Journal of Coastal Conservation (2019) 23:881–898
https://doi.org/10.1007/s11852-018-00677-5

The systems approach framework for collaborative, science-based management of complex systems

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Received: 18 April 2018 / Revised: 14 December 2018 / Accepted: 18 December 2018 / Published online: 14 January 2019

Abstract
Sustainable management of coastal systems can only be achieved with an effective science-policy interface that integrates the three pillars of sustainable development: environmental protection, social progress and economic growth. The Systems Approach Framework (SAF) provides a structure to guide such a process by embracing the challenge of assessing complex systems for scenario simulations to support potential policy decisions. Based on applications of the SAF in six Baltic Sea case studies within the BONUS BaltCoast project, the SAF was revisited and further developed. Two additional steps were introduced partly to enhance implementation and decision validation and partly to facilitate the reiterative process with the addition of monitoring and evaluation. The SAF now includes six steps (Issue Identification, System Design, System Formulation, System Assessment, Implementation, Monitoring and Evaluation). A list of actions for each step clearly defines what needs to be done before progressing to the next SAF step. Activities within each step were improved to better integrate governance - citizen collaboration and improve the science-policy interface. Three auxiliary tools, developed in the BONUS BaltCoast project to support particular actions, were integrated in the different steps to facilitate application of the SAF by practitioners and scientists alike. The added focus on the stakeholder participation resulted in further actions being listed in the new steps to maintain stakeholder engagement and counteract stakeholder fatigue. The revised SAF is presented and discussed together with lessons learned from the different applications in five Baltic Sea study sites.

Keywords Integrated coastal management · Stakeholder engagement · Science-policy · System analyses

Introduction

Human activity increasingly threatens the function of coastal ecosystems, as more people inhabit coastal areas and continue to rely on goods and services from coastal systems (Halpern et al. 2008; Ban et al. 2010). Renewable energy, growing aquaculture, coastal fishing, tourism and recreational use of the coast, second homes and urban sprawl, public health, dredging and aggregate extraction, transport and accessibility, ports and marine industry and cultural heritage are common uses in Europe's coastal zone. Many of these uses are increasing in intensity and competition for space becomes stronger while habitat destruction, chemical and heat pollution, loss of biodiversity or coastal erosion increase. Further challenges arise from climate change with warmer waters, rising sea level and increasing acidification (Stocker 2015). Apart from understanding how anthropogenic pressure affect coastal systems, we need to understand how these drivers interact with climate change (Borja et al. 2017) and how to deal with them.

The USA was the first to come up with a policy framework for coordinated coastal zone management (Knecht and Archer 1993) and the concept has since gained worldwide recognition. By 1997, a stepwise approach to an Integrated Coastal Management (ICM) policy cycle was introduced starting with issue identification to evaluation of outcomes (Olsen et al. 1997). In Europe, this concept inspired the recommendation to implement ICZM in 2002 (2002/413/EC) and many ICZM policies, projects and initiatives were developed at local, national or regional level (Sorensen 1997; Shipman and

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Stojanovic 2007; OutCoast 2014). The Systems Approach Framework (SAF), developed during the EU-funded project SPICOSA (Science and Policy Integration for Coastal Systems Assessment, EU 6th, Nr. 036992), further refined this structured approach to ICM. The Systems Approach, founded on Systems Theory (Von Bertalanffy 1968), acknowledges that systems are highly complex, often behaving in non-linear fashion and cannot be understood in their entirety by breaking them down into compartments and examining each individually. A systems perspective requires a holistic view and focuses on the relationships between components. It is interdisciplinary and can be applied to all types of systems (e.g. Link 2018). The SAF was developed to provide a structured method for ICM that ensures a holistic (ecosystem-based) approach, deals with complex systems and is multidisciplinary by including environmental, socio-economic and cultural elements (Hopkins et al. 2011). The SAF guides an ICM process to consider ecological, social and economic issues in harmony to get the balance right between resource conservation and use, between costs of maintenance and recovery, between citizen choices and preferences based on community versus individual profit. The first set of applications provided several examples of benefits from the systems approach (Hopkins et al. 2012), such as addressing multi issues simultaneously, implementation of transdisciplinary science and simulation analyses to quantify dysfunctions in complex systems.

Application of the SAF also showed up several weaknesses such as insufficient political and legal status, the need for supportive tools for engaging with stakeholders and for the development of indicators (Hopkins et al. 2012). A further weakness of the SAF description was complex terminology or insufficient clarity of actions rendering it inaccessible to practitioners. Clearly, if we are to address existing and arising problems in coastal systems in a sustainable and integrated manner, a stringent guiding framework is needed and the SAF needed to be refined and further developed. Although ICM was deleted from the Maritime Spatial Planning Directive (MSP, Directive 2014/89/EU), ICM ideas were maintained. An improved Systems Approach Framework is a major step towards promoting ICZM and its practical implementation in local areas and regions. This may serve to reverse current coastal management practices that only consider single activities or single species in isolation, ignoring cross-boundary issues that require co-ordinated multinational collaboration (Andersen 2016; Støttrup et al. 2017). Recently, Link (2018) described the successfully managed fisheries in the Eastern Bering Sea, Alaska, as an example of the benefits of applying the systems approach to fisheries management.

Since citizens' cooperation is often required (behavioural change) to apply management decisions, their "buy-in" is required to facilitate acceptance and encourage compliance (Schernewski et al. 2017b; Gillgren et al. 2018). Furthermore, stakeholder fatigue may arise when stakeholders are engaged in a process to resolve an issue, but which goes off track at some point. There was a clear need to ensure not only clear common objectives, but to introduce 'validation' whereby stakeholders can observe how their input has contributed to the decision and how the decisions is being implemented.

This work aimed to: i) develop and refine the SAF to turn it into an applicable process for practitioners and policy makers; ii) introduce new steps to enhance science and policy integration and prevent stakeholder fatigue; iii) demonstrate how the new tools developed to support several actions in the SAF can be implemented and their value from trial applications; iv) to analyse five study site SAF applications in the Baltic Sea and provide insight to lessons learnt.

Methods

The SAF developed within the project SPICOSA was re-visited in the BONUS BaltCoast project with applications in five case studies from five different countries in the Baltic Sea (Fig. 1; See Box). The cases varied in complexity of the environmental, social or economic elements to provide feedback for further development. Some of the issues addressed were primarily driven by economic needs such as: (i) the economic recovery of a lagoon system (Vistula Lagoon, Rozynski et al. 2019); (ii) the establishment of beaches in an eutrophic lagoon (Curonian Lagoon, Schernewski et al. 2017a); (iii) maintaining fisheries and recreational activities in a eutrophic lagoon (Schernewski et al. 2018a) and; (iv) improving management for coastal fisheries experiencing declines in local stocks (Kattegat and western Baltic Sea, Dinesen et al. 2018; this issue). However, each case study had complex environmental, social or legal aspects to deal with. One SAF applications addressed broader, complex issues such as the effects of climate change on public safety and maintenance of coastal activities and infrastructure (Pärnu Bay, Tönisson et al. 2018; this issue). The SAF applications in the different study sites were analysed relative to each SAF step and lessons learnt were used to develop and improve the SAF. The improvements made included clarification and further development of the terminology and actions within each of the SAF steps, as well as inclusion of new, supportive tools. The supportive tools also provided better information on the public role and benefits of stakeholder engagement in decision making and improved the flexibility of the ESE assessment.

Two new steps, 'Implementation' and 'Monitoring and Evaluation' were introduced and actions developed for these steps. Social science aspects aimed to improve the governance-citizen interaction (Gillgren et al. 2018; this issue) were developed and embedded in the SAF.

