Πανεπιστήμιο Αιγαίου

Τμήμα Επιστημών της Θάλασσας-Σχολή Περιβάλλοντος

Ανοικτό ακαδημαϊκό μάθημα

Διαχείριση Παρακτίων Περιοχών

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Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης
ΕΣΠΑ
2007-2013
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ

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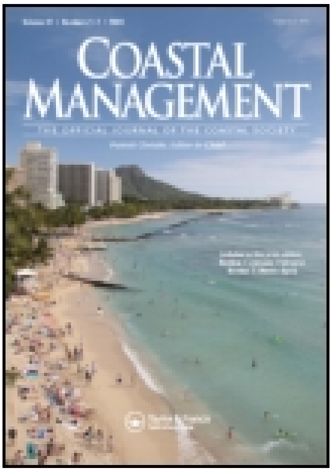

Coastal Management
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/ucmg20

Applicability of Decision Support Systems for Integrated Coastal Zone Management

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Published online: 18 Dec 2007.

To cite this article: Frank Van Kouwen, Carel Dieperink, Paul Schot & Martin Wassen (2007) Applicability of Decision Support Systems for Integrated Coastal Zone Management, Coastal Management, 36:1, 19-34, DOI: 10.1080/08920750701682007

To link to this article: http://dx.doi.org/10.1080/08920750701682007

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Coastal Management, 36:19–34, 2008
Copyright © Taylor & Francis Group, LLC
ISSN: 0892-0753 print / 1521-0421 online
DOI: 10.1080/08920750701682007

Applicability of Decision Support Systems for Integrated Coastal Zone Management

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The use of Decision Support Systems (DSSs) in Integrated Coastal Zone Management (ICZM) has declined since the 1990s. In this article we investigate the opportunities for enhancing the applicability of ICZM-DSSs by considering the following research questions: (1) "What DSS functionalities are important for ICZM decision-making?" and (2) "which of these functionalities are part of present-day ICZM-DSS tools?" The first question has been answered by a literature survey. We identified knowledge- and process-related ICZM challenges and DSS functionalities that may help in meeting these challenges. For the second question, a selection of ICZM-DSS tools has been evaluated. The study shows none of the tools have all of the identified functionalities. The tools support either problem structuring/exploration or impact assessment while none of the tools manages to combine these functions. The implications for both DSS users (coastal managers) and DSS developers are discussed.

Keywords decision support systems, integrated coastal zone management, knowledge utilization, policy support, stakeholder participation

Problems with Decision Support in ICZM

Coastal areas are often densely populated, which requires optimal use of available spaces. The need for optimization has grown worldwide and the need for sustainable practices in coastal areas has been garnering increasing attention (for example, see Bakri, 1996; Barragán et al., 2005; Brochier et al., 2001; Fletcher, 2000; Mokhtar et al., 2003; Shamsul Huda, 2004; Shi et al., 2001). Managing the need for sustainability in the coastal zone is usually referred to as Integrated Coastal Zone Management (ICZM). In Europe, the European Union (EU) encourages member states to implement ICZM (CEC, 2002) and has

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This research has been funded by NWO, the Dutch organization for scientific research. The authors thank the Research Institute for Knowledge Systems (RIKS), Elisabeth Ruijgrok; the National Institute for Coastal and Marine Management (RIKZ), Resource Analysis, Harm Albert Zanting (Arcadis); Stephan Mai, Jeroen Aerts, Hugo Niesing, Robbert Misdorp and Jochen Hinkel for giving relevant information about the several DSS tools. The authors also thank Jeroen van der Sluijs and three anonymous reviewers for their comments and advice. Finally, the authors thank Leo Pollock for correcting the article with respect to grammatical and style issues.

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therefore initiated a Demonstration Program promoting ICZM (Burbridge & Humphrey, 2003; CEC, 2000). This program illustrates a general trend toward more interactive policy-making and stakeholder involvement (EU, 2006).

