred from template to analysis)
- fix: ensured proper transfer of apparent source types
- fix: repaired broken loading of existing metadata into a dataset during import (would fail when basic categorization was not comparable)
- fix: do not show “ghost” sources anymore together with the real sources of a dataset
- fix: do no longer pre-select items for metadata fields which are optional so user can leave them alone
- fix: do no longer pre-select items for metadata fields when user hasn’t previously stored them

- enhanced: changed metadata field for 'unit' to a table for easier usage and added an 'undefined' unit when the requested unit is not in the predefined list

8.3.4.11 Version 2.0.2 (released 2025-02-18):

This is the second bugfix release of version 2.0. Notable fixes are:

- fix: an error when importing an (ordinary) table from an Excel file
- fix: an incorrect definition of "sensitivity" in pre-defined CIA indicator implementations
- fix: an error preventing viewing indicator metadata
- fix: a sparse NEAT dataset no longer leads to an error during sensitivity analysis
- fix: ensured that analysis templates and indicator implementations really can not be altered when they should be read-only
- enhanced: detection of spatial datatype when upgrading an older project file

8.3.4.12 Version 2.0.3 (released 2025-02-26):

This is the third bugfix release of version 2.0. Fixes are:

- fix: corrected error introduced in version 2.0.2 making CIA indicators crash the toolbox
- fix: made sure that a newly created project works properly

8.4 Overview

When launching the toolbox, you will see the main window. This window is divided into three panels (see Figure @fig:start-view).

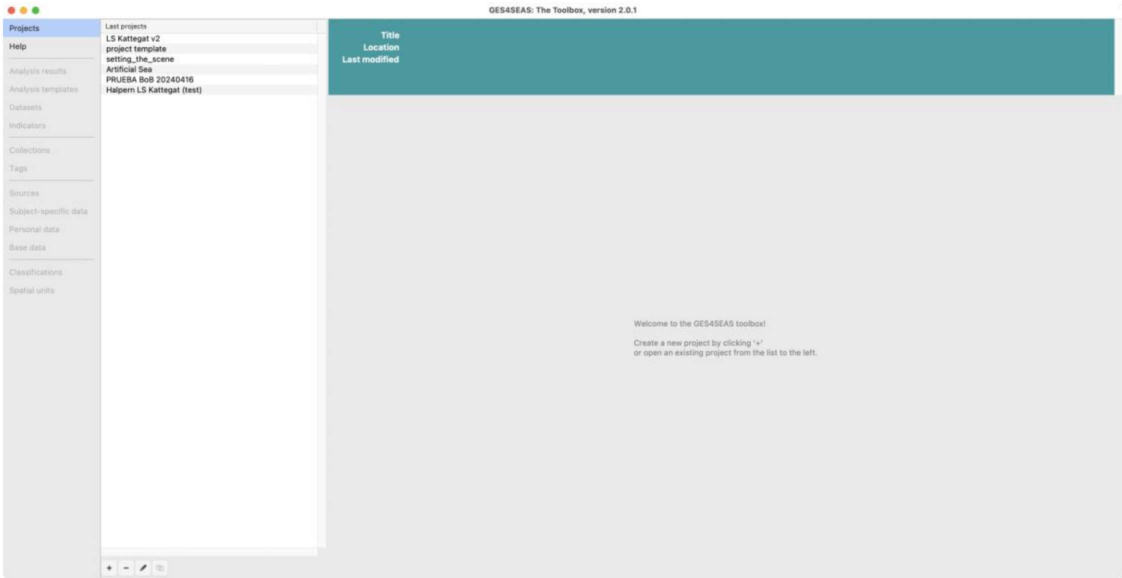
The *left panel* shows a navigation bar containing the various sections/components of the program with the different areas of functionality the program offers. On startup, you are looking at the project section.

The *middle panel* shows the list of datasets/results that are in the specific section of the program. It is a list of things that you can click on (single click) in order to see what's inside. If you have not created a project file yet, the list in most sections (including the project section) will be empty. In this manual, we will call this list the catalogue. There is one catalogue for each section of the program. As an example, we have the catalogue of projects, the catalogue of user datasets and the catalogue of indicators.

The *right panel* is the area where the content of the selected item in the catalogue are shown. This can be tables, maps and other types of content. Any item you click on in the catalogue (middle panel) (single click) will be opened and presented here (the only exception is the projects which are opened with a double click or by clicking on the “Open project” button in the right panel).

This third panel is divided into the metadata (upper part) und the actual data (lower part).

On start-up, the **Project** section is shown (Figure @fig:start-view). When a project has been used already, the catalogue remembers it for easy access.



Main toolbox window (macOS version 2.0.1) showing the three panels of the program. The window shows the start-up view of the toolbox with the list of projects (which is empty here)

To load an existing project, click on the corresponding entry in the list of projects and then click on the button saying Open project. Alternatively, you can double-click on the entry. The program then switches to the section where the Datasets are shown.

In the **Datasets** section you can view and review your own datasets that you loaded into the toolbox. You can also add/import datasets into the toolbox here.

There are two ways to run an analysis:

1 Either, go to the Analysis templates section in the navigation bar. Then either choose one of the pre-defined example templates and run them or create your own template. Then, you can create a new analysis from such a template. You are then directed to the Analysis results where you can then actually run the analysis based on the template and view the results. Click the Zoom in button in order to enlarge the resulting map. You can also zoom out.

2 Or, go to the Indicators section and choose one of the indicators which already has an implementation. You can then either make a copy of this implementation into a template that you can subsequently modify, or you can create an analysis directly from this implementation.

The latter is the easiest way to actually apply some dataset you have to a specific indicator and thus apply the indicator with your data.

The generated results are automatically saved to the project file when you operate on existing projects. There is no need to specifically save the data or projects manually.

9 Main components

The toolbox includes a number of tools to operate with. These are currently:

- Analyses = results of calculations done with some data – this can be simple calculations but also complex ones as used in assessment systems
- Indicators = a catalogue of environmental indicators including their metadata, partly with an indicator implementation used to calculate the indicator value(s)
- Datasets = spatial and non-spatial datasets added by the user and used to do analyses with
- Sources = a catalogue of literature references used for the various components and items in the toolbox
- Analysis templates = abstract descriptions of a numerical analysis that can be applied to datasets – a description of the processing/calculation steps needed to perform an analysis

These main components are described in detail in the following sections.

9.1 Projects

This section lists all the projects that you have once created or opened with the toolbox.

Projects are a good way of structuring your data. You might want to have one project for a specific assessment you want to make or for a specific other task. Projects are separate from each other so the datasets are also separate and can't interfere. (Later, we will support copying datasets, analysis templates and analysis results from one project to another).

In order to import datasets, you need to first create a new project. Click on the "plus" button below the project catalogue or into the menu item File ‣ Create new project …. You can then choose the name of the project which will appear in the project list inside the toolbox, and you can choose a file name.

After creating a new or opening an existing project, the view will automatically switch to the "Datasets" section unless you have switched that behaviour off under the toolbox preferences.

You can change some settings of the project (project title and associated file) under the menu item File ‣ Project settings …. You can e.g. fix the location of the project file when you have moved it to another folder on your computer and the toolbox is thus not able to locate it anymore as the location information is then out of date.

More to come later on …

- creating a new project
- open/load projects (project files)
- working with projects
- saving projects
- sharing project file

For even later: - merging projects - importing data from other projects

9.2 Analyses (and assessments)

Note: This section is clearly unfinished. For now, please also refer to the recording of the toolbox workshop from February 2025 which you can find on the GES4SEAS SharePoint under "WP4:Operational Tools > Meetings > toolbox v2.0 presentation".

An analysis is any manipulation of a dataset which is part of your project. As an example of a simple analysis, you might want to know the maximum value of all cells in a spatial raster dataset. For this, you can evaluate the dataset using the corresponding analysis function. An analysis can also involve a series of steps or functions. For example, a dataset might first be normalised to a specific range of values, then the average is taken from those normalised values. An assessment is typically a more complex kind of analysis, involving a classification of the resulting values into categories such as success/fail or good/bad. In other words: any assessment is an analysis, but not all analyses are also assessments.

9.2.1 Analysis evaluation

An analysis result is the outcome of the application of an analysis template (see section Template editor). In the evaluation, you specify which specific datasets should act as input data in the data blocks that are part of the analysis template. This also means, a template can be use multiple times for different datasets resulting in different analysis results. The input data are then different, but the specific calculation steps are the same for all analyses using the same template.

After the evaluation of the analysis, the result is shown in the right panel of the toolbox. An analysis can have more than one result. If this is the case, the individual results are listed under the name of the analysis and clicking on the items will show the individual result. If your analysis template has more than one action block, you can specify to keep the results from the intermediate blocks as individual results. As default, only the results of the last evaluated block will be kept.