Supportive tools such as the Stakeholder Preference and Planning Tool (Schumacher et al. 2018) and the Marine

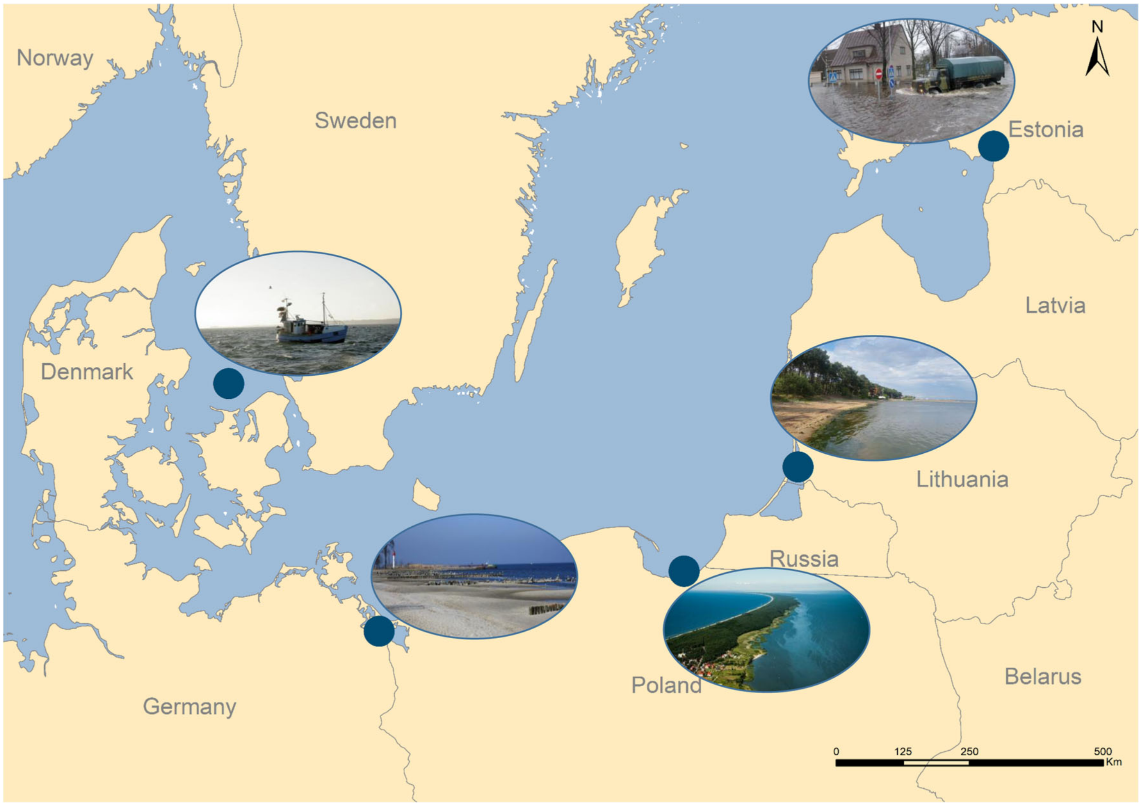

Fig. 1 Map of Baltic Sea with the location of the case studies and a representative photo of each case study

Ecosystem Services Assessment Tool (MESAT, Inácio et al. 2018) were developed and tested in a few study sites and embedded in the SAF. The Indicator-based Sustainability Assessment Tool (InSAT, Karnauskaite, pers. comm.), was further developed from lessons learnt from testing an indicator-based ICZM 'best-practice' evaluation tool (Karnauskaite et al. 2018). InSAT is a user-friendly tool to support the decision-making process in ICM, with particular focus on sustainability and integration of environmental, social and economic dimensions This tool is embedded in the revised SAF, but has yet to be tested.

Results

The SAF revisited

The SAF breaks down the ICM process into six steps (grey box, Fig. 2). The original five steps of the Ecological-Social-Economic (ESE) Assessment (Hopkins et al. 2011; Reis 2014) were revised and merged into four steps (Issue Identification, System Design, System Formulation and System Assessment). Two new steps (Implementation and Monitoring and Evaluation) were introduced. The two new steps help to strengthen the science –policy integration, secure appropriate monitoring and evaluation, and maintain stakeholder participation. A major innovation was the stringent listing of specific actions within each step and the provision of appropriate supportive tools for the application. As in the first version, the ESE Assessment is conducted in collaboration with stakeholders. Of the study sites implementing the SAF, two had previous experience of the SAF and one of these had already conducted one SAF cycle.

Issue identification

The first step of the SAF (Fig. 3) is a vital element of the ICM process as it sets a solid basis for the discovery phase. In this revised SAF, we have listed the actions for this step but the order in which they are conducted is not of vital importance for the outcome. However, the selection of the Policy Issue should be discussed with all stakeholders and thus can first take place after the mapping. Several tools support and guide these actions.

Table 1 shows the progress of the study sites in their implementation of the Issue Identification. The issues and the drivers for the issues varied among the study sites. All were high risk and two issues were also classified as high outrage. In two of the study sites, the institutional mapping had to be revised due to governance restructuring, in the Danish study site, restructuring happened three time during the application.

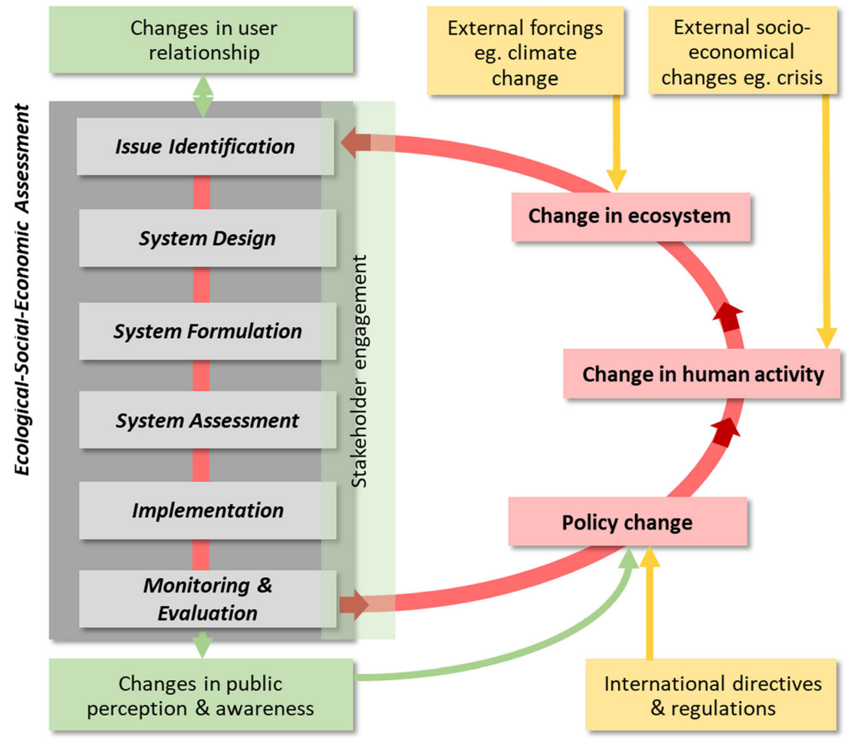

Fig. 2 The six steps (grey box) of the revisited Systems Approach Framework (SAF). A SAF is initiated when conflicts or a complex problem arises that needs to be dealt with in a sustainable manner. Stakeholders are engaged from the outset and throughout the process

The supportive tools, DPSIR (Driver-Pressure-State-Impact-Response; EEA 1999) and CATWOE (Customers-Actors-Transformational process-Worldview-Owners-Environmental constraints) (http://www.coastal-saf.eu), were specifically included as supporting tools to help develop a common understanding of the issue/problem, its causes and consequences and was invaluable for all the study site applications for generating the first generation conceptual model in the System Design step. In the Danish study site, it revealed the multitude of potential causes for the decline in fish in coastal areas, and the need to first address the cause-effect chain.