Definitions of the concept of ICZM (Cicin-Sain & Knecht, 1998; WorldBank, 1996) demonstrate this concept is broad and involves complicated problems; ICZM thus implies difficulties in the decision-making sphere. To support decision-making at various institutional levels, several computer tools have been developed (for example, see de Kok et al., 2001; de Kok and Wind, 2003; Engelen, 2000; Uran, 2002; Westmacott, 2001). Usually, these tools are referred to as Decision Support Systems (DSSs). DSSs are capable of dealing with multiple objectives and are considered to be useful tools for sustainable development (Quaddus & Siddique, 2004). For example, the DSS tool WadBOS has been used in an environmental impact assessment for the Enclosure Dam (Afsluitdijk) in the Netherlands (Hoogenboom et al., 2005; Verbeek & Wind, 2001). Broadly defined, DSSs are computer-based information systems which are designed to support unstructured problem solving, decision-making, and decision implementation (Le Blanc, 1991). A DSS helps decision-makers to utilize data and models to solve unstructured problems (Sprague & Carlson, 1982). Westmacott (2001) defined an integrated coastal management (ICM) DSS as "a computerised system capable of supporting and assisting decision-making in ICM." Densham (1991) defines a spatial DSS as a computer tool, which is "explicitly designed to provide the user with a decision-making environment that enables analysis of geographical information to be carried out in a flexible manner." Both definitions are rather vague in identifying what the role of the DSS should be, and in doing so allow for a broad interpretation of the potential function of DSSs in ICZM decision-making. Janssen (1992) was somewhat more explicit about the main purposes of a DSS:

- to assist individuals or groups in their decision processes
- to support rather than replace judgment of these individuals
- to improve effectiveness of decision-making rather than its efficiency

All of these definitions and statements about the role of a DSS use verbs such as "provide," "assist, "support," and "improve." The definitions share the concept that a DSS should contribute to the decision-making process. This article is based on the paradigm that, in the process of ICZM decision-making, a DSS may effectively help users to get a better understanding of issues and to assess pros and cons of policy interventions. We formally define an ICZM-DSS as "a computer system that contains information about ICZM issues, and is designed to perform analysis to help coastal managers in decision-making."

The application of DSSs for coastal management has been limited in comparison to other sectors (Wiggins, 2004). The EU Demonstration Program suggests that DSS tools developed by the scientific community are usually so complex that it is difficult for managers and policymakers to apply them (Doody, 2003). We found two ICZM-DSS evaluation studies in literature. Uran (2002) investigated five spatial DSSs that were used for coastal zone and water management in the Netherlands. She concluded that spatial DSSs are not essential tools because there is a mismatch between the complexity of the information generated by the tools and the users' ability to interpret the information (Uran & Janssen, 2003). Westmacott (2001) evaluated three DSSs used for integrated coastal management in the tropics and concluded that end users are often not involved in the development of DSSs, which is a key factor for the usefulness of any system. From these studies it appears that, in spite of their potential usefulness, there is a mismatch between the functionalities of ICZM-DSSs and the needs of ICZM decision-makers. This article aims to elaborate on this mismatch, such that it provides knowledge and insight that can be used to enhance the applicability of DSSs for ICZM.

Approach

The aim of this article is to investigate opportunities to enhance the applicability of DSSs for ICZM. Other than the case studies of Uran (2002) and Westmacott (2001), we make an explicit comparison between (1) what is potentially technically possible in terms of addressing ICZM challenges versus (2) the current capabilities of existing tools. To make this comparison, we consider the following research questions:

1. What DSS functionalities are important for ICZM decision-making?
2. Which of these functionalities are part of present-day ICZM-DSS tools?

To address the first research question, we found no existing DSS evaluation framework for ICZM issues in the literature. Therefore, we firstly identified challenges faced by ICZM decision-making. For this, we adopted Hisschemöller's problem typology (Hisschemöller, 1993; Hisschemöller & Hoppe, 2001) to classify the problems ICZM decision-makers face as *unstructured* problems. Such problems can be characterized by (A) uncertainty regarding relevant knowledge and (B) a lack of consensus concerning relevant norms and values. Based on this classification, we define challenges for coastal management as being either knowledge-related or process-related. The latter include the incorporation of human norms and values. For each of these challenges we then identified DSS functionalities that may help in meeting them.

For the second research question, we inventorized to what extent the identified DSS functionalities are present in a selection of 13 present-day ICZM-DSSs. In doing so, we investigate opportunities to enhance the applicability of DSSs for ICZM decision-making. Our methods and criteria for selecting DSSs will be discussed in the corresponding section.