Depending on the type of the result, you get a different view:

spatial raster data

A geographical map will be shown representing the result of the analysis (see chapter Maps to learn more about the map display)

tabular datasets

a table will be shown with the resulting numbers

a number

the resulting numeric value will the displayed

Obviously, when an analysis has been evaluated, the result is valid, as shown in the metadata panel above the result. However, there can be reasons why an already evaluated analysis becomes invalid:

- a dataset was deleted that was used in the last evaluation
- the analysis template has changed its structure or content in some ways

This will invalidate an analysis, meaning that it will probably not give the same result when evaluated again. It does not mean that the analysis cannot be repeated or the current result is now wrong. It just means that your current result will probably not get reproduced. So, if you want to keep the previous result you should rather create a new analysis with a (changed) copy of the template instead of re-evaluating the existing analysis.

When a spatial map is the result of an analysis, you can export this map to the Esri ASCII GRID format (more formats will come later). When the result is a table, you can export the data as a csv file. Just as for user datasets, click on the export button below the analyses catalogue (the icon looks like an arrow in a box pointing upwards).

9.2.2 The pre-defined analyses

The toolbox comes with two pre-defined analysis templates. The templates exemplify some calculations that you can do with the toolbox. These templates are located in a folder within the catalogue called “toolbox templates”. You can not edit or delete them but you can make a copy of them if you want to change these templates for your own use. Your own templates are within the folder called “user templates”.

9.2.3 Interpreting analyses results

9.3 Indicators

Indicators in terms of the toolbox are not abstract concepts just as indicators in e.g. the commission decision of the MSFD. Rather, they are specific entities that can be practically used to indicate something quantitatively about an ecosystem. An indicator can have a specific analytical implementation and then takes datasets and calculates some quantity that then indicates something about the ecosystem the dataset is from.

The toolbox includes all indicators that have been collected during the DEVOTES project, including their metadata. In addition, the indicators used for making analyses within the toolbox have been supplemented with an implementation, i.e. a series of steps needed to actually calculate the indicator using some specific real datasets. This implementation uses the same framework as the “analyses templates”.

Currently, two groups of indicators have an implementation: CIA/CEA cumulative impact score, NEAT nested environmental status assessment tool.

There are two ways to actually calculate the outcome of an indicator (when an implementation is available in the toolbox). You can either directly do the analysis using the implementation stored in the toolbox or you can make a copy of the implementation first.

The first method is applied by clicking on the “Export/Share” button below the indicator catalogue and choosing “Make new analysis from this indicator”. The implementation is then directly applied and a new analysis is generated which you will give a name. The analysis is subsequently stored under the section “Analysis results”. Note, that this action only creates the analysis but does not run it yet. To do the calculations, click on “Run analysis” in the “Analysis results” section. As this method uses the implementation of the indicator stored in the toolbox, every update of the toolbox may alter this implementation (e.g. when errors/bugs are found) thus making the analysis result invalid, meaning you will not be able to reproduce the previous result.

The second method is applied by clicking the “Export/Share” button below the indicator catalogue and choosing “Copy indicator implementation to a new analysis template”. In this case, you will get a copy of the implementation and this copy will be placed into the “Analysis template” section. You could then also modify the template here as it is no longer write-protected as is the case for the indicator implementations provided by the toolbox. To make an analysis using this template, follow the instructions as outlined in chapter Analyses (and assessments).

9.3.1 Cumulative impact score (based on Halpern)

This group of indicators is based on the work by Halpern et al. (2008, 2009)[1]. It is fundamentally a weighted sum of products where the weighting comes from a sensitivity matrix assigning a weighting factor to each pair of a pressure and an ecosystem component. Two variants of the algorithm are currently implemented. One is following the original approach (sum, based on Halpern et al. 2008) and uses the weighted sum. The other is adjusted in a way (average, Halpern et al. 2009) where the cumulation sum is also divided by the sum of ecosystem components *present???* (per grid cell) to form a kind of average. This variant should be used as the default.

For both variants, the input data are one set of spatial datasets representing ecosystem components and another set representing pressures. In addition, a sensitivity matrix needs to be specified (a non-spatial dataset).

The implementations of these indicators contain the calculation steps needed to do the cumulative effects assessment based on the work of Halpern et al. (2008). The implementation has three different types of data as input datasets to be able run an analysis:

- datasets representing ecosystem components (classified under *Management stage > State > Biotic state components*)
- datasets representing pressures (classified under *Management stage > Pressure*)
- a sensitivity matrix between the above two (specified as *Format > File > Data type: 'non-spatial data'*)

The three types of datasets you provide for this analysis must share the same classifications (specified in the metadata). The data themselves should be raw data representing the real levels of ecosystem components (ideally no presence/absence data but using abundance/biomass or another measure) or pressures (pressure levels, concentrations, magnitude of pressure, …). The implementation then takes care of data transformations.

There is a setting for each variant that allows to treat certain combinations of ecosystem components and pressures specially. A cell in a spatial dataset can have three different kinds of values. A real (numerical) value above 0, the value 0 (zero) or NO DATA (when nothing is known about the data). If for some datasets a cell has a value of 0 or NO DATA, then the combination with another dataset will give different results when combining ecosystem components (EC) with pressures (Pres) by

[1] Halpern BS, Walbridge S, Selkoe KA, Kappel CV, Micheli F, D'Agrosa C, Bruno JF, Casey KS, Ebert C, Fox HE, Fujita R, Heinemann D, Lenihan HS, Madin EMP, Perry MT, Selig ER, Spalding M, Steneck R, Watson R (2008) A Global Map of Human Impact on Marine Ecosystems. Science 319:948–952. — Halpern BS, Kappel CV, Selkoe KA, Micheli F, Ebert CM, Kontgis C, Crain CM, Martone RG, Shearer C, Teck SJ (2009) Mapping cumulative human impacts to California Current marine ecosystems. Conservation Letters 2:138–148.

multiplying their values to a partial result/score (note, that the table is symmetric in the sense that you could change the order of the first two columns and still the result will be the same.):

EC	Pres	Partial result	Case explanation
NO DATA	NO DATA	NO DATA	0
NO DATA	0	0	1
NO DATA	value	NO DATA	2
0	NO DATA	0	3 (a)
0	0	0	3 (b)
0	value	0	3 (c)
value	NO DATA	NO DATA	4
value	0	0	5
value	value	value	5

- 0 = Obvious case with no information whatsoever
- 1 = We do not know whether the ecosystem component is present, but we know there is no pressure, therefore the result will always be 0
- 2 = The pressure is present, but we do not know whether it acts on the potential ecosystem component, therefore we know nothing about the resulting * effect
- 3 = The ecosystem component is not present, so a pressure cannot act on it, regardless of it being (un)known or its value
- 4 = The ecosystem component is present, but we do not know whether the pressure is, therefore we know nothing about the resulting effect
- 5 = The only cases where there is no doubt about what the result will be

When the algorithm determines NO DATA for any partial result in the process, the total score for that cell will be NO DATA (even if some of the combinations would result in numerical values). The additional option allows to you to ignore this. When active, the setting treats the three cases of NO DATA (in terms of the result) as zero instead.

Important warning: Activating this setting may result in some very low impact scores (depending on the amount of datasets used and the fraction of NO DATA values) making some cells look as if the score indicates an almost pristine condition in the resulting map. That is because of NO DATA being treated as zero and thus pretending to indicate no impact/effect. Use this option for testing/prototyping only!! Otherwise your maps may end up being completely misleading in terms of the resulting impact score!!

The input data are the raw values for both ecosystem components and pressures. The algorithms will take care of value transformations as needed. The only precondition is that all values provided should be non-negative numbers. The calculations will skip combinations for which a sensitivity score is not defined in the sensitivity matrix (but for every combination where the sensitivity matrix provides information there must be a value present).

The calculation principle of a cumulative impact score is not restricted to these two types of data (ecosystem components and pressures). It can also be applied to other entities instead such as human activities instead of pressures (using them as a proxy for pressures). As long as it makes sense ecologically, any sensible type can be used.

The calculation process is as follows (for every dataset individually):

1 An ecosystem component dataset not used in terms of presence/absence is rescaled to values with a maximum of 1. The dataset will only have zeros if the value was 0 in the original dataset.

2 A pressure dataset is further log-transformed using the logarithm with base 10 on the value plus 1 ($\log(value + 1)$). The addition of one is done to avoid negative results. (Note: There is no log-transformation on ecosystem component values.)

Note, that the log transformation is not done exactly as written above. In order to avoid the transformed values depending on the range of untransformed values and hence, different measurement units that might have been used for the datasets, the following scheme is used: rescale the value to a maximum of 9, then add 1 to the result and apply the logarithm base 10. This makes sure that the minimum value is 0 and the maximum value is 1 ($= \log(9 + 1)$).

In both variants of the impact score (sum or average) there are five different configurations of which two are already implemented:

EC as presence/absence

This is the most simple impact score where the values for the ecosystem components (EC) are treated as 1 (present) or 0 (absent) or are supplied as such already. For the pressures, the values are used.

EC with values

In this configuration, the values for both the ecosystem components and the pressures are used.

EC with values and hierarchical structure (not yet implemented)

This configuration is like “EC with values” but the final weighting of both the pressure and ecosystem components are calculated using the hierarchical structure of those entities (see “NEAT” for details).