In order to deal with issues such as stakeholders defending their own interests rather than what is sustainable the Stakeholder Preference and Planning Tool (Schumacher et al. 2018) was developed for the SAF implementation. The tool is a spreadsheet-based method that helps to map stakeholder perceptions of the current state of sustainability and preferences for action. For this, stakeholders determine the relative importance of sustainability pillars, and define and weigh underlying issues that can be translated into success criteria. The Stakeholder Preference and Planning Tool was applied in the Issue Identification step in the German (Oder Lagoon) and Polish (Vistula Lagoon) case studies, to assess stakeholders' perception of the current state of sustainability and preferences for future development.

Listing ecosystems goods and services were included in this revised SAF in recognition of the need to assess the state of the system. The ESAT (Inácio et al. 2018) was developed to guide this action. This tool was specially developed to be applied in coastal and marine areas; focusing on the assessment of temporal dynamics of ES provision. It uses 54 indicators to represent 31 ES covering Provisioning, Regulating & Maintenance and Cultural ES. The tool was tested in two case

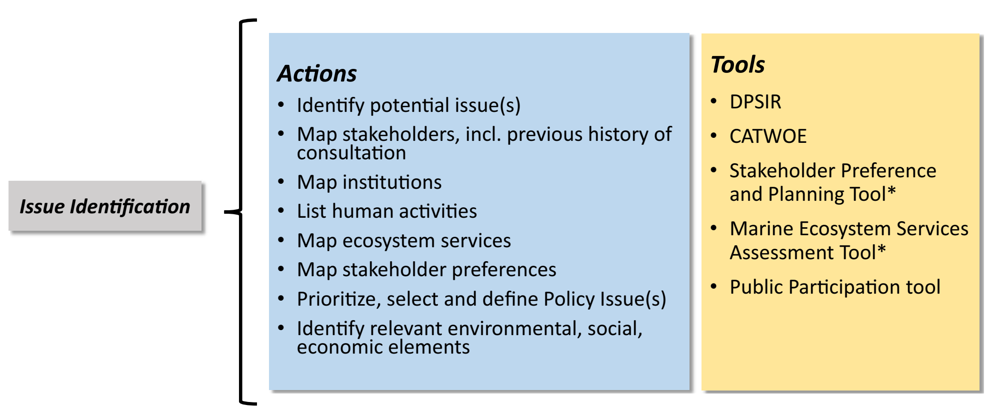

Fig. 3 List of actions and available tools within the Issue Identification step of the Systems Approach Framework (SAF). Tools marked with an asterisk were developed for this revised SAF

Table 1 The application of the Issue Identification step of the SAF in the different Baltic Sea study sites

	Oder Lagoon	Vistula Lagoon	Curonian Lagoon	Parnu Bay	Inner Danish waters
Issue	Eco-technologies and eutrophication	Economic development	Bathing water quality and tourism	Coastal protection	Changes in fish distribution and declining productivity
Lead/other country	Germany/Poland	Poland/Russia	Lithuania/Russia	Estonia	Denmark/Sweden
Risks and Outrage	High risk and outrage	High risk	High risk	High risk	High risk and outrage
Stakeholder mapping	Well-developed and defined stakeholder group with good interaction. Down-scaled in Design step	Well-developed and defined stakeholder group with good interaction	Well-developed and defined stakeholder group with good interaction Down-scaled in Design step	Well-developed and defined stakeholder group with good interaction	Well-developed and defined stakeholder group with good interaction. Down-scaled in Design step
Institutional mapping	Constant throughout SAF application	Constant throughout SAF application	Constant throughout SAF application	Mapped but governance restructured towards end of SAF application	Mapped but governance restructured several times during the SAF application
Human activities/Goods and services	Comprehensive list	Comprehensive list	Comprehensive list	Comprehensive list	Comprehensive list
DPSIR/CATWOE	Several DPSIR	Single	Several DPSIR	Single	Single, but cause-effect chain unresolved
Engage stakeholders	Meetings/workshops. Focus on German stakeholders only due to lack of common procedures	Meetings	Meetings	Meetings	Meetings, interviews
Issue identification/ driver	Different stakeholder opinions on the main issue / environmental and economic	Clear issue/ economic	Clear issue/ environmental and economic	Clear issue/ social (safety)	Needed stakeholder interviews to clarify issue/ environment and economic.
ESE components	Defined	Defined	Defined	Defined	Complexity of the environmental component delayed this action. Needed first to resolve cause-effect chain

studies (Oder and Curonian Lagoons). For each case study, a list of the relevant ES is drawn and the actual provision of services assessed. For example, in the Curonian Lagoon, 15 experts defined 29 out of 31 ES as being important for the case study area (Inácio et al. 2018).

The Public Participation Tool (Robinson 2002) guides a step-wise decision process (Inform – Consult – Involve-Partner) on how to engage with stakeholders depending of the level of complexity and risk involved. If the Issue is sufficiently complex or of high risk that stakeholders should be engaged at the level of "Involved" or "Partners", then a full-scale SAF is required. This tool was not available during the study site implementations but included in Fig. 1.

System design

The aim of this step of the SAF is to develop a conceptual model of the system states and processes for the ecological, social and economic components relevant to the Policy Issue. In the revised SAF the actions are clearly identified and listed (Fig. 4). Additional actions are added to secure the formation of a SAF core team with the appropriate skills and knowledge and to ensure stakeholder participation.

Table 2 shows the progress of the implementation of the Design Step by the study sites. In Oder and Curonian Lagoons, the virtual system was down scaled to a local level, which enabled better communication with stakeholders and a more manageable conceptual model. In contrast, the virtual system in the Danish study site was maintained at regional level. Four of the five study sites acquired new data and information needed for the modelling.

The InSAT helps to develop the indicators most relevant for the success criteria defined for the issue. The tool ensures that the indicators represent environmental, social and economic dimensions, that they can be scored and are responsive to potential measures (http://www.safhandbook.net/design/success-criteria, accessed 16-04-2018).

System formulation

This step comprises the mathematical modelling work using a transdisciplinary approach and ensures the integration of stakeholder and scientific knowledge, inclusion of empirical data and statistical methods (Fig. 5). This part of the SAF process starts with formulation of the ecological and socio-economic sub-models. Tools are not listed here as the scientific team can utilize any modelling approach, and a wide range of statistical methods as well as qualitative information (Table 3). The sub-models can be discussed with stakeholders to strengthen stakeholder understanding and credibility in the model, and ownership in the process.

In cases where in situ scenario simulation by stakeholders are vital to the process, consideration should be given to using software with a user-friendly interface such as the ExtendSim™ software used in the many applications of the initial SAF (such as in Mongruel et al. 2011).

Table 3 shows the development of the study sites during the System Formulation. Most study sites applied existing models or developed these further to suit the purpose. Qualitative assessments were used to supplement information in all but the Danish study site. Two study sites (Oder Lagoon (Schernewski et al. 2018a) and Danish inner waters (Dinesen et al. 2018)) used larger auxiliary models to support the environmental sub-model.