ICZM Challenges and DSS Functionalities

Since the knowledge and information needs for ICZM decision-making are often case-specific (Dahl-Tacconi, 2005), we defined a number of general challenges that are broadly relevant to ICZM decision-making and therefore would not only apply to specific cases. These challenges were identified by means of a literature survey. In the next subsections the knowledge- and process-related challenges and associated DSS functionalities are discussed.

Knowledge-Related Challenges and Functionalities

In this subsection we will discuss the knowledge-related ICZM challenges and DSS functionalities that can help in meeting these challenges.

Uncertainty. ICZM decision-making will inevitably have to deal with uncertainties (e.g., climate change and sea level rise). In environmental modeling there is general acceptance that parameters contain a degree of uncertainty, but most models seem to be built on the assumption that all parameters are known and data sets are free of errors (Wainwright & Mulligan, 2003). Van Asselt (2000) made a typology of uncertainty, which demonstrates that a distinction can be made between uncertainty due to variability and uncertainty due to lack of knowledge. Van der Sluijs (1997) distinguished three types of uncertainty: inexactness, unreliability, and ignorance. In this article we choose to distinguish between quantified uncertainties due to measurable variability and unquantified uncertainties due to a lack of knowledge. For each of the DSSs we first assessed whether or not the tools were able to handle quantified uncertainty ranges. We then determined if each tool enables the user(s) to deal with incomplete knowledge. In addition to being able to handle uncertainties in the input, it is also important that a DSS can handle uncertainties in the output. When showing the calculated results of scenarios, it is desirable that the tool is capable of providing visualizations of the uncertainties inherent in the output information (Aerts, 2002).

Spatial and Temporal Patterns and Behavioral Dynamics. Spatial information can be crucial in ICZM practices, as measures undertaken for a specific location may have dramatical effects elsewhere. The capability to calculate spatially explicit scenarios is a desirable functionality of a DSS, for instance by the use of spatial models and Geographical Information Systems (GIS). ICZM also deals with dynamics processes, so it is preferable that the tools can handle temporal variations. An important dynamic factor for ICZM is human behavior, as this is an important steering factor for management. A modeling approach dealing with human behavior is known as agent-based modeling (Boulanger & Bréchet, 2005; Otter, 2000). This rule-based technique derives from the field of Artificial Intelligence and models interactions between units, which are labeled agents. Multi-agent-based simulations are potentially effective for problems integrating social and spatial aspects (Bousquet & LePage, 2004). In our analysis, we determined whether or not DSS tools support agent-based modeling.

Forecasting and Backcasting. Decision-making is about making plans for the future. This policy process can be supported both by forecasting and backcasting (Holmberg, 1998; Robinson, 2003). Forecasting implies that effects of a proposed measure are predicted. Backcasting refers to reasoning in the opposite direction: if we want to achieve certain objectives in the future, what actions need to be taken now and how can these best be implemented? Backcasting can help in creating a vision of what the future should be and how this future can be realized (Couclelis, 2005). This distinction between forecasting and backcasting is also addressed in literature on Integrated Assessment Models (IAMs) for climate change. In these studies (Janssen & Rotmans, 1995; Rotmans & Dowlatabadi, 1996; Schneider, 1997; Tol, 1996; van der Sluijs, 1997; Weyant et al., 1996), the authors discern between policy-evaluation tools and policy-optimization tools. Policy-evaluation tools describe the system in order to forecast the possible effects of implementing certain measures, whereas policy-optimization tools identify what measures can be considered optimal given desired targets. Ideally a computer tool would support both policy evaluation and policy optimization.

The challenges and the associated possible DSS functionalities with respect to knowledge in ICZM are shown in Table 1.

Process-Related Challenges and Functionalities

In this subsection we will discuss the process-related ICZM challenges and DSS functionalities that can help in meeting these challenges.

