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Deliverable 4.2 Report on types of models that exist

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1. Introduction

Transactional Environmental Support System (TESS) is an RTD project which, among other expected results, must collect and analyse the existing modelling and data sources to enable concept generation, together with social and technical design for a decision support software platform. The aim of the gap analysis was to map the existing and missing resources for the generation of decision support software solutions in the TESS areas of interest. Hence, these gaps might be missing knowledge, concepts, software, data, links etc.

The scoping phase of WP4 revealed that the database of models should be targeted at activities where local ecosystem management decisions bring via improved ecosystem services direct benefits to the manager (Aruvee & Piirimäe, 2010). Of various types of ecosystem services, this project is targeted on the management of ecosystem services which generate local benefits through long-term sustainability as well as any immediate gains. Thus, the database focuses on health of terrestrial ecosystems.

2. Methodology

Preliminary gap search was based mostly on the database of models, delivering preliminary gaps. These were rechecked, using web search, leading to additional models to the database and to the final gap identifications.

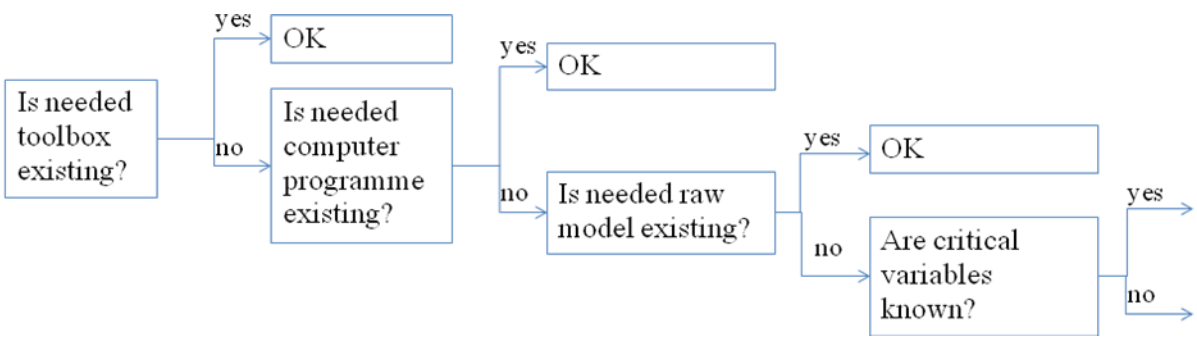

Fig 1. Vertical strategy in gap search

A Vertical gap search. On the basis of providing resources for three toolboxes for local management of terrestrial ecosystems, we started with searching for readily available tools. If such tool(s) were already existing and meeting all the user requirements, no gaps were identified in that management area (Fig 1). Otherwise, the existing tools were either imperfect or missing. In such case, a **'toolbox gap', or 'integration gap'** was identified and gap search moved to one order more detailed level – to check which of the needed computer programmes are already existing. In case of missing or imperfect software model, a **'software gap'** was identified, directing the gap search again to a more detailed level – to search for knowledge from literature, identifying **'knowledge gaps'**. More specific information about stakeholder needs for information on various environmental issues was acquired from Hodder et al. (2009).

B Mismatch search. Vertical and thematic gap search could not indicate if models can be pipelined with each other. Due to conceptual incommensurability or technical incompatibility with other tools, a model in the database might appear inconsistent. Hence, we classified all models to eight potential clusters within which the models should adapt well to pipelining with each other, but not between clusters. Models in small clusters could hence appear incoherent as components in integrated tools, indicating additional gaps – **'mismatches'**.

3. Results

3.1. Integration gaps

Although the database contains 25 items, reported as 'decision support systems, organizing or enabling several modelling tools', our expert assessment qualified only seven real toolboxes: InVEST, RAT Toolkit, DSSAT, Apollo, MicroLEIS DSS, SFM Toolkit and BAP Toolbox (Table 1). Of them, RAT Toolkit (www.alarmproject.net), however, is targeted on large-scale management and policy issues, falling, thus, out of the TESS project scope. All the other references in the database fell finally into the category of 'computer models'.