The complete ESE model combines the separate environmental, social and economic components. The coupling of the ESE model takes place after the separate ecological and socio-economic sub-models are formulated, calibrated and validated. With the complete ESE model, it is now possible to test sensitivity to estimate how uncertainties in the parameter values affect the model output. These uncertainties may arise from inaccuracy in the data due to poor temporal or spatial resolution, lack of data or poor data quality. Model parameters that have a high sensitivity are important to identify as these may influence the reliability of the model scenarios. An example of an integrated bio-economic (ESE) model developed

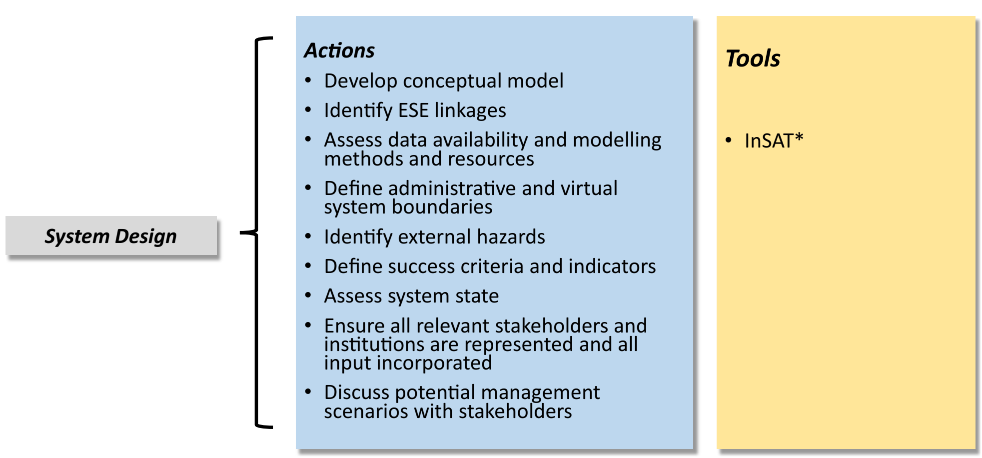

Fig. 4 The list of actions and available tools within the System Design step of the Systems Approach Framework (SAF). The tool was developed for the SAF application

Table 2 The application of the System Design step of the SAF in the Baltic Sea study sites

	Oder Lagoon	Vistula Lagoon	Curonian Lagoon	Parnu Bay	Inner Danish waters
System definition	Redefined with new SAF cycle and down-scaled. Confined to the German part.	Confined to the Polish part of the Vistula Lagoon. Administrative boundaries identical to a NATURA2000 area	Developed as SAF progressed and down-scaled. Confined to the Lithuanian part of the Curonian Spit.	Defined and includes the bay and low-lying land surrounding the bay	Defined, large scale
Conceptual model	Revised as SAF progressed	Revised as SAF progressed	Revised with down-scaling	Modified with sub models for erosion and inundation	Revised iteratively during System Formulation
Data and methods	Most data available from previous projects. New data acquired. Numerical modelling planned	Available from previous projects Existing used for sub-models + auxiliary models	Data acquired for the hydrodynamic modeling. New data acquired for the economic component	Numercial modeling and relevant data available for storm and storm surge modeling.	Acquired new data and auxiliary modelling for fisheries (VMS; AIS, logbook information) and fish behaviour (DSTs), and a hydrodynamic spatio-temporal high resolution model at basin scale
Problem scaling	Down scaled	Partial, not so needed, discussed with stakeholders	Down scaled	Defined from the outset	large scale resolved at a spatio-temporal high resolution

using the SAF is the German study site (Oder Lagoon (Schernewski et al. 2018a).

System assessment

At this point the simulation analyses is completed and the results ready to be discussed with all the stakeholders (Fig. 6). The simulation results need to be processed in a manner that is easy to communicate to stakeholders and tools are available to aid these actions.

Table 4 shows that all study sites had pursued scenarios for different management options and had discussed these with stakeholders. In the Oder, Vistula and Curonian Lagoons, the ESE assessment was completed with scenarios simulated and discussed with stakeholders. In Parnu Bay, a number of options were analysed or simulated and discussed with the stakeholders. The complexity of the environmental sub model in the Danish case study caused delays in completing the ESE assessment, but once completed, discussions with stakeholders helped to identify scenario options for which social and economic elements could be included in the ESE model.

The ESAT, originally developed to assess historical changes, can be used to assess future changes in ES and was tested in the Oder Lagoon (Schernewski et al. 2018a, b). Eight experts and two students were asked to provide their input regarding the impact of four scenarios on future provision of ES and the results aggregated to a single scoring class for each service and measure (Table 5).

At this point stakeholder preferences can be re-visited by re-applying the Stakeholder Preference and Planning

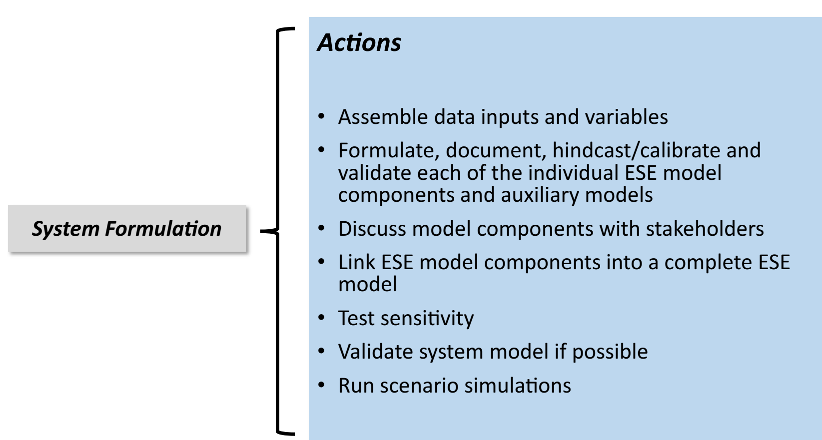

Fig. 5 The list of actions within the System Formulation step of the Systems Approach Framework (SAF)

Table 3 The application of the System Formulation step of the SAF in the Baltic Sea study sites

	Oder Lagoon	Vistula Lagoon	Curonian Lagoon	Parnu Bay	Inner Danish waters
Model development	Existing simulation model adopted (GETM + ERGOM). New sub-models developed for water transparency and macrophyte impacts. Cost-benefit model used for mussel farm scenarios. Cost effectiveness model applied to the different options	TRISULA modeling environment was initially used. Later Delft3D model applied.	For the hydrodynamic modeling, SHYFEM modeling system was used, as this was easy to adapt for the case study. Willingness to pay (WTA) model was used for the economic component	Numerical modeling included a 2D hydrodynamic model combined with WRF atmosphere model and FVCOM ocean model and a dissipation model for one of the scenarios that would deal with inundation. Cost effectiveness analyses included	Developed new models using existing auxiliary models and new data and information
Scenarios	Scenarios developed to improve growth conditions for macrophytes, economic prospects from improving water quality and mussel mitigation measures and introduction of mussel farms.	Scenarios developed focused on optimizing channel use as a means to improve local economy. Scenarios included costs of its maintenance or introducing new channels.	Scenarios for different pollution levels, beach uses and beach maintenance were conducted and presented to stakeholders	Five scenarios developed	Multiple spatio-temporal scenarios could be explored pertaining to vessel-based Individual Transferable Quotas
Model validation and calibration	Calibration data for mussel sub model acquired	Model calibrated and validated in a previous project and found to be sufficiently accurate	Hydrodynamic model was calibrated and validated in previous studies.	Conducted and model found to be sufficiently accurate	Partial, where data available, auxiliary models validated

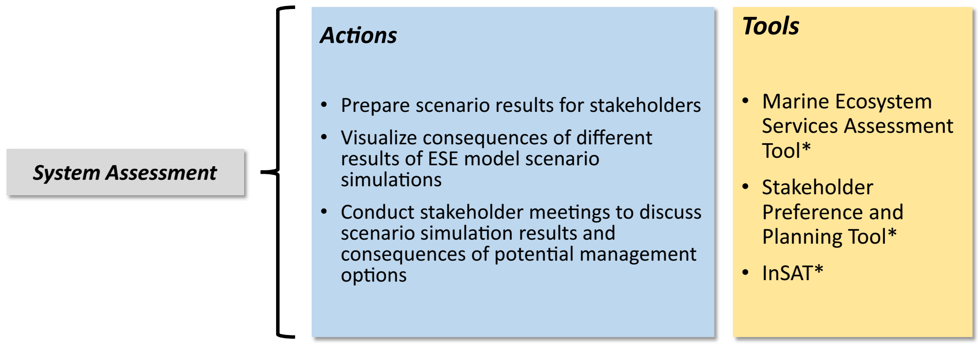

Fig. 6 The list of actions within the System Assessment step of the Systems Approach Framework (SAF). Both tools were developed for the SAF implementation

Tool, to assess whether the determined success criteria are still relevant or if stakeholder preferences have changed throughout the process. The revised success criteria could then be used to evaluate the suitability of different management scenarios/options to fulfil stakeholder preferences. The tool was tested in this step in the German case study (Oder Lagoon), to evaluate the suitability of different mussel farm scenarios to fulfil previously defined success criteria (Schumacher et al. 2018).