Science-Management Integration. Utilization of knowledge is a key aspect related to DSSs, as confirmed by The EU Demonstration Program (Doody, 2003). In practice however,

Table 1
Challenges regarding ICZM *knowledge* and DSS functionalities that can help in meeting them

Challenges	DSS functionalities that help in meeting the challenges
Interdisciplinarity	Integrated modelling, taking into account both socio-economic and biophysical aspects and their interrelationships
Uncertainty	Can handle uncertainty ranges Can handle incomplete knowledge, weak/unknown relationships Can visualize uncertainties
Spatial dynamics	Spatially explicitly calculated scenarios
Temporal dynamics	Can handle temporal dynamics
Human behavior	Agent-based modeling, multi-agent systems
Forecasting	Policy-evaluation
Backcasting	Policy-optimization

policy-related research is often not sufficiently linked to the formal policy-making process itself (Boogerd, 2005; in ‘t Veld, 2000), especially with regard to impact assessment (Deelstra et al., 2003). For effective ICZM decision-making, the interactions between the science and policy spheres need to be improved (Cicin-Sain & Knecht, 1998). This requires increased communication between decision-makers (i.e., the management) and scientific experts from diverse disciplines. The aim of a science-management integration is to make scientific knowledge manageable for decision-makers and to generate scientific knowledge, which is needed by the decision-makers. This can be achieved by having policy-makers participate in the process of building the DSS (van Leeuwen & Breur, 2001). Ewing et al.’s (2000) theory on adaptive management suggests that building models interactively is a potentially effective approach for addressing this problem. Therefore we investigated the degree to which tools support interactive model construction. This means that the tool itself has been built by the developers, but the knowledge in the model can be adjusted directly by the users without interference from the tool developers.

Stakeholder Participation. In the field of environmental management, there is a tendency towards stakeholder participation in both the development of the DSS and the decision-making process (Matthies et al., 2007). In coastal management, it is desirable to have open, flexible policy processes in which stakeholders actively participate (Treby & Clark, 2004), preferably from the very beginning of the process (UNEP, 1999; WorldBank, 1996). ICZM operates in a multi-actor context (Schouten et al., 2001). This implies that the stakeholders will have different perceptions of the problems at stake (van de Riet, 2003), which will have consequences for the decision-making processes and the way these should be organized. We have examined if the tools are designed to support multiple users simultaneously. A special category of these tools use gaming techniques, simulations that can be played much like a computer game. Gaming may be suitable for complex, ill-structured problems in a multi-actor context (Mayer & de Jong, 2004) because gaming techniques can potentially address the diversity in problem perceptions. This clearly has relevance to ICZM issues. The real-life interaction of gaming helps to make formal modeling more valid and relevant to the policy context (Geurts & Joldersma, 2001). Furthermore, interactive model construction as described earlier can be helpful too, as stakeholders may participate in the process of building DSSs (Ewing et al., 2000).

Making Complex Information Understandable. A technique called concept mapping, known also as mental model mapping or cognitive mapping, can be helpful to represent knowledge about a certain system or problem (Kolkman et al., 2005; Soini, 2001). Concept mapping is a graphical representation of the understanding of relationships between concepts. Nodes (points or vertices) represent concepts, and links (arcs or lines) represent the relationships between these concepts. Such conceptual models can present complex problems schematically, in a way that is relatively easy to understand. We have assessed whether or not the DSSs support such conceptual models.

Different Phases. Like any policy process, the ICZM decision-making process can be subdivided into several phases. There are many steps distinguished by ICZM literature and by literature from policy sciences in general. Fabbri (1998, 2002, 2006) developed the "triple-S" framework for ICZM, involving the phases of Screening, Scoping, and Scanning. Screening is about constructing a knowledge base and finding causal linkages. The latter is shared with the Scoping phase. However, in the Scoping phase the problem is being explored and structured by stakeholders and decision-makers. This phase leads to the definition of ICZM strategies (options), which are simulated and evaluated in the Scanning Phase. Therefore, the Scanning phase is about impact assessment which may include a multi-criteria analysis.

Consistent with the distinctions of Fabbri, but also taking into account the phases as defined by Cicin-Sain and Knecht (1998), by Doody (2003), by the Scientific Council for the Dutch Government (Vermeulen et al., 1997), and by the Social Learning Group (SLG, 2001), we defined seven generally accepted phases related to ICZM decision-making processes: problem structuring/exploration, generation of options, impact assessment, agreement on actions, implementation, monitoring, and evaluation. A DSS will be especially useful in the first three phases; the fourth phase "agreement on actions" is in fact the very moment that policy decisions are being made. We assume that it is the responsibility of the decision-makers, not the tool, to make the actual decisions. Implementation, monitoring and evaluation are considered to be phases in which a DSS plays a minor role; if one of these phases results in new insights and problem perceptions, the process is then assumed to return to the problem structuring/exploration phase. For our characterization of DSSs, it was important to determine the appropriateness of the tools for each of the three phases. To do this, we asked tool developers to identify the phases for which the DSS tool was designed to be used.