Table 1. Integration gaps in the existing decision support toolboxes

Field Health Toolkit	Forest Health Toolkit	Recreational Site Management Toolkit
DSSAT Apollo MicroLEIS DSS	SFM Toolkit BAP toolbox	*Integration gap!*

InVEST (Tallis et al., 2008) is a toolbox which models and maps natural capital: the delivery, distribution, and economic value of ecosystem services (life-support systems) and biodiversity. The tool, being developed in the United States, helps users visualize the impacts of potential decisions, identifying tradeoffs and compatibilities between environmental, economic, and social benefits.

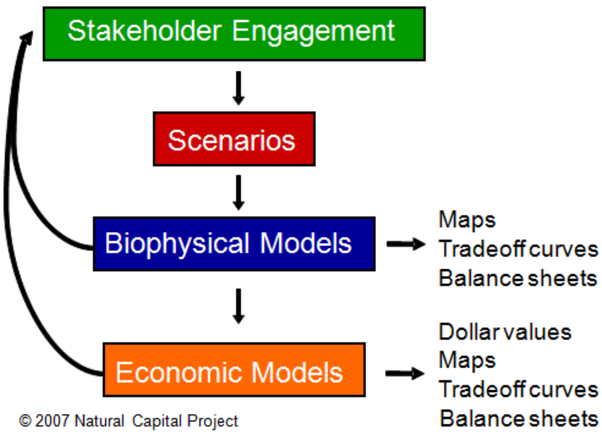

Fig 2. InVEST toolbox collects various decision support models for the management of various ecosystem services

InVEST models run as script tools in the ArcGIS ArcToolBox environment. InVEST 1.0 includes models for carbon sequestration, **pollination of crops**, **managed timber production**, water pollution regulation and sediment retention for reservoir maintenance. It also includes a biodiversity model so that comparisons and tradeoffs between biodiversity and ecosystem services can be analyzed. The next release of InVEST will probably include a suite of new ecosystem services: flood mitigation, **agriculture production**, irrigation, **open access harvest** and hydropower production. The tool is modular in the sense that you do not have to model all the ecosystem services listed, but rather can select only those of interest.

The individual models in InVEST 1.0 are very simple. Hence, the toolbox remains very limited in its ability to provide effective decision support for the environmental management in the EU. However, the conceptual comprehensiveness of the InVEST project is striking,, providing a sound integral framework for the provision of more useful versions of the toolbox.

3.1.1. Integration of Field Health Toolkit

InVEST, although having a simple **crop pollination model**, still lacks a comprehensive field health toolkit, although an agricultural production model is under development. Until that time, other agricultural production toolkits remain more functional. Of them, the most prominent are DSSAT and MicroLEIS.

Decision Support for Agrotechnology Transfer (DSSAT).