In cases, where numerical modeling is not possible, the InSAT helps visualize consequences of different management options and to assess their sustainability. The graphic results are three dimensional with an axis for each ESE dimension and thus provides an integrated overview.

Implementation

The Implementation step (Fig. 7) is vital for the successful completion of science-policy integration. The activities within this step are related to implementing the decision(s) and preparing for the assessment of the success of the implementation through the use of indicators and success criteria already established during the Design Step. In the Oder Lagoon, it was decided to test one of the solutions before actually implementing it. In the other study sites, there is great interest among stakeholders and managers in the scenario results but unclear as to whether any will be implemented.

Monitoring and evaluation

Monitoring is necessary to provide a status for the system and evaluate the results of implementing management decisions (Fig. 8). The monitoring can be tailored to answer the question: has the implementation of the decision had the expected outcomes relative to the success criteria defined in the beginning of the SAF application? The indicators that were developed during the previous steps can be effectively used to monitor status, progress and outcomes. None of the study site applications had reached this step within the time-frame of the project. However, the indicator-based tool (Karnauskaite et al. 2018) can be implemented to evaluate changes in the state of sustainability as well as to evaluate the efficacy of the management process. This tool was applied in a retrospective analysis of 18 'best practice' case studies from the OURCOAST database (Karnauskaite et al. 2018). The targets and indicators identified in the Design step of the SAF using InSAT can be re-assessed in this step to ensure that the objectives have been reached. The indicators can be used to guide the monitoring plan, thus ensuring that results from monitoring can be used to evaluate progress and supplement the ESAT, which also can be here applied to assess ES after the measure have been implemented (Inácio et al. 2018).

Discussion

The Systems Approach Framework in its original form was tested in a number of study sites demonstrating its potential, but also the need for development to improve the participatory processes and to arrive at implementation of solutions (Hopkins et al. 2012). Further, the re-application in the Baltic Sea case studies highlighted several requirements to ensure broad applicability: (i) the guidance needed to be more stringent with clearly distinct steps and actions within each step; (ii) tools needed to be developed or described that could help with successful completion of the different actions; (iii) the science-policy integration needed to be further elaborated to enhance implementation of solutions; and (iv) the stakeholder-governance integration further emphasised to ensure and maintain stakeholder participation. To achieve the above, the steps were revised within the ESE assessment to improve demarcation of the work involved, and two new steps introduced. The Implementation step helps to cement the science-policy and governance-stakeholder integration and the Monitoring and Evaluation ensures an adaptive management of rapidly changing systems.

For science to influence policy it needs to have three attributes; saliency, credibility and legitimacy (Clark et al. 2002 in Wilson 2009). Saliency reflects how narrowly the assessment addresses the Issue but may result in reduced legitimacy if perceived politically biased. The inclusion of stakeholders may reduce saliency but increases credibility. Credibility also infers scientific reliability and technical competence, and

Table 4 The application of the System Assessment step of the SAF in the Baltic Sea study sites

	Oder Lagoon	Vistula Lagoon	Curonian Lagoon	Parnu Bay	Inner Danish waters
Scenarios discussed with stakeholders	Scenario results produced as NetCDF and transferred to GIS-layers and maps. Most feasible at local scale.	Real time simulations not possible with model chosen. Scenarios results presented as posters and discussed with stakeholders	Scenarios presented included maps of potential areas of *E. coli* pollution. Scenario results discussed with stakeholders and prioritized. New suggestions arose from the stakeholder meeting	Scenarios discussed and changed stakeholder and scientist perception of earlier solutions. Became aware that the larger part of the affected population are mostly unaware of the threat to their safety and livelihood.	Potential scenarios discussed with stakeholder.

Table 5 The extent to which the Baltic Sea study sites reached the Implementation step of the SAF

	Oder Lagoon	Vistula Lagoon	Curonian Lagoon	Parnu Bay	Inner Danish waters
Implementation/plans	Developed scenarios could not be implemented due to unclear legal situation resulting from the invasion of an alien *Dreissena* species. Trial mussel (*Mytilus*) farm to be test in a new project building on the lessons learnt from the SAF application	A government decision to construct a cross-cut through the Spit changed the baseline for the scenario choices, as this option was not included in the SAF application and the SAF should be reiterated with this option	The establishment of a new beach should be low-cost to test its acceptance. This may likely be implemented. Other emerging suggestions may also be taken up	Delayed due to administrative reform and coming elections. Planned meeting with future responsible administrative committee once elections are over and new administration in place	Governance restructuring and the complex modeling delayed the process, but priority for resolving the issue still high

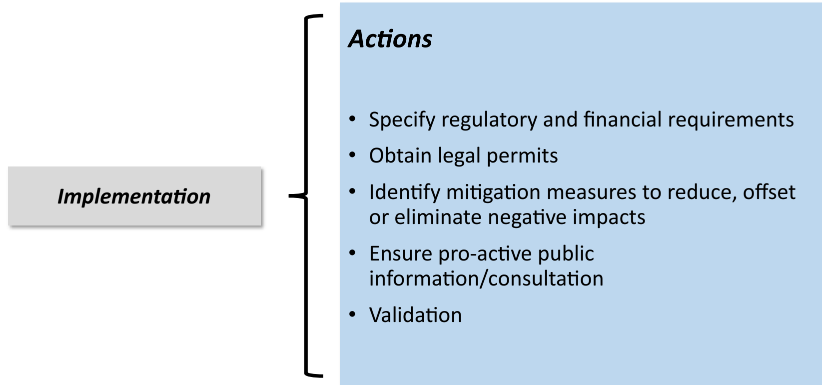

Fig. 7 The list of actions within the Implementation step of the Systems Approach Framework (SAF)

uncertainties and knowledge gaps should be openly acknowledged. Thus, a balance of these three attributes is needed for science to help shape policy.

All issues need some degree of public input, but the level of participation needs to be evaluated for each issue. Not all issues may require a full-scale SAF. Some issues may easily be resolved by a manager and only require information to the public. Other issues may need consultation with stakeholders but still not require a transdisciplinary or multi-sectorial approach. The complexity of the issue and the level of risk involved needs to be assessed during the Issue Identification to determine the level of effort required and approach necessary (Robinson 2002). The assessment of risk has two facets. Sandman (1987) argues that Risk = Hazard + Outrage. 'Hazard' relates to technical, evidence-based danger, whilst 'outrage' deals specifically with what angers, upsets, scares or horrifies people. It is therefore important to respect these concerns, which can then be addressed as part of the SAF.

Identifying the issue

The identification of the issue seems straightforward at the outset. However, it has proven to give rise to much debate and re-formulation within the study site teams that have applied the SAF. This may be due to a significant number of people, or particular groups, having strong and/or competing views on the issue (both positive and negative), insufficient information available on the issue or the technical complexity of an issue. Often questions proposed by stakeholders may be more open-ended and unspecific. It may be useful to understand how the issue arose and evolved. A discussion of the issue in an interdisciplinary group, where scientists familiar with systems thinking participate, may help to frame a more focused question or problem, which can be approached more systematically. Identifying the drivers for putting this particular issue on the agenda helps to fully define its underlying nature and clarify where the responsibility lies for addressing it.