EC as ES with values (not yet implemented)

This configuration is also like “EC with values” but instead of using the values for the ecosystem components, these are first transformed into a value representing the ecosystem services (ES) they provide.

EC as ES with values and hierarchical structure (not yet implemented)

This configuration is a combination of “EC as ES with values” and “EC with values and hierarchical structure”.

Note: it is only possible to use these cumulative impact scores directly with data blocks as input data. If an action block is the input of the cumulative impact score action block, then it will fail. This may change in future.

9.3.2 Status assessment (based on NEAT)

The Nested Environmental status Assessment Tool (NEAT) developed during the DEVOTES project (Berg et al. 2019)[2] is the basis of this status assessment indicator used in GES4SEAS. The original NEAT system is not a spatial indicator in the strict sense as it does not produce spatial output (maps with NEAT values). However, as NEAT values also can be assigned to specific spatial assessment units (SAUs), they can easily be assigned to raster cells of a map and thus shown on a map of SAUs. The inherent spatial nature of NEAT can thus be exposed in the form of maps.

9.3.2.1 Non-spatial NEAT

9.3.2.2 Data preparation

In order to calculate NEAT in its original form, you need to supply a table with indicators and their values, error values etc. This data is imported into the toolbox as an ordinary table. The table can be imported from a simple text file (csv) or from Excel and must have at least these seven columns:

column	description	formatting
Indicator	This is the name of indicator for which a value is supplied. Currently, this name can be anything as it will not be linked to the indicators present in the toolbox. (This makes importing indicator values easier. In a future version, indicators will be linked to the ones present in the toolbox. If an indicator is missing, it would then need to be created in or	A text string identifying the indicator.

[2] Berg T, Murray C, Carstensen J, Andersen JH (2019) NEAT – Nested Environmental status Assessment Tool. Manual – Version 1.4. Update of Deliverable D6.3 of the DEVOTES project (grant agreement 308392). 39 pp.

column	description	formatting
	imported into the toolbox in the first place.) There can be as many entries of a specific indicator as needed (e.g. the same indicator but applied to different SAUs).	
Value	This is the value which the indicator was calculated to in the specific setting used here.	A numerical value.
Error value	The is the error value assigned to the indicator value. Typically, the standard error can be used here but any other quantitative measure of an error margin is possible.	A numerical value.
Spatial unit	This is a SAU, the spatial assessment unit name which the indicator value was applied to. The name can be anything but needs to be assigned to a spatial unit as defined by the toolbox during import.	A text string.
Habitat	This is the habitat within the SAU for which the indicator was calculated. The name can be anything but needs to be assigned to a classification item from the 'State' category during import.	A text string.
Ecosystem component	This is the ecosystem component within the habitat for which the indicator was calculated. The name can be anything but needs to be assigned to a classification item from the 'State' category during import.	A text string.
Class boundaries	This is the list of class boundaries into which the indicator value falls and defines the indicator scaling and class for the indicator value. These boundaries are specific for the combination of a SAU/habitat/ecosystem component.	A list of key value pairs. See below for the exact format.

The class boundaries must be specified in a standardized way so that the toolbox can parse them. As an example, the list may look something like this:

```
min 0 max 1 gm 0.6
```

So, the list contains of words where each word specifies a class boundary and the following word is the value for that class boundary. The scale always describes a scale having five status classes. The following keys are defined representing an ordered set of classes as (from the worst to the best) 'bad', 'poor', 'moderate', 'good', 'high':

- min = the minimum value an indicator can have on the scale of possible indicator values
- max = the maximum value an indicator can have on the scale of possible indicator values; this is equivalent to the reference value

- hg = the boundary between the 'high' and 'good' status class
- gm = the boundary between the 'good' and the 'moderate' status class; this is equivalent to the threshold value between success/failure, passed/failed, GES/non-GES
- mp = the boundary between the 'moderate' and the 'poor' status class
- pb = the boundary between the 'poor' and the 'bad' status

In the example above, this translates to having a scale where 0 marks the minimum value, 1 marks the reference value and the threshold boundary between good and moderate status is 0.6. These three keys and corresponding values always must be present. The others are optional and will be calculated by linear interpolation if they are not specified. A full specification might look like this:

```
min 0.3 pb 0.45 mp 2.383 gm 5 hg 7.2 max 12.9
```

Note 1: The scale of values must not go from 0 to 1 as in the first example. The toolbox will, however, internally transform your custom scale to a normalized scale ranging from 0 to 1 and having equi-distant class boundary values leading to classes that are exactly 0.2 in width. This is necessary for comparing values of different indicators using different class boundary scales.

Note 2: The ordering of the keys in the list is arbitrary. You do not need to start with 'min' and then follow the order of the classes. The toolbox will figure out automatically (using the names of the keys) where the values need to be applied.

Note 3: The class boundaries are interpreted such that the values themselves always belong to the higher class. It can be represented like this (using the normalized scale as an example):

```
0 <= bad < 0.2 <= poor < 0.4 <= moderate < 0.6 <= good < 0.8 <= high <= 1
```

So, a value of 0.4 will already belong to the 'moderate' class, not to the poor class anymore.

Besides these monotonously increasing/decreasing classification scales, the toolbox also supports bell-shaped indicators. These are characterized by having one maximum value and two minimum values (one lower minimum and one upper minimum) and then also two values for the other class boundaries. Such indicator scales are specified by adding the suffix '1' or '2' to the respective boundary key. For example:

```
min1 0 max 1 gm1 0.6 min2 2 gm2 1.5
```

9.3.2.3 Running the indicator implementation

For calculating NEAT on a specific file containing indicator values, follow the instructions in the beginning of this chapter.

The actual process of running the analysis is the same as for other analyses. First, you need to specify the dataset which contains the NEAT values. Next, you can specify if you want to keep also intermediate results of the calculations. As for NEAT, there are none. Finally, you can specify the setting for this particular analysis.

NEAT has quite a number of settings that you can change to your particular situation. The most important ones are that you need to assign the analysis to a SAU, habitat and ecosystem component hierarchy. You simply pick the ones from the available classifications that are fitting the classifications used in the datafile during import.

The other options may be left alone, leaving them in the default configuration. Currently, these options are only described in the original NEAT manual (Berg et al. 2019 [3]) but will be included here also later.

The result of such a NEAT assessment has at least three different individual results: a table with the NEAT values, a table with the final weights of a habitats involved in the analysis and a table with the confidence data used to also produce the spark lines in the first table. When you have chosen to also run the sensitivity analysis, an additional table is produced.

9.3.3 Spatial NEAT

9.3.3.1 Data preparation

The first part of preparation for a spatial NEAT assessment is the same as for the non-spatial variant (see above). On top of that we need to prepare a map of SAUs so that the NEAT values can be put into a map. This map is just a spatial raster dataset like any other map used for an analysis. Every value for a pixel/cell of the map represents a specific SAU. However, as the raster map only stores numeric values, the toolbox does not know which value corresponds to which SAU. This needs to be specified by clicking on the "…" button below the dataset catalogue having the SUA map selected. Here, you can choose "Assign raster map values to spatial units …". A window appears which two lists/tables. In the upper (hierarchical) list choose the spatial unit scheme you want to use. It must fit to the ones used for the indicator values. Then, in the lower table your pixel values from the map will be shown in the left-most column. In the right column you can subsequently choose the specific spatial unit which is represented by the corresponding pixel value. After this process, this assignment of pixel values to

[3] Berg T, Murray C, Carstensen J, Andersen JH (2019) NEAT – Nested Environmental status Assessment Tool. Manual – Version 1.4. Update of Deliverable D6.3 of the DEVOTES project (grant agreement 308392). 39 pp.

spatial units is stored along with the map data and now the map can be used as the seconds input dataset of a spatial NEAT assessment.

9.3.3.2 Running the indicator implementation

Run the indicator analysis just like the non-spatial one. In the results you now have one additional individual result which is the map with the resulting NEAT values.

9.4 Datasets

This is the section where your datasets live. After creating a new project, you will want to import some datasets here. For the time being, you can import spatial data in terms of raster data and non-spatial data in terms or matrix data (e.g. sensitivity matrices) or ordinary tabular data (e.g. NEAT indicator scores).

What is spatial raster data? In principle, every image file carrying geographic information so it can be shown in a GIS (geographical information system) at its correct geographical position and extent is spatial raster data. Such an image file consists of square cells (pixels) and each cell is identified spatially by a pair of geographic coordinates when it is of the type "spatial raster data". This is the case for e.g. the GeoTiff format which is a tiff image file enhanced with geographical information. – Spatial raster data can also be represented in other ways. Tabular data in text form (csv or Excel, as an example) can also be spatial raster data when the datasets have columns with coordinates and a column with some value representing something that is present at this coordinate.

Note: the toolbox only supports raster data with square raster cells. For datasets that are not text (csv) or Excel files, the toolbox has a tolerance value of 0.001 in CRS units when checking for square cells. If the difference between both dimensions of the cells differs by more than 0.001 CRS units, it is assumed that the cells are not square and the import will fail.