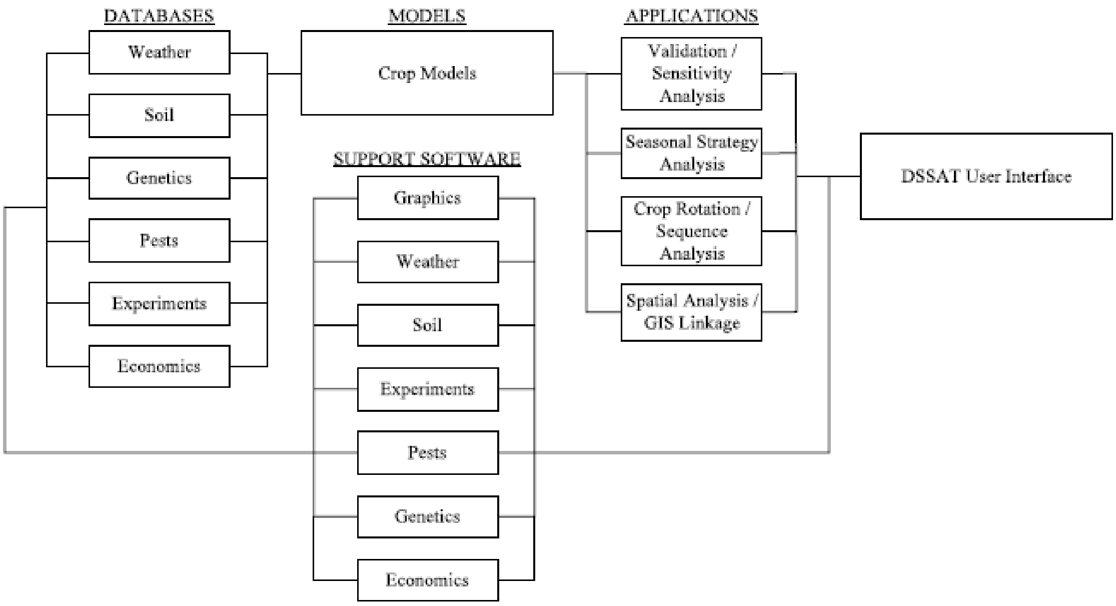

Fig 3. Diagram of database, application, and support software components and their use with crop models for applications in DSSAT (from Jones et al., 2003)

DSSAT has been developed by the International Consortium for Agricultural Systems Applications (ICASA, www.icasa.net). The Cropping System Model (CSM), released with DSSAT Version 4, incorporates all crops as modules using a single soil module and a single weather module (Fig 3). CSM contains models of 17 crops derived from the old DSSAT CROPGRO and CERES models. The major modules are land module, management module, soil module, weather module, soil-plant-atmosphere module, CROPGRO plant growth module, CERES Plant Growth Module, SUBSTOR Plant Growth Module, and Soil Organic Matter Module.

CROPGRO plant growth module simulates the following crops:

- Grain Legumes - Soybean, peanut, dry bean, chickpea, cowpea, velvet bean, and faba bean
- Vegetables - Pepper, cabbage, tomato
- Grasses – Bahia, brachiaria

CERES Plant Growth Module simulates Grain Cereals: Rice, maize, millet, sorghum, wheat, and barley

SUBSTOR Plant Growth Module simulates potato.

A SOM–residue module from the CENTURY model has incorporated in the DSSAT crop simulation models, including a residue layer on top of the soil. By incorporating the CENTURY SOM–residue module, DSSAT crop simulation models is suitable for simulating low-input systems and conducting long-term sustainability analyses.

DSSAT allows consistent access to the crop models, data, input and output tools, and analysis programs. The hierarchy is commodity-based within a tree structure where model inputs can be created and results analyzed.

A suite of tools is supplied for data management and analysis. XBuild is used to create and modify experiment files (X-Files). The suite of tools includes (but is not limited to) ATCreate (observed data), Weatherman (Weather data), GBuild (Graphing of outputs), and SBuild (Soil database).

In addition to the suite of applications installed with DSSAT, a number of accessory tools can be installed. These tools (ICSim, Stats, EZ Grapher and others) are applications that access the data in DSSAT for applications designed by the developers. The functionality exists for users to dynamically add their own application to the DSSAT toolbar.

DSSAT has been in use for the past 15 years by researchers all over the world, for a variety of purposes, including crop management (Fetcher et al., 1991), climate change impact studies (Alexandrov and Hoogenboom, 2001), sustainability research (Quemada and Cabrera, 1995), and precision agriculture (Paz et al., 2001, 2003), and is well validated for a number of regions and crops. Included in the DSSAT family are modules which simulate the growth of 16 different crops, including maize, soybeans, wheat, rice, and others. DSSAT uses common modules for soil dynamics and soil–plant–atmosphere interactions regardless of the plant growth module selected. Data requirements include weather inputs (daily maximum and minimum temperature, rainfall and solar radiation), soils classification, and crop management practices (variety, row spacing, plant population, fertilizer and irrigation application dates and amounts). While the DSSAT family of crop growth models provides many opportunities for critical analysis, it is tedious to use for precision agriculture studies and decision support because the model is built for simulation of a single homogeneous field unit. In order to facilitate the use of DSSAT for precision agriculture decision support, automated procedures and related tools are needed to implement crop growth simulations spatially across field-level management zones. Additional information about the model can be found in http://www.icasa.net/dssat/.