The challenges and the associated desirable DSS functionalities with respect to the process and people involved in ICZM are shown in Table 2.

Functionalities of Present-Day DSS Tools

To answer the second research question, we first needed to create a list of existing DSS tools to evaluate. We restricted ourselves to computer-based tools that have been developed or used for an ICZM issue. Additionally, we use the following prerequisites for the DSSs:

1. The system is an integrative tool designed to take physical processes, human activities, and their interrelationships into account;

Table 2

Challenges regarding the ICZM *process* and DSS functionalities that can help in meeting them

Challenges	DSS functionalities that help in meeting the challenges
Science-management integration	Policy-support tool that is aimed at making knowledge interactively accessible for policy-makers Interactive model construction
Stakeholder participation	Multiple simultaneous users Gaming Interactive model construction
Making complex information understandable	Visualization of conceptual models
Problem exploration/structuring	Tool is supposed to be used for problem exploration/structuring
Option generation	Tool is supposed to be used for generation of options
Impact assessment	Tool is supposed to be used for impact assessment

2. The system is aimed at structuring knowledge to make it interactively accessible for decision-makers.

Condition one is necessary as addressing sustainability issues involves recognizing the interconnectedness of natural and human systems. The interconnectedness implies that knowledge and expertise from several research areas, including both natural and social disciplines, will be required. The second system requirement is important as it ensures the exclusion of models that have only been designed for scientific purposes. By including this as a prerequisite, we guarantee that only ICZM-DSS tools that are specifically designed for interactive usage by policy- and decision-makers will be investigated. We consider the knowledge to be interactively accessible when these tools can make rapid calculations (disregarding use of a specific time limit).

We found hundreds of DSSs by searching the Internet and scientific journal databases. We discarded DSSs that were not explicitly dealing with coastal areas and issues. We evaluated the remaining DSSs with respect to condition 1 by determining whether or not the tools take biophysical and socioeconomic aspects into account. We only selected tools that take both aspects into account. We evaluated the tools with respect to condition 2 by reading the descriptions to see if it is really designed to be used by policymakers and managers interactively. From the original list of hundreds of DSSs, finally 13 ICZM-DSSs met both conditions. We should note that information about ICZM-DSS tools is often difficult to find; not every tool is well documented in internet resources and many have been developed by private institutions. We only investigated tools documented in English or Dutch. Although we consider our list of DSSs to be representative, we do not suggest that it is an exhaustive list. A brief description and some references for the tools are given in Figure 1.

Documentation about the tools has been studied to evaluate their characteristics. For questions that could not be answered with the available information, we consulted the developers of the DSSs. Table 3 identifies which knowledge-related functionalities can be

The **CORAL** decision support system enables managers to assess interventions for coral reef protection and management on the basis of criteria related to cost-effectiveness, social acceptability and political feasibility (NWP, 2000; Rijsberman and Westmacott, 1997).

The **COastal zone Simulation MOdel (COSMO)** is a computer-based decision-support model that allows coastal zone managers to evaluate potential management strategies under different scenarios, including long-term climate change. A version of COSMO has been developed to demonstrate characteristics, constraints, and limitations of institutional arrangements for coastal zone management. The program simulates day-to-day management of a coastal zone (UNFCCC, 1999).

The **Dynamic Interactive Vulnerability Assessment (DIVA)** tool is an instrument for integrated assessment of coastal zones which has been applied in the DINAS-COAST project (Hinkel, 2005). This project is about the vulnerability of coastal zones to climate change and sea-level rise. DIVA comprises a coastal database, an integrated model of the natural system and socio-economic factors, and a graphical user interface for selecting data and scenarios, running the models, and analyzing and visualizing the results (Hinkel and Klein, 2003).

The **Estuary Decision Support System (EDSS)** consists of a qualitative tool for rapid assessment, as well as some analytical geomorphologic models for complex calculations. The tool has been made operational for the Westerschelde estuary in The Netherlands and the Yangtze-estuary in China (RA, 2005).