After importing a dataset, it will be shown in the dataset catalogue and you can click on it to see the spatial data as a map in the right panel. It may take some seconds to show up, depending on the size of your dataset. We have tested that datasets with up to roughly 1,000 by 1,000 cells should be reasonably fast. Larger datasets become increasingly slower to work with and the toolbox may seem frozen working with very large datasets right now.

9.4.1 Working with datasets

When you click on a dataset entry in the catalogue of datasets, a map will show up when the dataset is a spatial raster dataset and a table will be displayed when the dataset is non-spatial.

The map is a simple grey-scale coloured map where white corresponds to a value of 0 and black corresponds to the highest value in the dataset. A pale greenish colour specifies the area within the map where no data are present. You can change this colour in the toolbox preferences.

You can always edit the dataset metadata after import. To do so, click on the pencil button below the list of datasets. The metadata editor will appear and you can change some of the metadata.

9.4.2 Exporting datasets

Currently, you can export your datasets in the Esri ASCII GRID format. This is a very simple format which virtually any GIS system should be able to read. We do not yet export metadata together with the dataset.

To export, just click the dataset, then click on the export button below the list of datasets. It looks like an arrow pointing upwards out of a box. You will be prompted for a file name and the file is then saved into the chosen location.

10 Specific functions

In several places within the toolbox, some tools or functions appear repeatedly:

- Data importer = a set of pages used to import data into the toolbox
- Metadata editor = an editor to create, edit and inspect metadata associated to toolbox data
- Template editor = an editor used to create, edit and inspect data processing workflows
- Maps = geographical maps that can appear as showing datasets and analysis results

The following sections describe in more details what these tools do.

10.1 Dataset importer

Note: Right now, we are mainly putting functionality into the toolbox. Speed optimisation is on our list but needs to wait a bit still.

Note further: You can import datasets using geographic coordinates (such as WGS84 or ETRS89 in decimal degrees). In order for this to work, the cells also need to be square in terms of the CRS units. As an example, if the cell size is 0.05 then the cells are 0.05 degrees wide in each of the two directions. To be on the safe side, use projected coordinates instead, such as “ETRS89-extended / LAEA Europe” or “ETRS89 / UTM zone 32N”. These coordinates are in metres instead of degrees and behave the way you will expect at all times.

The toolbox currently, assumes that all data values in spatial raster datasets are non-negative values. Thus, the data should contains either the value 0 (zero) or positive numbers.

10.1.1 Loading/importing datasets

Once you import datasets into the toolbox, they will be stored in the project file of your open project. Thus, you only need to import the datasets once and after this they are always available when you open the project.

To import data, you click on the “plus” button below the list in the catalogue of datasets. Then, a window appears having five pages that you need to step through during the import process.

Be patient! Right now, the software is not yet speed-optimised. You may encounter delays when moving from one page to the next or within a page when you change options and customise your import. A lot is going on behind the scenes and sometimes you just need to wait a few (or a few more) seconds until something happens.

In one of the next releases, we will hopefully provide a progress bar or a similar visual indicator of the progress during each step!

10.1.1.1 Page 1 – Data file and options

Here, you choose the file to import. Depending on the type of data you have, different file formats are supported. During the process of importing data, you will need to pick the non-spatial or spatial datatype so the toolbox knows how the data are organized. The following table gives an overview:

Datatype	File format
Spatial – raster	Geopackage, tiff, GeoTiff, ESRI ASCII grid
Spatial – coordinates representing a regular grid	csv text file, Excel
Non-spatial – matrix	csv text file, Excel
Non-spatial – (ordinary) table	csv text file, Excel

As an example, a text file containing a sensitivity matrix is the datatype “Non-spatial – matrix” while a raster map imported from a Geopackage is datatype “Spatial – raster”.

On Windows, the file dialog defaults to only show Geopackage files as these are probably the most frequent file format you will import. To see other file format, use the button on the lower right of the file dialog to change the format. On macOS, this option does not exist and all files are shown.

After picking the file, check the “data options”. These determine what kind of information is requested on the following pages and gives the toolbox the necessary information to check the correctness of the data. The most important options is to specify whether you are importing spatial data (.i.e. a raster map or a set of coordinates in a regular grid) or non-spatial data (.i.e. a matrix or table). If you are importing a file having a format that only allows spatial data anyways (Geopackage, tiff, GeoTiff), this option is set to “spatial data” and disabled.

If you data is taxon-specific (e.g. a map of the abundance of a specific species) then check the corresponding checkbox. When the data covers a time period as opposed to a specific point in time, you can also specify this. The consequence of these two options is that you get to see some metadata fields were you can further specify what kind of taxon and what time period is covered in your data. It has currently no influence on how you will be able to use the data in the toolbox. Especially, checking “Data contains a period of time” does *not* imply that you can import time series data, e.g. a file containing the abundance of a species with data for every year over a 10 year period.

Click “Next” when you are ready.

10.1.1.2 Page 2 – Data type

Depending on whether you have spatial or non-spatial data, you will be asked what data type the file contains.

1.1.1.1.1 1. Spatial data

When you are importing raster data (tiff or geopackage or some other binary format), the toolbox will automatically detect the needed information and show you some dataset info on this page. If you are importing a text-based datafile (csv/txt or Excel), you need to specify what type of data you have. For the time being, it is always “coordinates representing a regular grid”. As the toolbox can not automatically determine the CRS, cell size and cell reference, you have to specify this for text-based datafiles.

1.1.1.2 2. Non-spatial data

When you are importing non-spatial data, you need to specify whether your data represent an (ordinary) table or a matrix as defined above.

10.1.1.3 Page 3 – Preview

Depending on the data format (binary file or text/Excel file) you will see a page with either a coloured preview image (when importing a raster data image file) or a page with a table (when importing text/Excel file).

1.1.1.2.1 Binary spatial files (images)

When opening datasets in tiff/GeoTiff or Geopackage format, you will be presented the possibility of choosing the layer to import (for Geopackage) or the raster band (for both Geopackage and tiff/geotiff). Below the options, you will see a preview of your data. Real data values are shown in shades of red, “no data” values are shown using the colour defined in the toolbox preferences (the defaults is some pale green). A value of zero is white and the maximum value in your dataset is displayed as black (i.e. the colouring is relative to the range of the values).

Choose the layer and/or band you need, then press “Next”.

1.1.1.2.2 Text/Excel files

For tabular data representing spatial data (text files as csv or similar and for Excel), there are more options. You can choose to specify whether your table has a header row and in which row the actual data start. The preview in the lower part of the page is by default restricted to show only 100 rows of your input data. You can change this if you need to see more row but be aware that this slows down the preview. If you are importing data from Excel, there will be an option to select from which sheet of the Excel file the data should be imported. You can change the values of these options and the preview will update and show a part of your dataset so you can see how the import will be done.

Also, for this kind of data format, you need to assign the columns to specific meanings. For spatial data, three of the columns in your dataset must be assigned a meaning. Each spatial dataset needs to have a column for the x coordinate (latitude/northing), for the y coordinate (longitude/easting) and for the value (the actual data). This, means that you need to pick a specific column in the preview section and set the combobox in the row “Assignment” for the respective columns to either “x” or “y”. The third column will carry the actual value for the corresponding raster cell represented by the coordinates and needs to be assigned to “value”. All other columns are subsequently “not assigned”.

For each of the columns, you should also set the correct “Columntype” in terms of the datatype (integer number, double (= real floating point number), text or EQR (a floating point number between 0 and 1)). This helps the toolbox to make sure the data are correctly imported.

You also may want to keep more columns of your dataset, not only the assigned ones which are automatically included in the import. To do so, just check the box saying “include” in the respective column and other “not assigned” columns will also be imported. These can later be used for reference when viewing the dataset.

For non-spatial matrix or tabular data, the process is similar. You assign columns and rows of the dataset to a specific meaning by using the corresponding comboboxes and picking the correct item. In some cases, it is enough to just pick an item from the list. In other cases, a new window will appear where you need to specify for each value in your dataset column/row, what this value represents. This is the case when you assign a column/row of your dataset to a classification or a spatial unit.

When all is done and no error message have popped up, press “Next”.

Note 1: When you import text files having a comma (“,”) as the decimal separator, the comma will be treated as if it was a decimal point. You do not need to convert your (localised) files from comma to point in order to import them. This will be a setting that you can customise in a future version if you want to treat the comma specially.

Note 2: A csv file for import should only contains lines for cells where you have data (each of the lines have at least three columns: two coordinates specifying the location of the raster cell and a third column with the actual value). There is no value to specify missing data. Missing data are not part of the file. All cells in between the ones you have in the file are found automatically and treated as “NO DATA”.

Note 3: If a cell in the header row of your data is empty, the toolbox will generate a generic name for this header cell starting with "myCol".

Note 4: Empty lines in text files are ignored during import and do not show up in the preview while empty lines from Excel will show up as they appear in Excel, namely as a row of empty cells.

10.1.1.4 Page 4 – Checking the dataset

In this step, the toolbox will check whether it can use the dataset. If some problem occurs, you will get a message and can possibly correct the information you provided. Sometimes, you will get a pop-up message telling you that the toolbox can't use your dataset for some reason. If everything is well, click "Next" to proceed.