Apollo

Apollo, a prototype decision support system (DSS) was developed to assist researchers in using the DSSAT crop growth models to analyze precision farming datasets (Thorp et al., 2008). Because the DSSAT models are written to simulate crop growth and development within a homogenous unit of land, the Apollo DSS has specialized functions to manage running the DSSAT models to simulate and analyze spatially variable land and management. The DSS has modules that allow the user to build model input files for spatial simulations across predefined management zones, calibrate the models to simulate historic spatial yield variability, validate the models for seasons not used for calibration, and estimate the crop response and environmental impacts of nitrogen, plant population, cultivar, and irrigation prescriptions.

A land evaluation decision support system for agricultural protection (MicroLEIS)

MicroLEIS system is interactive software with comprehensive documentation for anyone planning, researching or teaching the sustainable use and management of rural resources, with especial reference to the Mediterranean regions (Rosa et al., 2004; www.microleis.com). This agro-ecological system provides a computer-based set of tools for an orderly arrangement and practical interpretation of land resources/agricultural management data (Fig 4). The design philosophy follows a toolkit approach, integrating many software tools: databases, statistics, expert systems, neural networks, Web and GIS applications, and other information technologies. Its major characteristics are:

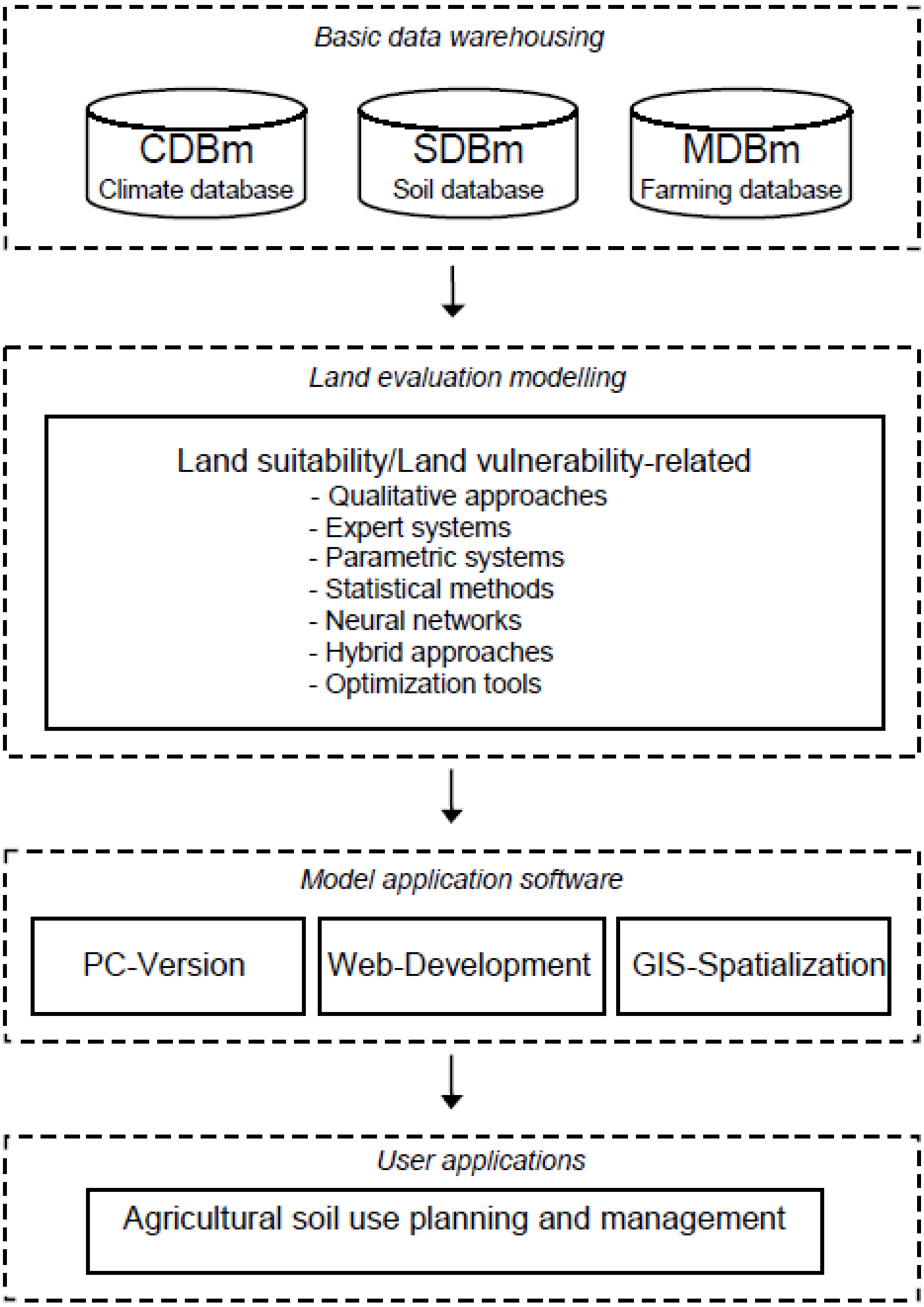

Fig 4. Conceptual design and component integration of the current status of MicroLEIS DSS land evaluation decision support system (from Rosa et al., 2003)

- data and knowledge engineering through the use of a variety of databases and innovative modelling techniques;
- scaling-up of process knowledge from the micro-scale to the landscape-scale (regional, national and continental);
- land evaluation by using the following study-units: place (climate), soil (site+soil), land (climate+site+soil), field (climate+site+soil +management)
- use of monthly meteorological data and standard information as recorded in routine land resource surveys; integrated agro-ecological approach, combining biophysical data with agricultural management experience;

- incorporating the soil quality and sustainable agriculture concepts, towards an agro-environmental decision support system;
- and software development for PC platforms, and Web- and GIS-based versions.

Conclusion