While the CATWOE is helpful in providing insight as to how humans are involved with the Issue (Basden and Wood-Harper 2006), the DPSIR is particularly useful to structure the discussions and invite input from all stakeholders (Gari et al. 2015). This tool was found helpful in all the SAF applications to help analyze causal links between social and natural elements relevant to the issue. In the Danish case study (Dinesen et al. 2018; this issue), the inability to reveal the cause-effect chain for the problem required the advancement to the Design and Formulations steps to discover the cause of the absence of fish in coastal waters, before the Policy Issue could be identified and scenarios for simulations could be proposed. In

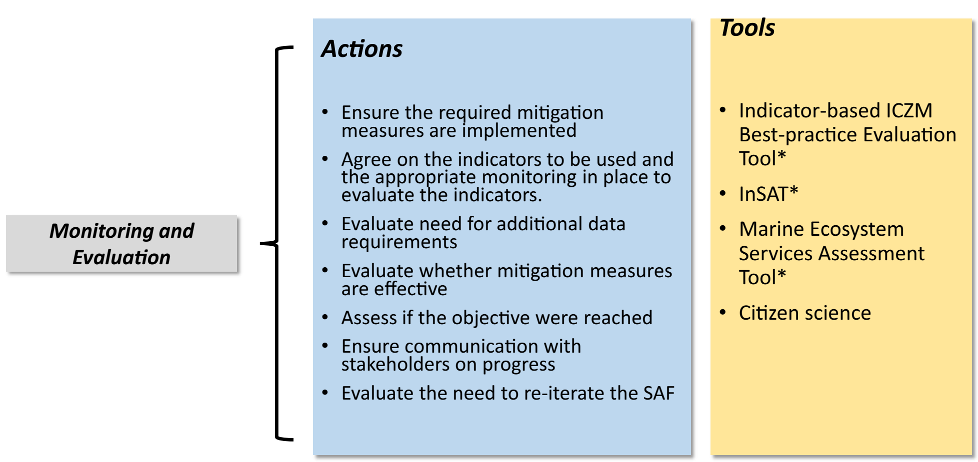

Fig. 8 The list of actions and available tools within the Monitoring and Evaluation step of the Systems Approach Framework (SAF)

complex issues, it may be necessary to design multiple DPSI(R) maps as demonstrated by Camilleri et al. (2015) in conducting an ICM process for the sustainable management of a nature park. Here, an initial DPSI(R) framework captured local, national and global elements, important for the scoping phase of a systems approach, but excluding the Response. In the second DPSI(R), a more detailed analysis of the causal links for the priority issue was mapped. In the Oder Lagoon, a similar approach was taken with multiple DPSIR analyses to help define the causal links each time the virtual system for the Policy Issue was down-scaled (Schernewski et al. 2018a). The DPSIR and the developed version DAPSI(W)R(M) (Elliott et al. 2017) has been put forward as a unifying framework for ICM. The SAF ensures the inclusion of the ESE assessment (System Design, System Formulation and System Assessment) between The DPSI (or the DAPSI(W)) and the R (or R(M)). The ESE assessment is an important feature of integrated management as it guarantees the integration of the sciences, the integration of science into decision-making, as well as engagement of stakeholders, and oftentimes procurement of additional data and information, in this part of the ICM process.

The issue may affect the rights and entitlements of members of the community, citizen quality of life (e.g. Pärnu Bay, Tönisson et al. 2018; this issue) or the availability of natural resources (fish, Dinesen et al. 2018; this issue). Yet, examples of such participatory scoping approaches are uncommon, except in spatial planning (Flannery and Cinnéide 2012). However, even in spatial planning, although the three value dimensions may be considered during scoping, examples of their integration in subsequent analyses are scarce (Rassweiler et al. 2014; Pinarbaşı et al. 2017). The engagement of stakeholders in defining the Policy Issue and listing the Ecosystem services ensures: (i) a common understanding of the problem, its causes and consequences; (ii) an appreciation of the different perceptions of both the problem and the system; (iii) a broader understanding of the system uses and values; and (iv) the significance of stakeholder opinion and input to the process. This helps to ensure their continued involvement in the process. Once there is consensus on what constitutes the Policy Issue, the next step is to translate this to a common goal or objective/s. Discussions with stakeholders on the Policy Issue often focus on solutions, with different groups possibly having strong opinions on what should be done. A common consensus can be gained on having a common goal or over-arching objective to work towards. For example the Policy Issue concerning the establishment of new bathing sites at the Curonian Lagoon had the common objective to enhance local economic development without negative ecological consequences (Schernewski et al. 2017a). The Policy Issue to improve management of coastal fisheries had the common objective to maintain local coastal fisheries for the benefit of local fishing communities (Dinesen et al. 2018; this issue). The Policy Issue to improve coastal management in Pärnu Bay had the overall objective to reduce risk of disaster ecologically, socially and economically (Tönisson et al. 2018; this issue). A common over-arching objective provides the opportunity for more open discussions, setting up success criteria (See under System Design) and focuses the participants on working to achieve a consensual, often passionately negotiated, outcome. Agreement with and acceptance by the community will be critical to the longer-term success of the ICM process.

Stakeholder and institutional mapping

Stakeholder mapping is essential to ensure all involved have the choice to participate. This includes stakeholder typing (e.g., those affecting resources negatively, those interested and/or affected but not responsible, those affected by further change or by not doing anything), their role (e.g. resource extractors, regulators) (Newton and Elliott 2016), and degree of "interest" or engagement (e.g. highly involved, attentives, browsers) (Gillgren et al. 2018). A re-analysis of ICM applications (Støttrup et al. 2017) showed that stakeholder mapping and effective engagement were essential for sustainable ICM processes. A failure to properly map stakeholders led to unbalanced participation causing prolonged ICM processes, citizen discontent and lack of trust in decision-makers. Further, it may lead to one-sectorial decisions that may give rise to new issues needing involvement of additional stakeholders and institutions (Andersen 2016; Schernewski et al. 2017c; Støttrup et al. 2017).

Institutional mapping provides an overview of the power and influence structure as well as the social structure and hierarchy important for the decision-making process (Dutra et al. 2015). Institutional mapping also shows how different organisations interact. Further, historical information may be useful to prevent discussing unfavourable options that may already have been rejected or failed in their implementation. Discussing the Issue with the managers not only helps to gain a common understanding of the problem, but also ensures that the SAF process is embedded in policymaking; i.e. that it becomes a Policy Issue/s. Later on in the SAF, potential Policy scenarios can then be discussed with the scientists and other stakeholders increasing the likelihood of proceeding to Implementation.

The interaction with managers provides an overview on the space policy-makers have to take action and thus the opportunities and constraints to decision-making. It may also reveal differences between institutions at local and national level. The degree of personalized contra institutionalised learning, reliance on key individuals and difference in cultures and perceptions may influence the capacity to make decisions at local, national or international level of governance (Næss et al. 2005) as was also revealed in the case of the cormorant case study revisited by Andersen (2016). Knowledge gained among stakeholders and managers from previous and on-going ICM process is an important factor (Folke et al. 2005; Næss et al. 2005) that may be lost if governance re-structuring is regularly taking place. Re-structuring may delay or prevent the completion of an ICM process and hinder adaptive capacity (Dinesen et al. 2018; this issue). An important aspect that ensures reaching this step is the duration of the process. A time frame of 1.5 years was considered a key element for Implementation (Schernewski et al. 2017a).

Stakeholder and institutional mapping highlighted cultural or political structures that prevented communication in some of the SAF applications. In the transboundary Curonian lagoon, shared by Lithuania and Russia, the SAF was only applied to the Lithuanian part, but the encouraging results were perceived as an ideal basis for future cross-border collaboration with Russia (Schernewski et al. 2017a). The transboundary problems in the Vistula lagoon are slightly more complicated in that access to the Baltic Sea is only from the Russian part. The SAF application circumvented this problem by focusing on solutions that only required Polish participation (Rozynski et al. 2019). However, the SAF results here may also be a step towards improved communication, cross-border collaboration and a more holistic management of this and other cross border lagoons.