10.1.1.5 Page 5 – Entering metadata

Here, all metadata should be entered in order to provide the toolbox with the necessary information to actually use the dataset properly. Some elements of the metadata are mandatory (marked with an asterisk), others are optional. The metadata are divided into nine different categories ranging from basic information to specific metadata information (see chapter … for details). The list on the left of the page shows these categories. Clicking on the categories will bring you to the metadata you can enter within the categories. When all mandatory elements are specified, the background colour in the category list turns from reddish to green indicating that the input meets the minimal amount of metadata to enter. See section Metadata editor for details about the individual metadata items.

To get a compact summary of the entered metadata, click on "Show summary". The right part of the page will then show all entered metadata across all categories at once. The button changes to "Show editor" and clocking on the button again will bring you back to editor where you can edit the metadata.

If you have an existing dataset in the toolbox already that is very similar to the one you are importing, you can click on the button "Load metadata", choose an existing dataset and the toolbox will populate the metadata editor with the metadata from that dataset. You can recognize the populated fields by the blue colour of the label in front. Note: when you had entered some metadata already, these will be overwritten.

Click "OK" when you are done.

When everything is correct, you can see your dataset in the toolbox. When the dataset is a spatial one, you will now see a map representing these geographical data (see chapter Maps to learn more about the map display). When the dataset is non-spatial data, you will see a matrix or tabular representation of the dataset.

10.1.2 Notes on loading/importing non-spatial datasets

Currently, the only sensible types of non-spatial datasets to import are matrix and tabular data.

10.1.2.1 Matrix data

These are data that assign a value to a specific combination of two entities. An Excel spreadsheet is a typical matrix. You have columns that are named by letters (A, B, C, …) and rows that are named by numbers (1,2,3, …) and each numerical value that you have entered inside the spreadsheet can be referenced by a combination of the names of a column and a row. As an example, the combination "A3" would reference the cell in column "A" and row "3" and thus the value inside that cell.

In the toolbox, matrix data are used when doing specific analyses such as *cumulative impact scores*. For these, you typically need sensitivity scores that specify the sensitivity of an ecosystem component against a certain pressure. If you imagine an Excel spreadsheet where the ecosystem components are written into the cells of the first column (column "A") and the first row (row "1") contains the names of the pressures, then the sensitivity score would go into the cells referencing the various combinations. This is now a sensitivity matrix and the toolbox is able to load these kinds of matrices. Here's an example of such a matrix table:

	Physical disturbance to seabed	Input of other substances	Input of nutrients	Input of organic matter
Other benthic habitats	1	6	20	4
Circalittoral mud	2	7	30	6
Infralittoral sand	3	8	40	5
Infralittoral rock and biogenic reef	4	9	50	3
Pelagic broad habitats	5	10	60	2

The ecosystem components are listed in the first column, the pressures are in the columns starting from column 2. The sensitivity scores are then in the cells starting from row 2, column 2. Note, that a number has to be specified for each combination of an ecosystem component and a pressure (later versions will be able to use categories instead of numbers). You cannot leave the cell blank.

How to import such a matrix is best explained using the shown example data. When opening such a matrix file in the toolbox (either from a text file or from an Excel file), you need to pick the right import options:

What kind of data do you have? Make sure that “non-spatial data” is shown here (page 1 of the import process)

Row/Column assignment in: if you have a matrix as in the example above, you click into the first column/row within the blue area at the margin of the preview. However, you might have a matrix that has multiple column/row headers (more than one header row). Then, click into the row margin of the row/column that contains the actual names of what you want to be imported (typically either pressures or ecosystem component names)

Matrix data are in cells: Click into the preview table where the upper left cell of you data is, i.e. where the actual data values begin. The toolbox will then use all cells starting from here and ranging to cell at the bottom right of the datafile

Rows to show: if you have a very large dataset, you can limit the number of rows to show up in the preview below. For matrix data, 1000 rows will be shown by default

Delimiter: This is the character that separates the columns in the dataset. Typically, this is a comma or a semicolon. If you do not see the correct data columns in the preview below, the toolbox will probably not have chosen the correct delimiter here for your particular dataset

Value format: specify here what kind of data you have. This will help the toolbox to check the data for correctness

Every time you change one of the options and go to another option field, the preview area updates and indicates you the dataset according to the chosen rows/column and cells. This may take some time when the dataset is large, so be patient.

When specifying the row/column assignment, a new window will appear where you specify the row/column items as belonging to a specific classification. As we have (in our example) something we can call a “Biotic component”, we choose that item from the list. Note: this (hierarchical) list is essentially the same as in the “Classification” category of the metadata. You can also find these in the “Classification” section of the toolbox.

Note: Which classification to pick here depends on your needs. However, when you want to later make some analyses, you will want to pick the very same classification that you have used or want to use for your corresponding spatial datasets (you classify your spatial datasets in the “Classification” category of the metadata editor during import). Otherwise, the analysis algorithm cannot locate the sensitivity scores.

After choosing a class from the list we get the contents of the row/column. In the lower panel you will see a list containing the values of your row/column of the matrix. In the second column, you will either have the text “not assigned” (in a red row) or some string matching your column name (in a green row). How this looks like depends on your row/column values/names. If you have named the ecosystem components the same as the entries of the classification you are using, the toolbox will automatically pick the first matching entry and display the automatic match. If you have chosen some other names, a match may not be possible and you have to do it manually. In order to do this, you click on the text saying “not assigned” and a combobox appears offering the possibility to pick one of the entries of the classification chosen in the upper panel. After you have done that, the row gets a green colour indicating that everything is fine. If you have entries you don’t want to use, just leave them unassigned. They will then be ignored in a subsequent analysis. (Note, that you can currently not edit the classification after the import is finalised.). Of course, you can also the green entries when the toolbox got it wrong. When finished, click OK.

10.1.2.2 Platform-specific notes

Importing text files from various platforms (Windows, macOS, Unix) can cause unexpected behaviour. While macOS (and often also Unix) use utf-8 as the encoding scheme for the characters in the file, Windows typically uses something like cp1252 (Western European or ANSI codepage). The toolbox always assumes text files to be in the utf-8 encoding. This means that reading a file in another encoding may lead to garbage in the importing process, e.g. reading a file from Windows encoded using cp1252. In a future version of the toolbox, we may provide the possibility to specify the encoding of the import file.

Note: Sometimes, a character such as “ï»¿” may appear as the first sequence in a text file in the preview area. This indicates that you are trying to import a file encoded in utf-8 and containing a “byte order mark” at the beginning of the file. This may have undesired side-effects. Avoid importing text files having a “byte order mark”.

10.2 Metadata editor

What are metadata and what are they for? Metadata are defined as **information** about data, assessments, sources, etc.. It is data about data. They give a structured and shortend description of the things, which helps to organize, comprehense, find and understand them. In the toolbox context metadata represent all information connected to analysis, dataset, indicator, source, template, result and background information necessary for regulated toolbox procedures.

There are various concepts for metadata, but most of them only cover specific data types, such as INSPIRE for geodata (EU 2007) or Darwin Core for species collections (www.tdwg.org 20.09.2022). We here follow the more general metadata concept of Dublin Core (www.dublincore.org 20.09.2022) and implement specific metadata elements underneath the "umbrella" of the fifteen Dublin Core terms.

The ***Metadata editor*** is a special function of the toolbox enabling viewing, input and editing of metadata specifically for each type of the main toolbox components (analysis, dataset, indicator, source, template).

For better usability, a grouping of metadata topics (categories) is used in the main view of the editor. Each topic includes a set of single metadata (elements) that relate to specific topics (and Darwin Core principles). In individual cases, subcategories are inserted between topic and elements:

- **Basic information** – *What is the input about?* – Subcategories: content, lineage, history
- **Classification** – *How does the input relate to various relevant thematic topics?* – Subcategories: management stage, ecosystem components, EU directives and regulations, others
- **Format** – *How is the input formatted?* – Subcategories: file (format), specification (setting)
- **Origin** – *Where does the input come from?* – Subcategories: bibliographic citation, rights
- **Spatial coverage** – *Where is the input geographically located?* – Subcategories: crs, extent, location, spatial properties, scope of application
- **Temporal coverage** – *From which time does the input originate?* – Subcategories: period
- **Contribution** – *Who is importing, analysing it?* – Subcategories: contributor, (address)
- **Publication** – *Who is exporting it (if applicable)? [currently disabled]*
- **Metadata information** – *Who has created the metadata (= metadata about metadata)?* – Subcategories: creator, (address) metadata format

The topics are visible and selectable in the list on the left side of the editor view. The selected topic is indicated by a highlighted background in the sidebar. The selection determines, which metadata subcategories and elements are visible in the main window. The elements for ***Basic information*** are displayed in the start view by default and respectively highlighted in the list on the left.

Elements marked by * in the editor are mandatory. Saving metadata without entries in those fields is disabled. The number of fields being mandatory varies between data types.

In the following sections each topic, subcategory (if applicable) and individual metadata element is described by their basic properties, with instructions for completion by the user (if applicable) or by given examples.