MARXAN is software that delivers decision support for reserve system design. MARXAN finds reasonably efficient solutions to the problem of selecting a system of spatially cohesive sites that meet a suite of biodiversity targets (Ball and Possingham, 2000; Possingham et al., 2000). MARXAN has been used with both socio-economic and ecological data from coastal and marine systems in South Australia to explore practical and theoretical aspects of spatial reserve design (Stewart et al., 2003).

The **Nature Development and Valuation (NDV) module** is a tool to support decisions on changes in land use. Its two main objectives are: (1) to predict the occurrence of species and the formation of ecosystems and landscapes; and (2) to support the trade-off between ecological and economic interests by valuing nature. (Ruijgrok, 1999). The NDV module has been developed for and applied to the planned extension of the Rotterdam Harbour in the Netherlands (Ruijgrok, 2000).

RAMCO (Rapid Assessment Module Coastal Zone Management) describes the natural and anthropogenic processes in a coastal zone under the influence of the dynamic behavior and interaction of spatial agents, such as inhabitants of the coastal area and economic activities (fishery, cultivation of shrimps, agriculture, industry, tourism and commerce) (RIKS, 2005).

The **Risk Information System Coast (RISC)** is a DSS tool that provides information on the probability of failure of dikes in the German North Sea coast derived from water levels and geometry of the coastal zone. The consequences of dike failure are visualized including maps of flood zones and the calculation of loss and risk (Mai and Liebermann, 2002).

SimCoast is aimed to provide coastal and regional planners with a management tool, supplying guideline information to them prior to and during development programmes (Hogarth and McGlade, 1998). A two-dimensional multi-zoned transect lies at the heart of SimCoast; this can be populated by zone-specific features (e.g. ports, mangroves) and activities (e.g. shipping, aquaculture) (UP, 1999).

SimLucia is a decision support system for vulnerability assessment to climate change and dynamic land use planning in St. Lucia, West Indies. It was developed in 1996. Three coupled subsystems are modelled: the natural, social and economic subsystems, each represented by sets of linked variables (RIKS, 2005).

The **STREAM** instrument (Spatial tools for river basins and environment and analysis of management options) is an instrument for river basin studies with emphasis on management aspects (Aerts et al., 1999). Modules that have been developed include saltwater intrusion in the delta, an ecological module for mangrove habitats and socio-economic scenario development (VU, 2005).

The **Thematic Orientation on Project definition in an Interactive Context (TOPIC)** tool was developed to offer support in the inventory and assessment of problems concerning coastal management and to enable the development of appropriate solutions. It is aimed at problem structuring and exploration, and communicating about identified issues (RIKS, 2005).

WadBOS is a decision support system, specifically developed for the (Dutch) Waddensea. It is an integrated, analytical model of physical, ecological , as well as socio-economical processes in the Waddensea. It models only aquatic ecosystems in the Waddensea, and does not include terrestrial ecosystems (Engelen, 2000; Hoogenboom et al., 2005; RIKS, 2005).

Figure 1. Brief description of the investigated ICZM-DSS tools.

associated with the specific tools studied. The rows represent the DSS tools and the columns represent the desirable functionalities of the DSS tools.

The results in Table 3 demonstrate that none of the tools possess all of the knowledge-related functionalities. Uncertainty ranges are only partly incorporated in the *RISC* tool which pertain to uncertainties from the calculation of dike failure, for example, parameterizations of wave generation or tolerable overtopping rate (Mai, 2005). Only two

Table 3

Knowledge-related functionalities of ICZM-DSS tools

System	Can it handle uncertainty ranges?	Can it handle incomplete knowledge?	Visualization of uncertainties?	Spatially explicitly calculated scenarios?	Dynamic?	Agent-based modeling?	Policy-evaluation?	Policy-optimization?
CORAL	No	No	No	No	No	No	Yes	Yes
Cosmo	No	No	No	No	No	No	Yes	No
DIVA	No	No	No	Yes	Yes	No	Yes	Yes
EDSS	No	Yes	No	No	No	No	Yes	No
MARXAN	No	No	No	Yes	No	No	Yes	Yes
NDV-module	No	No	No	Yes	Yes	No	Yes	No
RAMCO	No	No	No	Yes	Yes	No	Yes	No
RISC	Partly	No	No	Yes	Yes	No	Yes	Yes
SIMCOAST	No	No	No	No	No	No	Yes	No
SimLucia	No	No	No	Yes	Yes	No	Yes	No
STREAM	No	No	No	Yes	Yes	No	Yes	No
Topic	No	Yes	No	No	No	No	Yes	No
WadBOS	No	No	No	Yes	Yes	No	Yes	No