Stakeholder participation

Certain "rules of engagement" need to be observed for effective stakeholder participation (Newton and Elliott 2016; Gillgren et al. 2018). There should be a genuine desire to find out the views of stakeholders and the parameters for discussion, and commitment to a collaborative decision-making process (for example the 10-tenets in: Elliott 2013). Engaging stakeholders will not be effective or appropriate if: i) community input will not be incorporated; (i) participants are not fully informed of any constraints such as technical issues, budget or political commitment; (iii) the issue requires an urgent decision; (iv) a final decision has already been made; or (iv) the commissioning body cannot influence the final decision. Schernewski et al. (2017a) found that understanding the prior consultation experience of stakeholders was an important aspect of the mapping, especially if there was tension, fatigue or low level of support due to poor previous experience. Engaging stakeholders becomes a commitment to complete the ICM process and ensure resources are available also to implement and evaluate/validate results.

The Stakeholder Preference and Planning Tool developed by Schumacher et al. (2018) aided to generate a common understanding of the problem (Issue), define common objectives, define success criteria and discuss the suitability of different scenarios for management to fulfil the defined success criteria. In a stakeholder workshop of the Oder lagoon case study (Schernewski et al. 2018a), it was used to discuss different mussel farm scenarios. Hereby, the tool helped to generate a structured and focused discussion within the stakeholder group and to ensure that all stakeholder views are heard and equally taken into account. At the same time, the tool's application helped the science team to better understand stakeholders' perceptions of the management options and identify what additional information is required. Consequently, the use of the Stakeholder Preference and Planning Tool within SAF can contribute to a more transparent process and support social learning among all involved.

The list of human activities and mapping of ecosystem services, in collaboration with stakeholders, ensures the inclusion of all value dimensions (ecological, social, economic), apart from creating social capital (Lopes and Videira 2016). The Ecosystem Services Assessment Tool was useful to visualize historic changes, present state and future scenarios as well as aiding in communication with stakeholders in the decision-making process (Inácio et al. 2018). The application of this tool in the Issue Identification helped the SAF core team gain information on how the local socio-economic system interacted with the environment. This information was later used to communicate and highlight the importance of the study area to human wellbeing and why it was important to take action. The results of the assessment of potential impacts of different scenarios on ES served as a basis for discussions among stakeholders and decision-makers. It also helped to assess which management option would be most suitable to fulfil the objectives of the case study and ensure the sustainable deliverance of ecosystem services. During the Monitoring and Evaluation step, the tool allows stakeholders and decision-makers to check if the a priori impacts of future scenarios on ES provision are in line with what is observed in the ecosystem. If the outcomes are according to those expected, then the measure turned out to be successful. However, if the outcomes are different from those expected, this monitoring phase can help decision-makers to re-think or maybe re-direct their efforts to understand the real extent of the implemented measure on ES, and what are the consequences for the ecological-social-economic system.

Discussion of the individual model components with stakeholders during the System Formulation step ensures these sub-models reflect the stakeholders' perception of the system. This contributes to capacity building as participants become more knowledgeable of the issues, models and their impacts. At the same time, managers/ scientists become more aware and appreciative of community issues and perspectives, and local knowledge. Additional data provided by stakeholders during this step helped improve the bio-economic model (Timmermann et al. 2014). Communication in this step increases credibility of the process and builds ownership for the model being developed which will eventually provide the scenario simulations on the chosen management options.

An open discussion of these results with and among stakeholders is possible if: i) the model components are easily understood; ii) the model components reflect the stakeholders' perception of their system; and iii) scenario simulations provide insight into the environmental, social and economic consequences of management options.

There are no generally accepted guidelines on communicating complex ecological and socio-economic models with non-scientists, limiting their integration in decision-making processes. For this reason, the EU project SPICOSA (www.spicosa.eu) made it compulsory for all study sites to use the software ExtendSim™ for building ESE models with a user-friendly interface enabling in situ scenario simulation to be carried out by stakeholders at public meetings and workshops (e.g. Dinesen et al. 2011; Mongruel et al. 2011; Konstantinou et al. 2012). Such single-basin modelling softwares as ExtendSim™ are useful for scenario simulation of issues with a relative simple cause-effect chain. Such software is however unsuitable for modelling highly dynamic and complex systems as experienced in Oder Lagoon (Schernewski et al. 2018a) and the Danish study site. Regardless of the modelling approach and methods chosen, communicating ESE model uncertainties and limitations with stakeholders is vital for building trust among the SAF team and ensuring reliability in the scenario simulation output. When stakeholders provide information and data proved important to the model components this should be emphasized and demonstrated as this can encourage further citizen information to be provided and increase their involvement. Transfer of knowledge and collaboration between the general public and scientists is facilitated by the activities of emerging citizen science projects.

The ESE assessment

The ESE assessment seems daunting for most scientists that have to deal with imperfect data, incomplete understanding of the system and the challenge of predicting bio-socio-economic consequences of potential management scenarios. However, the systems approach does not require in-depth understanding of all the components, but rather key facets of an aggregate system (Franzén et al. 2011; Mongruel et al. 2011). The inclusion of scientists in the SAF core team ensures best possible evidence/data being put to use to guide the process towards a decision, which may most likely provide the desired outcomes. The role of the science team is to provide scientific guidance in a form that is accessible to non-experts. The inclusion of a professional and experienced moderator to guide and lead the stakeholder meetings is recommended (Schumacher et al. 2018), and has been shown to be a key element in successful SAF applications (Dinesen et al. 2011; Schernewski et al. 2017a).

The conceptual model helps to identify the data needed, such as time-series data for natural, social or economic elements, process information and data from public questionnaires (examples of conceptual models can be found in: Dinesen et al. 2011; Schernewski et al. 2017a; Tönisson et al. 2018; this issue). In the Curonian Lagoon, several smaller projects were initiated to obtain social and economic data and information important for the ESE assessment (Schernewski et al. 2017a).

The model components require defining the virtual boundaries, based on the level of data available and the scaling required for the model components as well as for the final merged bio-socio-economic model (e.g. Schernewski et al. 2017a). Scaling can be problematic as seen in the Danish case study, where fisheries management takes place at regional level, implemented at national level, yet the decline in coastal fisheries is a highly localized problem. Scaling down and narrowing down the boundaries to focus on the Policy Issue played an important role to be able to proceed to the Formulation Step in both the Curonian Lagoon (Schernewski et al. 2018a) and the Oder Lagoon (Schernewski et al. 2018a). Transboundary issues involving different languages, cultures and governance systems may increase model complexity but may also be circumvented (Rozynski et al. 2019), although these hurdles may also arise at very local levels (Schernewski et al. 2017a). Also, management of geographical features (rivers, lagoons) and organisms such as fishes, birds and mammals with transboundary populations needs to be addressed collaboratively to have the desired outcomes (Andersen 2016; Dinesen et al. 2018; this issue; Link 2018).

Considering the trans-disciplinarity of the SAF science team, a genuine integration is crucial to the SAF process. Multiple SAF implementations have shown focused workshops to provide the common ground needed for this integration leading to a common language, reciprocal trust and respect between the sciences represented. For example, familiar words, such as "growth" have a different meaning in biology and economy. Furthermore, this step also helps the SAF team become aware of the limitations and uncertainties of the model and the scientific output. This knowledge exchange and team-building needs to be extended to encompass the stakeholder group for the Policy Issue being addressed to establish a common basis that benefits the process.

Most often, the environmental model component is developed independently from the social and economic model components, although the links have already been identified within the conceptual model. In cases where the environmental model component is highly complex and detailed, empirical models can be applied using auxiliary models to establish simple correlations that are calibrated with data (Franzén et al. 2011; Timmermann et al. 2014). This helps to produce a simpler model, with a shorter computation time that provides reasonable results and is easily understood and communicated.