10.2.1 Basic information –- What is the input about?

In this topic all metadata are grouped which define and characterise the basic features of the entry. In this context, element **Basic categorization** is particularly noteworthy as it defines the necessity of other metadata topics and elements as precondition, e.g. specific metadata to define temporal, spatial and/or taxon-specific features of the entry.

10.2.1.1 Content — Information relating to the content of the input

Content elements	Description
Title	A name given to the input. A mandatory element as free text.
Subtitle	An additional name given to the input, providing additional details. Can be used to shorten or detail titles. An optional element as free text.
Description	An account of the input, may include but is not limited to an abstract, a table of contents or a free-text account. A mandatory element as free text.
Basic categorization	Various checkboxes to mark, if entries have a taxon-specific, spatial and/or temporal relation. Multiple selection is possible. Especially for spatial relations it is required to make a choice between *yes* (= with spatial relation) and *no* (without spatial relation).
Identifier	An automatically assigned code by the toolbox as unique identification of the entry within the toolbox environment.
Origin identifier	The code/identifier the entry may have in its original data reference, for example a dataset identifier in a webservice (WFD) or a data base oid. For sources the original identifier (e.g. reference Id in a literature data base like endnote number is part of the topic origin). An optional element as free text.

1.1.1.3 Lineage — Information relating to the background of the input

Lineage elements	Description
Validation	The overall quality of the input. An optional free text element. (Confidence/uncertainty input for indicators are preliminary displayed in this element)
Version	A version number or string (not a date!) describing a specific point in the history of the input. A conditional free text element.
Revision date	The date of the last revision of the originally imported input (this predates the entries under History as those are meant for modifications after importing the dataset, indicator, etc.). A conditional free text element.

10.2.1.2 History – Information relating to the history of the entry within the toolbox environment

(not yet fully implemented)

This metadata subgroup is automatically created and updated by the toolbox, whenever an entry is imported, edited, deleted or exported.

The toolbox stores the date and time, the kind of action (import, editing, …), a short action description and the responsible person of the action (if logged in). The history of each entry can be viewed by the user in the editor.

Example:

History	Date - Time (UTC)	action	description	responsible
	2024-08-03 13:00	import	import	Torsten Berg
	2024-08-12 08:45	editing	edit dataset language	NN
	2024-08-12 11:08	editing	edit dataset unit	Henrike Wilken

10.2.2 Classification -– How does the input relate to various relevant thematic topics?

In this topic all metadata are grouped, which define the content of the data.

10.2.2.1 Classification categories

Here, the data are described in terms of their management state, their relation to EU directives and other regulations. You can pick more than one item.

10.2.2.2 Keywords

These are free text keywords describing your data.

10.2.3 Format –- How is the input formatted?

In this topic all metadata are grouped, which define and characterise the format features of the entry and define specific properties necessary for the usage of the entry.

10.2.3.1 File – Information relating to file properties of the input

This subgroup is filled automatically by the toolbox during import. It informs about the file name, meta type (mimetype) and the file size.

File elements	Description
File name	The name of the file that was imported (if the input comes in a container such as a zip file, it needs to be unpacked and the file name refers to the input file inside the container, not the container itself); the toolbox automatically detects the file name during import action.
Media type	The media type and subtype in terms of the MIME type identifying the intended input format; the toolbox automatically detects the file extension during import action.
Size [bytes]	The file size in terms of the number of bytes (one kilobyte is 1024 bytes); the toolbox automatically detects the file size during import action.

In case of errors during import action the data importer will guide you through the troubleshooting and manual metadata input processes.

10.2.3.2 Specifications – Additional information and settings relating to the input

Some elements below this subcategory are specific to indicators. Accordingly, the individual elements are specifically defined to characterize indicators with their specific properties.

1.1.1.3.1 Dataset specification elements

Specification elements	Description
Data type	only relevant for non-spatial datasets (precondition: Basic categorization) - The nature or genre of the information in the file. This is a list of non-spatial data types (e.g. matrices, text) from which one entry needs to be selected.
Unit	The unit of your data values - a list of various units including basic SI units (metre, kilogram, kelvin, mole), derived SI units (degree Celsius, joule, newton) and coherent and non-coherent derived SI units (square metre, cubic metre, metre per second, newton metre) and specific non-SI units (practical salinity unit, individuals, individuals per square metre) from which one entry needs to be selected from; Caution: as many data may represent unitless features the default value is set to unitless.
Character set	only relevant for specific media types (precondition) - The character set of the strings within the input, e.g. of attribute columns (typical character sets include ISO-8859-1, UTF-8); a list of various character sets from which one entry needs to be selected. Caution: the default value is set to UTF-8.
Dataset language	only relevant for specific media types (precondition) - The language in which the textual input is written; a list of various languages from which one entry needs to be selected. Caution: the default value is set to English

1.1.1.3.2 Indicator specification elements

Specification elements	Description
Indicator type	The nature or genre of the indicator, if the indicator … This is a hierarchical list from which one entry needs to be selected.
Indicator status	A list for status of development from which one entry needs to be selected.
Indication objective	A hierarchical list for objectives from which one ore more entries need to be selected.
End value (type)	A hierarchical list for end value types (e.g. Index - EQR, Index - BQI, Ratio - Sex ratio, Absolute value - biomass) from which one entry needs to be selected.
Unit	The unit of the indicators end value - a list of various units including basic SI units (metre, kilogram, kelvin, mole), derived SI units (degree Celsius, joule, newton) and coherent and non-coherent derived SI units (square metre, cubic metre, metre per second, newton metre) and specific non-SI units (practical salinity unit, individuals, individuals per square metre) from which one entry needs to be selected; Caution: as many indicator end values may represent unitless features the default value is set to unitless.
Calculation variable(s)	A hierarchical list for Calculation variable(s) from which one ore more entries need to be selected.
Algorithm	A hierarchical list for algorithm types for indicator reference and class boundary evaluation from which one entry needs to be selected.
Target/reference	
Collection method	
Costs	

10.2.4 Origin -– Where does the input comes from originally?

In this topic metadata needed to precisely reference the source of your data are listed. This includes basically every information needed to cite a source in a proper bibliographic way. As citation styles in some cases differ significantly between digital sources (such as a web services) and print/e-print sources (such as a journal article) a source type is the precondition for the individual citation elements needed for a source.

The toolbox offers two possibilities to reference the origin of an entry:

1. The user can choose one of the sources already part of the toolbox
2. The user can create a new sources

10.2.4.1 Bibliographic citation

Information covering fields appropriate to the source type with varying elements such as title, author, publication year, accession date, host of e.g. webservice, publisher, DOI, ISSN, ISBN, URI and others. Mandatory elements within a source type are marked with an asterisk in the table below.

Source type	Citation elements	Example
Webservice	Title, Provider, Accession date*, Web address (URL)*, Point of contact - responsible name, Point of contact - responsible email, Point of contact - provider name, Point of contact - provider email, Origin source identifier	
Website	Title, Provider, Accession date*, Web address (URL)*, Origin source identifier	
Database	Database title, Provider*, Accession date*, Point of contact - provider web address (URL), Point of contact - responsible name, Point of contact - responsible email, Origin source identifier	
Article	Title*, Author*, Publication year*, Series title (incl. volume, issue, pages)*, DOI, ISSN, E-Print access address (URL), Origin source identifier	
Book	Title*, Author*, Publication year*, Publisher (incl. pages)*, DOI, ISBN, E-Print access address (URL), Origin source identifier	
Book chapter	Book chapter title*, Author*, Publication year*, In: Book title*, Book editor*, Publisher (incl. Bookchapterpages)*, DOI, ISBN, E-Print access address (URL), Origin source identifier	
Report	Title*, Author*, Publication year*, Series title (incl. volume, issue, pages), Publisher (incl. pages), DOI, E-Print access address (URL), Origin source identifier	
Conference output	Conference output title*, Author*, Conference*, Publication year*, Conference venue, Conference host*, Series title (incl. volume, issue, pages), Publisher (incl. pages), E-Print	

Source type	Citation elements	Example
	access address (URL), Origin source identifier	
Technical documentation	Title*, Author*, Publication year*, Release organisation*,DOI, Publisher (incl. pages), E-Print access address (URL), Origin source identifier	
Working paper	Title*, Author*, Publication year*, Publisher (incl. pages), Release organisation*, DOI, E-Print access address (URL), Origin source identifier	
Dissertation	Title*, Author*, Publication year*, Academic degree*, Academic organisation (incl. pages), DOI, E-Print access address (URL), Origin source identifier	
Legal document	Title*, Author*, Enforcement/release year, Enforcement/release date, Release organisation*, Series title (incl. volume, issue, pages), Publisher (incl. pages), ELI, E-Print access address (URL), Origin source identifier	
Guideline/standard	Title*, Version*, Provider, Publication year*, E-Print access address (URL)*, Origin source identifier	
Personal communication	Communication theme*, Comment partner*, Communication date*, Point of contact - author email*, Point of contact - organisation of communication partner*	

10.2.4.2 Rights – Information related to the input constraints in use and access properties

Right elements	Description
Access rights	A list of various access right types from which one entry needs to be selected. Either *access rights* or *license* is a mandatory element. Caution: the default value is set to open access.
License	A list of various license types from which one entry needs to be selected. Either *access rights* or *license* is a mandatory element. Caution: the default value is set to CC BY (to distribute, remix, adapt, and build upon the material in any medium or format is allowed, so long as attribution is given to the creator).