of the tools can handle incomplete knowledge, whereas none of the tools can visualize uncertainties of the information. Several tools can show spatially explicit calculated scenarios with maps. Seven out of thirteen tools are dynamic: *DIVA,* the *NDV module, RAMCO, RISC, SimLucia, STREAM,* and *WadBOS*. None of the tools use agent-based modeling. Most tools appear to be policy-evaluation tools rather than policy-optimization tools, except for *CORAL*, *DIVA, RISC,* and *MARXAN*, which also use optimization techniques.

The results with respect to the process-related functionalities are shown in Table 4.

The results in Table 4 indicate that none of the tools possess all of the process-related functionalities. Interactive model construction is only possible with the *EDSS* tool and *Topic*. The only tool that can handle multiple users (simultaneously) and supports gaming is *Cosmo*. Most tools can show conceptual relationships, apart from *DIVA, RISC,* and *MARXAN*. Only two tools, *Topic* and the *EDSS*, are aimed at supporting problem structuring and exploration. These two are the only tools that are specifically *not* designed to be used for impact assessment. All tools are supposed to be useful during the stage of option generation.

Discussion

This study aimed to investigate opportunities to enhance the applicability of DSSs for ICZM decision-making. The chosen approach has some implications. First, it results in *general* conclusions about the applicability of DSSs in ICZM, meaning that the conclusions are not related to specific cases, but offer an overall indication of the applicability of the available tools for ICZM. For example, if literature shows that agent-based modeling (ABM) is a potentially helpful technique for the issues addressed in ICZM, this does not imply that ABM should be applied to every ICZM case. Rather, it is concluded that ICZM faces certain challenges, some of which could be adequately addressed with ABM. Our observation that none of the ICZM-DSSs use ABM enables us to draw the overall conclusion that ABM can be characterized as an unused potential. Secondly, we note that our approach is not a comparison of 13 DSS tools to judge their quality and we will not attempt to rank them. The selected DSSs are merely used to provide insight into the extent to which promising functionalities are part of present-day ICZM-DSSs. The tool possessing most functionalities does not suggest that it is always the best option; the relative importance of a certain functionality depends on the context in which the tool will be applied.

With regard to combining functionalities, *integrated modeling* aims to build one model that takes all relevant processes into account (Wainwright & Mulligan, 2003). However, there are also arguments as to why multiple models should be used (Fisher et al., 2002); in particular because of uncertainty in models. We agree with Fisher et al. that it is always better to apply (if available) multiple models for one process or problem, because modeling always involves value-laden assumptions (Schneider, 1997). However, integrated management (including ICZM) demands an integrated approach that deals with multiple processes and problems. An integrated model combines these processes and problems in a more holistic way and makes interlinkages that cannot be made with a set of sectoral (single-issue) models. Although we agree that sectoral models can be helpful to answer specific questions, we have chosen to focus on integrated systems. Especially because of the importance of intersectoral linkages in ICZM.

Table 4
Process-related functionalities of ICZM-DSS tools

System	Interactive model construction?	Multiple users?	Gaming?	Visualization of conceptual relationships?	Problem exploration/structuring?	Generation of options?	Impact assessment?
CORAL	No	No	No	Yes	No	Yes	Yes
Cosmo	No	Yes	Yes	Yes	No	Yes	Yes
DIVA	No	No	No	No	No	Yes	Yes
EDSS	Yes	No	No	Yes	Yes	Yes	No*
MARXAN	No	No	No	No	No	Yes	Yes
NDV-module	No	No	No	Yes	No	Yes	Yes
RAMCO	No	No	No	Yes	No	Yes	Yes
RISC	No	No	No	No	No	Yes	Yes
SIMCOAST	No	No	No	Yes	No	Yes	Yes
SimLucia	No	No	No	Yes	No	Yes	Yes
STREAM	No	No	No	Yes	No	Yes	Yes
Topic	Yes	No	No	Yes	Yes	Yes	No
WadBOS	No	No	No	Yes	No	Yes	Yes

**EDSS* was originally aimed to link a problem-structuring/explorative interactive tool to several analytical modules, which are aimed at impact assessment. As these modules do not match our criteria (Zanting, 2005) they are not considered as part of this interactive DSS.