The simulation scenarios are confined by the virtual boundaries of the model, the spatial and temporal scale and availability of data. These define what the model can answer and cannot. Scenarios not accounted for in the ESE model may pose external hazards and risk to management plans and implementation derived from the ESE modelled scenarios. Thus, potential external risks and hazards need to be identified. They comprise both natural and anthropogenic events not accounted for within the virtual boundaries of the ESE model, such as the risk of algal blooms (Timmermann et al. 2014; Schernewski et al. 2017a). Since external hazards may affect or entirely overrule the modelled scenario outputs, the potential risks imposed must be assessed, including evaluation of the probability of individual and cumulative external hazards occurring, multiplied by their intensity.

It became clear from the different SAF applications that refinement of the conceptual model takes place during the System Design step and continues during the Formulation Step. The final conceptual model becomes the description of the ESE model, which incorporates the ability to simulate the potential management scenarios identified by the SAF core team together with the stakeholders. System modelling provides likely outcomes of different management options, a process that ensures science-policy integration with stakeholder participation. Discussion of the results of scenario simulations increases recognition of the benefits of stakeholder participation and of the value of science guidance in decision-making (Franzén et al. 2011; Konstantinou et al. 2012; Schernewski et al. 2017a, 2018a). In one SAF application, the extreme events could not be ignored and the ESE assessment helped to identify which Policy options were feasible or cost-effective and worth focusing on (Tõnisson et al. 2018; this issue). Sometimes, scenarios which may not be potential management options are included to provide a basis for comparison (Moksness et al. 2011) or social learning and creating awareness (Tõnisson et al. 2018; this issue). Although they may not be operational or even directly address the problem, scenarios are generally useful in that they reveal other questions and options. The results from such scenario simulations may provide unexpected results, which give rise to discussion and enhance system understanding (Dinesen et al. 2011; results of no mussel fishing; Tõnisson et al. 2018; results of hard coastal protection measures).

Implementation of management decisions need to be followed by an assessment of their impact. Success criteria thus need to be defined for the common objective and indicators identified, which, through monitoring, can indicate how well the implemented decision is performing. Indicators have been developed to monitor states and development in coastal systems (Hoffmann 2009; Gallagher 2010) but are rarely applied due to lack of guidelines or supporting tools for their application. The InSAT (Karnauskaite et al. 2018), based on well-established indicators grouped into three categories for sustainable development help to evaluate the state and success of implemented solutions. A further set of indicators evaluates the management process and uses the SAF as the quality assurance for a sustainable ICM process.

It is evident from most of the SAF applications that the data available is often insufficient requiring researchers to find creative solutions and intelligent approximations to simplify simulations in order to obtain meaningful results. The economic and social model components for the issue can be especially challenging as the data can be generic or unavailable and there are examples of SAF applications that have required further data to be collated during the application (e.g. Timmermann et al. 2014; Schernewski et al. 2017a). An Ecosystem Services Assessment Tool was developed to allow stakeholders, manages and experts to assess different scenarios of change and discuss and prioritize ecosystem services (Schernewski et al. 2018b; this issue). With this tool, it was possible to harmonize views, mitigate misperceptions and encourage communication. Most indicator tools such as the HELCOM Eutrophication Assessment Tool (HEAT; Andersen et al. 2011) or biodiversity indicators (Teixeira et al. 2016) focus on the environmental status. For the SAF, a tool that encompasses environmental, social and economic elements is needed to evaluate the combined system services with stakeholders and experts.

The SAF application

The SAF was shown to be sufficiently robust as quality assurance for sustainable ICM processes (Støttrup et al. 2017). However, its true value will be in future applications using the SAF to guide ICM processes. Adaptations of the SAF can most likely also guide MSP process and other management where scientific evidence and stakeholder participation can ensure sustainable policy decisions.

Many of the published SAF applications have been science-led (Hopkins et al. 2011) including the publications in this issue, due to their being embedded in science projects (SPICOSA; www.spicosa.eu and BONUS BaltCoast; www.baltcoast.net). Thus, the science team starts by identifying a problem and thereafter embracing a wider participation to include stakeholders and managers. This decoupling of a decommissioning body with an aim to resolve a complex issue in a sustainable manner may be the reason why several SAF applications, although showing some highly interesting results of potential policy scenarios, faltered at the Implementation step. In the Vistula Lagoon, closer interaction with governance may have resulted in the incorporation of the scenario of constructing a cross-cut through the Spit to pursue ecological, social and economic consequences of such a Policy decision (Rozynski et al. 2019). The decision was taken by the government during the course of the project, presumably without the scientific evidence to back it or stakeholder input. Ideally, a SAF is initiated by a commissioning body with influence in decision-making and implementation, a genuine interest in the outcomes and in engaging stakeholders in the process and outcomes. However, the science-initiated approaches were successful in gaining the interest and in some cases commitment of stakeholders to the process, even leading in one case to Implementation (Schernewski et al. 2017a). Thus, whether or not the outcome of the System Assessment is implemented depends upon several factors: (i) good relations between the commissioning body and the SAF team; (ii) the commissioning body or the managers in the SAF team can influence the final decision; (iii) rigorous application of the SAF steps, especially the Issue Identification step; (iv) the duration of the process is within a reasonable timeframe; (v) the appropriate funding for implementation can be secured; (vi) the decision is not obstructed by legal or ethical constraints; (vii) the decision is not obstructed by a change in governance and hence priority issues.

Validation was introduced in the SAF as a separate action in the Implementation to introduce accountability and avert consultation fatigue. Participants can observe how their input has contributed to the decision and how the decision is being implemented (Gillgren et al. 2018). The action includes: i) to view the implementation plan or policy or law being proposed to demonstrate that the outcome of the SAF process is what is actually being implemented; or ii) if physical work needs to be undertaken, to ensure that (a) it is in accordance with agreed outcomes or (b) if implementation cannot be done according to outcomes due to unforeseen circumstances (e.g. archaeological discovery during excavations), working group can participate in identifying alternative solutions. This action enhances citizen trust in governance while counteracting the frustration and alienation that arises from procrastination or lack of implementing decisions. Citizen frustration may arise when policy effectiveness at a local scale is hampered by governance mechanisms operating at another scale, or with a change in government where the issue is no longer of priority and the process is halted (Gillgren et al. 2018). Validation is especially valuable in highly contentious issues or where there has been much cynicism.

A further new step was introduced to ensure evaluation of the outcomes and if the objectives have been achieved. The monitoring and evaluation provides several benefits. It is an opportunity to: (i) demonstrate the effect of the decision to the broader public; (ii) maintain communication with stakeholders; (iii) continue to engage citizens through citizen science; iv) evaluate and communicate whether objective were reached; (v) evaluate and identify data and research needs; (vi) evaluate the need for iteration of the SAF, or some steps of the SAF. It is hoped with the wider dissemination of the SAF, that examples will emerge of complete SAF applications with implemented Policy decisions and applied Validation, Monitoring and Evaluation.

Although hampered by differences in individual perception and level of knowledge, the indicator based assessment tool (Karnauskaite et al. 2018; this issue) provides insight on the extent to which the objectives have been achieved both in terms of the validity of the ICM process and the three pillars of sustainability; environmental sustainability, economic efficiency and social equity.

Acknowledgements This work was mostly funded by the BONUS BALTCOAST project. BONUS BALTCOAST has received funding from BONUS (Art 185) funded jointly from the European Union's Seventh Programme for research, technological development and demonstration, and from the Baltic Sea national funding institutions, InnovationsFonden, Denmark and the Federal Ministry of Education and Research of Germany (BMBF 03F0717A). We would like to thank our colleagues from BONUS BaltCoast for their input to testing and developing the SAF and supportive tools.

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