Right elements	Description
Resource constraints	An optional textual description of how the input can be used and which constraints are in place.

10.2.5 Spatial coverage -– Where is the input geographically located? (if applicable)

This topic is only applicable, if the data have any spatial relation. Relation means either the entry represents specific kind of geodata (raster, vector, coordinates) or a geographical locality in which the entry is valid, e. g. an indicator that is only valid in the Baltic Sea. The spatial relation is specified in the topic **Basic information** – *Basic categorization*. Only if the “spatial” checkbox has been selected there, the elements under the topic **Spatial coverage** can be specified.

10.2.5.1 CRS – coordinate reference system

Here, information relating to the input coordinate reference system (CRS) is shown. The toolbox tries to automatically detect the CRS during import of a spatial dataset. When it can not be detect, you have already entered the necessary data before in the process. Thus, these elements are already fixed and can not be changed.

Example:

CRS	crs_uuid	crs	notation	axis
	EPSG:4326	WGS 84 – WGS84, used in GPS	degree [°]	latitude (N/S), longitude (E/W)

10.2.5.2 Extent

Extent: Information relating to the spatial extent of the input in a predefined coordinate reference system (CRS). All elements in this subgroup are automatically detected by the toolbox during import of a spatial dataset/an spatial analysis result.

Extent elements	Description
Bbox - CRS	The EPSG code, crs (coordinate reference system) name, notation and axis order belonging to the given CRS name/identifier of the bounding box (Bbox).
Bbox - West	Western edge of the bounding box of the input.
Bbox - East	Eastern edge of the bounding box of the input.
Bbox - South	Southern edge of the bounding box of the input.
Bbox - North	Northern edge of the bounding box of the input.

10.2.5.3 Location – Information relating to the geographic location, region of the input (if applicable)

Location elements	Description
Geographic name	A geographic name of the location, region; preferably one listed in a gazetteer.
Gazetteer URL	The URL of a gazetteer where the geographic name of the location is listed; currently an optional feature
Location identifier	A UUID of the geographic name when it comes from e.g. a gazetteer; currently an optional feature

10.2.5.4 Spatial properties – Information relating to more detailed spatial specifications of the input

… at the moment only elements relevant for rasters and gridded polygons exist …

Spatial properties elements	Description
Spatial type	only relevant for spatial datasets (precondition: Basic categorization) - The nature or genre of the spatial information in the file. This is a hierarchical list for spatial types (e.g. Raster or Vector - Point Feature) from which one entry needs to be selected.
Cell size (cell unit)	The grid cell size of a spatial raster dataset, i.e. the length of each side of the cell, expressed in the units of the CRS.
Cell reference	Spatial representation type used for the coordinates of grid cells of a spatial raster dataset; a list of various representation types (like center point, lower left corner, etc.) from which one entry needs to be selected. Caution: the default value is set to lower left corner.

10.2.5.5 Spatial scope of application – Information relating to the spatial area of validity of the input

These elements are only used for indicator metadata.

Spatial application elements	Description
Spatial unit	A hierarchical list for spatial units of various lists with geographic names from which one ore more entries need to be selected, e.g. if indicators are operational in different spatial units
Country of validity	A list for countries from which one ore more entries need to be selected, e.g. if indicators are operational in different countries
Reference/class boundaries	A list for reference/class boundaries from which one entry needs to be selected - the entry which is valid for the specific spatial unit

10.2.6 Temporal coverage -– Which time (period) does the input refer to (if applicable)?

This topic is only applicable, if the data have a temporal relation. Relation means the data represent a specific information which is only valid within a certain period of time. The temporal relation is specified in the topic **Basic information** – *Basic categorization*. Only if the "temporal" checkbox has been selected there, the elements under the topic **Temporal coverage** can be specified.

1.1.1.4 Period

Temporal elements	Description
Period scheme	Determines which temporal unit is used for the start and end of the temporal period, like time, date, season, month, year; a list of various time schemes from which one entry needs to be selected. Caution: the default value is set to year.
Start	Start time, date, season, month, year
End	End time, date, season, month, year

10.2.7 Taxon information

10.2.7.1 Contribution -– Who is importing, analysing the input?

In this topic it can be specified who the contributor of the data is. Depending on the type of data (dataset, indicator etc.) it may be possible to select more than one contributor.

Contribution elements	Description
Contributor	A set of various elements: contributor name, contributor email, organisation (the contributor belongs to) and country (the organisation is situated) to choose from a list with possible contributor names (people from the GES4SEAS project are pre-defined in this list).
Submission date	The date of the first appearance in the toolbox environment; this date is identical to the first entry in history and is automatically filled by the toolbox during export (if applicable).

Example:

Name	Email	Organisation	Country
Torsten Berg	berg@marilim.de	MariLim GmbH	Germany

10.2.8 Publication –- Who is exporting the input (if applicable)?

not yet needed

10.2.9 Metadata information –- Who has created the metadata?

In this topic metadata about metadata are grouped. This includes information about the creator of the metadata and information about the metadata standard itself.

The creation date for metadata is automatically set by the first entry in the history topic. For export of metadata this first entry in the history of the specific element will be automatically used as metadata creation date by the toolbox without any action needed by the user.

Metadata information elements	Description
Creator	A set of various elements: creator name, creator email, organisation (the creator belongs to) and country (the organisation is situated) to choose from a list with possible creator names (people from the GES4SEAS project are pre-defined in this list).
Creation date	The date of the first appearance in the toolbox environment; this date is identical to the first entry in history and is automatically filled by the toolbox during export (if applicable).
Conformity	Information relating to metadata conformity.
Degree of conformity	[not yet defined, preferably a presetlist] a list of various languages from which one entry needs to be selected. Caution: the default value is set to xxx.
Metadata language	The language in which the metadata are written; a list of various languages from which one entry needs to be selected. Caution: the default value is set to English.

10.3 Template editor

The template editor is used in two places within the toolbox to create a visual representation of the processing steps needed to perform an analysis. The first place is its own section in toolbox, the “Analysis templates” section. The other place is under the “Indicators” section. There, templates are used to provide the numerical implementation of an indicator from the toolbox indicator catalogue.

10.3.1 Templates

Regardless of its naming and use (for indicator implementations or analysis templates), a template is always an abstract description of the individual steps that some defined input datasets have to go through, i.e. which kind of calculations and changes are to be made to the input datasets. Templates consist of blocks that either represent some datasets (data blocks) or some kind of data processing (action blocks). The blocks are connected with arrows indicating the flow of data. An analysis always starts with a data block and end with an action block. An action block can serve as the input to another action block to produce chains of data processing.

As the templates are abstract descriptions, they do not themselves hold datasets or results of the processing. They are just a receipt for some kind of data processing.

The datasets in these data blocks then are fed into action blocks. The action blocks can be defined to represent various kinds of data processing algorithms, from simple addition or data aggregation to complex algorithms representing complete assessment methods.

Note: templates can only be deleted when they are not used in any analysis.

10.3.1.1 Data blocks

The data blocks define some input datasets which are to be fed into the following action block. Data blocks describe the input data in terms of a query against their metadata. Specific parts of the dataset metadata can thus be used to specify which datasets should be allowed in a data block. This query acts as a filter. Only the datasets matching the query are shown. This can help to reduce the number of datasets to pick from, limiting the choices to the datasets that are sensible in the given context of the analysis.

Hint: If you are using e.g. one of the indicator implementations and your datasets are not showing up as input data when running the subsequent analysis, try to check what the data blocks of the indicator implementations have specified as the query. If your dataset metadata do not match this query, the datasets do not show up.

The query can contain elements from the “Classification”, “Spatial coverage” and “Format” metadata categories. You can have more than one item in the query by clicking the “+” button and you can delete individual items by clicking the “-” button. You can not have am empty query, one item will always be needed. The individual items in the query can be logically joined with either a logical “and” or a logical “or” in order to build more complex queries.

10.3.1.2 Action blocks

Action blocks are doing data processing. They process their input according to the definition given for the action. An analysis can contain various kinds of actions on data. These actions are grouped into six different categories:

- Transformation (looks at each cell at a time for every input datasets individually)

- Calculation (looks at each cell at a time for all input datasets at once)
- Aggregation (looks at each cell at a time for all input datasets at once and reduces from raster to number)
- Cumulation (in politics, this is called "impartiality" – everyone talks and negotiates with everyone)
- Classification (groups ranges of values in a dataset and assigns them to a category)
- Join (join two datasets based on a common field)
- Script (pre-defined scripts used in the toolbox or custom scripts the user can write to implement data processing functionality)

For all of these actions the principle is that you can feed one or multiple datasets into the individual actions. Depending on the action category, the actions will then either treat each dataset separately and thus outputs as many datasets as you feed into the action, or an action will in some way reduce the number of datasets (e.g. in terms of aggregation).