Conclusions

This article aimed to provide knowledge and insight that can be used to enhance the applicability of DSSs for ICZM. To address this issue, we identified DSS functionalities that can help in meeting knowledge- and process-related ICZM challenges. For 13 selected DSS tools we investigated which of these functionalities they possess. Our results show that none of the tools has all of the functionalities. Therefore it can be concluded that there are multiple ways to enhance the general applicability of DSSs. We will briefly summarize the most important knowledge- and process-related conclusions.

In the context of the knowledge-related challenges, the results demonstrate that the ability of the tools to deal with uncertainty is limited; only a few tools can handle incomplete knowledge and quantified uncertainty ranges. No tool is capable of providing a visualization of the information's uncertainties in the output. Agent-based modeling is a technique that has not been used in any of the tools. This is quite remarkable, since multi-agent systems seem to be the most promising modeling approach for sustainable development issues (Boulanger and Bréchet, 2005). All tools appear to be policy-evaluation tools, but only a few tools also offer policy-optimization functionality.

With regard to the process-related challenges, it was found that interactive model construction is a means to stimulate science-management integration and stakeholder involvement. Interactive model construction fits into more open policy processes and is desirable in a multi-actor context. As only few DSS tools support interactive model construction, there is room for improvement in this respect. This is in line with the conclusion of earlier studies that suggested that the interaction between users and developers needs to be improved. Our results also indicate that gaming has hardly been used in ICZM decision-making. Generating policy options is a major objective of DSS tools, because all tools support this. Our results show that some tools are highly interactive tools, capable of dealing with incomplete knowledge, helpful for problem structuring, problem exploration, and facilitating discussions. Others are more tailor-made for a specific case, allowing for complex calculations (for example, with risk of flooding or expectations about mussel populations). The most important conclusion is that none of the tools combine all functionalities. This has implications for both DSS users and DSS developers, which are discussed next.

Recommendations for DSS Developers

This article demonstrates that DSS development has a lot of dormant potential. We recommend to develop this potential to improve the applicability of DSS tools for ICZM. Promising approaches such as agent-based modeling and gaming are hardly used. Most importantly, combining several capabilities of the tools can lead to more effectiveness and applicability. For instance, it would be a step forward to have an interactive problem-structuring tool used for discussion in an early phase, that can be extended to a more analytical system that is also helpful for impact assessment during the decision-making process. A combination of interactive model construction and the possibility to deal with uncertainty are also regarded opportunities in future DSS development. Gaming can be a helpful extension for any tool. Combining policy-evaluation and policy-optimization functionality (as three of the tools have already done) may improve the usefulness of the systems because it enhances the degree of freedom for the user. Finally, we recommend to use a technical feature of *RISC*, which is that all numerical simulations are pre-calculated and stored in a database (Mai & Liebermann, 2002). This seems promising because it allows for complex calculations while maintaining interactive accessibility.

Recommendations for Coastal Managers

Coastal managers should realize that if they want to use a present-day DSS for impact assessment, the DSS cannot be used for problem structuring. If an issue is not well-structured, generated knowledge tends to be utilized ineffectively (Boogerd, 2005; Hisschemöller & Hoppe, 2001). Therefore, it is highly recommended to use these tools only when the issue is as structured as possible. If an impact assessment tool is used for a rather unstructured issue, the tool is likely to contribute nothing valuable to the process. Some DSS tools can be helpful because they support problem structuring. However, the same tools cannot be used for impact assessment. Another aspect that requires attention is that ICZM carries many uncertainties with it, but only a few tools can take these into account. None of the tools we investigated, however, is capable of visualizing uncertainties graphically. Finally, if coastal managers would like to be actively involved in the construction of a DSS, they should consider that interactive model construction is only supported by tools which are *not* capable of impact assessment. For the investigated impact assessment tools, it is not possible to participate in the model construction process without interference from the developers.

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