The table below gives an overview of this behaviour when using the two types of input data (numerical values & raster datasets) the toolbox now supports within actions (tables are only yet supported when using the higher-level pre-defined *toolbox system script* actions):

Action category	input datatype	output datatype
Transformation	single number *	single number
	set of numbers	set of numbers
	single raster	single raster
	set of rasters	set of rasters
Calculation	set of numbers	single number
	set of rasters	single raster
Aggregation	set of numbers	single number
	single raster	single number
	set or rasters	single number
Cumulation	set of rasters	single raster
Classification	…	…
Join	raster + table	raster
Script	any	any

- = Note that the transformation actions that rescale values to a maximum of 1 only work with rasters as they need more than one value to function.

Transformation

These actions transform datasets to different scales. All algorithms in this category represent unary operators, i.e. they operate on one value from one dataset.

Logarithm (base 10)

Takes the logarithm with base 10 of each cell value. Note that this can fail when you have values of zero in the data, as the logarithm of zero is minus infinity.

Logarithm (base 10) of value +1

Add 1 to the cell value and then take the logarithm base 10 of the resulting number. This prevents taking the logarithm of zero (as long as you don't have negative values in your data which is not allowed anyway).

Rescale to maximum 1

Takes the highest value in the dataset and translates it to the value 1. All other values are scaled accordingly by dividing the by the original maximum value.

Rescale to range 0..1

Takes the lowest and highest value in the dataset and changes these values to 0 and 1, respectively. Then, all values in between are rescaled onto that same scale to all values are between 0 and 1.

To presence/absence

This action changes all values in a dataset to 1 when it is above 0. Values of 0 will stay 0. No negative numbers should be in the dataset.

Calculation

These actions do something with multiple values that are provided. Calculations always need at least two inputs. If the input is a raster dataset, the calculation is done for each cell of the raster.

Add

If there is more than one input dataset, adds all values up (for a raster dataset the addition is done per cell). NO DATA values are ignored, if at least one input dataset has an actual value it will be used. Only when all input data are NO DATA, then the result is also NO DATA.

Subtract (not yet implemented)

If there is more than one input dataset, the minuend is a specific dataset and the values of other datasets are all subtracted from this initial dataset (for a raster dataset the subtraction is done per cell)

Aggregation

These actions reduce the input data to a single number. If the input is a raster dataset, all values in that dataset are aggregated to a single number.

The possible actions are:

Maximum

Returns the maximum value in a dataset or a set of datasets. “No data” values are ignored.

Minimum

Returns the minimum value in a dataset or a set of datasets. “No data” values are ignored.

Average

Return the arithmetic mean of the values in a dataset or a set of datasets. “No data” values are ignored as if they were not existing.

Median

Return the median value of all the values in a dataset or a set of datasets. “No data” values are ignored as if they were not existing. Note that this algorithm is currently very slow and even fails when millions of values are fed into it.

Cumulation

These actions do different kinds of cumulation on raster datasets which is considering the values in each involved dataset in a specific way and calculating a resulting value per cell across all datasets.

A cumulation principally takes two different groups of spatial datasets (two different input data blocks in a template). Every dataset from the first group is paired with every dataset from the second group and some calculation is then done. In the end there is a specific number of values (one from each pair) which are then cumulated. How the cumulation takes place is different for each of the algorithms, the easiest being to multiply the numbers from each pair and the add the products together in the end. This whole process is done individually for each single cell in the spatial datasets. This principle, that every dataset from one groups is paired with each one from the other group, is called “impartiality” in politics (everyone talks to everyone).

The possible actions are:

Sum of products

This cumulation action takes the values of each dataset in one block and multiplies them with the corresponding values of each dataset on a second block and then calculates the sum over all these products. This calculation is done for each cell in the dataset individually.

Classification

Join

Script

There are two types of scripts: “toolbox system script” and user scripts written in “Tcl” or “R”. Currently, only toolbox system scripts are implemented and used for the pre-defined indicators. See chapter Indicators for details.

10.4 Maps

Currently, the map display is very limited. When you click on a spatial dataset, a geographical map of the data is shown. You can zoom in and out using the buttons below the map.

The values of the data behind the map are displayed as grey rectangular cells. The shade of grey is determined by the underlying value assigned to this cell. For now, this scale is a relative one. This means that the highest value in the map is represented by a black cell and the value of 0 is represented by a white cell (assuming there are no negative values in the data). This also means that you currently cannot easily compare two different maps with each other by looking at their grey colours.

In future versions, the map will also support absolute scales where you will be able to assign a specific shade of grey (or a colour) to a specific value or range of values.

11 Background data

These are predefined datasets present in any project. They currently include hierarchical lists for data classification and hierarchical lists of spatial units. During import, metadata are entered about the datasets and one category of the metadata is *Classification*. The classifications currently included are mostly MSFD, WFD and HD classifications but also others such as the CICES hierarchy of ecosystem services. When doing analyses that involve the knowledge of spatial units (such as the spatial assessment units (SAU) of the NEAT tool), the predefined spatial units can be used.

Other background data are lists of countries, languages, access rights etc. which are utilized in the metadata of datasets, indicators and the other entities.

Currently, these background data cannot be edited nor deleted and new lists cannot be added yet. In future versions it will be possible to add custom lists and also add more entries to the pre-defined ones by defining user-specific lists. This is needed to e.g. provide sensitivity scores for a more detailed distinction between ecosystem components than provided by the MSFD lists.

Later version will also be supplemented with actual spatial datasets from public sources.

12 Tags

(Note: tags are not yet implemented … so cannot be documented now)

- what tags are
- how to tag data
- how to work efficiently with tags

13 Collections

(Note: this functionality is not yet implemented)

- what collections are and how to work with them

14 Outlook

The toolbox is a work in progress where the constant testing and learning gives us feedback for new features to implement and needed functionality to be even more productive. We can not do everything at once. So, here is what we have already planned or what is on the wish list.

In general, we will primarily implement all functionality that is the result of the various GES4SEAS project tasks, especially in WP4, and should be part of the toolbox as written in the GES4SEAS technical description. This is stage 1.

Next, we will look into features most wanted that prove to be very helpful, especially for the final version which should be available also for people outside this project. This is stage 2.

Finally, time and resources in the project may allow us to work on even more. Who knows? This is stage 3.

Please note: The following lists are rough plans and they do *not* list the functionality we promised in the GES4SEAS technical description but rather additional features. Reality often shows us that plans are nice but also that they do not hold completely. Thus, we cannot promise all these features will be implemented or in which specific version but we try our best. So, consider these lists as more or less loosely defined, incomplete and work in progress.

14.1 Stage 1: Planned features for the next releases (version 2.1 or 2.2)

For the next versions, these are the known features we want to implement:

- complete the software manual
- enable remaining still disabled analysis algorithms
- add the possibility to add custom ‘classifications’ for e.g. pressures or activities
- show a kind of progress bar when an analysis is being evaluated to see how long it will take
- allow custom colours for maps
- implement hierarchical Halpern-style CEA
- allow analysis results as input into new analyses
- implement filtering indicators in the NEAT assessment

14.2 Stage 1: Planned features for later releases

For one of the later versions (not sure which one), these are the known features planned to be implemented:

- include more input and export file formats (also include metadata in export)
- temporary import of dataset without entering metadata for quick testing purpose (data will be deleted when exiting the toolbox or project unless you enter metadata at that point)
- info button in metadata editor with explanation of what the individual elements mean
- provide a “one time analysis” directly evaluating a template but without saving the result and the need to provide analysis metadata
- show more metadata information in the GUI (green metadata block, item catalogue, …)
- enable import of prepared YAML metadata file
- copy datasets, analysis templates or analysis results from other project files
- include CIMPAL
- include SCAIRM
- include SEAS4GES decision tool
- translation of software into various languages
- implement “tags” and “collections”
- exporting the analysis result as GIS data, Excel or image (including metadata)
- use Tcl and R as script languages in analysis templates (planned for 2025)
- import data directly via Web Services (WMS) (planned for 2026)
- simple data transformations (projection in another CRS, change raster data resolution)
- difference plots of maps
- overlay of vector data on raster maps (e.g. coastlines, outlines of protected areas) and allow analysis statistics based on the vector data
- online updates of the toolbox
- general spatial functions for spatial datasets (such as “union” and “intersection”, using the GEOS library)
- abstract application layer on top of the assessment capabilities to provide a guided access to the toolbox functions (e.g. via the EBM elements)
- include EEA grid as pre-defined rasters (to map point data to the raster)
- clicking on a raster cell in the map to get information about this specific cell (from datasets or an analysis)

14.3 Stage 2:

- add possibility to import GIS vector layers (polygons) and let the toolbox convert them into raster data
- implement PlugIn system for custom, external extensions (incl. official API)

14.4 Stage 3:

- more data preprocessing such as loading point data and polygon vector data and let the toolbox apply the point data to the polygons and subsequently convert the vector layer to a raster layer
- enable GUI customisation

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This agreement will apply from the date of the installation of the software.

2025