As InVEST, a global ecosystem management toolbox, still fails to work as a toolbox in field health management, providing only one tool for pollination management, more specialised toolkits are needed. Of them, DSSAT with its extension, Apollo, as well as MicroLEIS DSS well cover sustainable agricultural management areas. However, some agricultural issues may still be left out from these toolkits.

3.1.2. Integration of Forest Health Toolkit

InVEST toolbox contains a **managed timber production model**. This model analyzes the amount and volume of legally harvested timber from natural forests and managed plantations based on harvest level and cycle. The valuation model estimates the economic value of timber based on the market price, harvest and management costs and a discount rate. and calculates its economic value. This model is very simple and designed for cases where little data on harvest practices and tree stand management exists. Although the project is developing an open access harvest model, the current toolkit outputs only roundwood, ignoring other services which forest provide. Hence, to our knowledge, nowadays there exists just one management toolkit which addresses health of forests. This is Sustainable Forest Management (SFM) Toolkit.

Sustainable Forest Management (SFM) Toolkit

SFM Toolkit integrates nine models of various scales and themes (Fig 5; Sturtevant et al., 2007). For example, SORTIE, an individual tree model, gives information about growth and yield of uneven-aged trees and complex successions. In the same time, SORTIE, in the toolbox, receives from D19aLM (SELES) model information about disturbance patterns. Such metamodeling strategy enables forest managers to deal with diverse objectives. The toolkit has been applied for the management of 2.1 million hectare forest planning in Labrador.

Biodiversity Assessment Project (BAP) Toolbox

BAP Toolbox, a part of SFM Toolkit, is a suite of indicator models used to assess diverse forest management strategies at three levels of biodiversity: landscape patterns, ecosystem diversity, and habitat supply for specific vertebrate species (Dolter, 2006). The toolbox translates a time series of landscape conditions output from landscape models into habitat types that serve as spatial units for ecosystem and the landscape biodiversity (i.e., coarse-filter) assessment.

Conclusion

InVEST, a global ecosystem service management toolbox, remains too general to aid local decision-making in forestry. Hence, a special forest health toolkit, named Sustainable Forest Management Toolkit, seems much more practical. The biggest challenge remains the adoption of this Canadian toolbox to the European conditions.

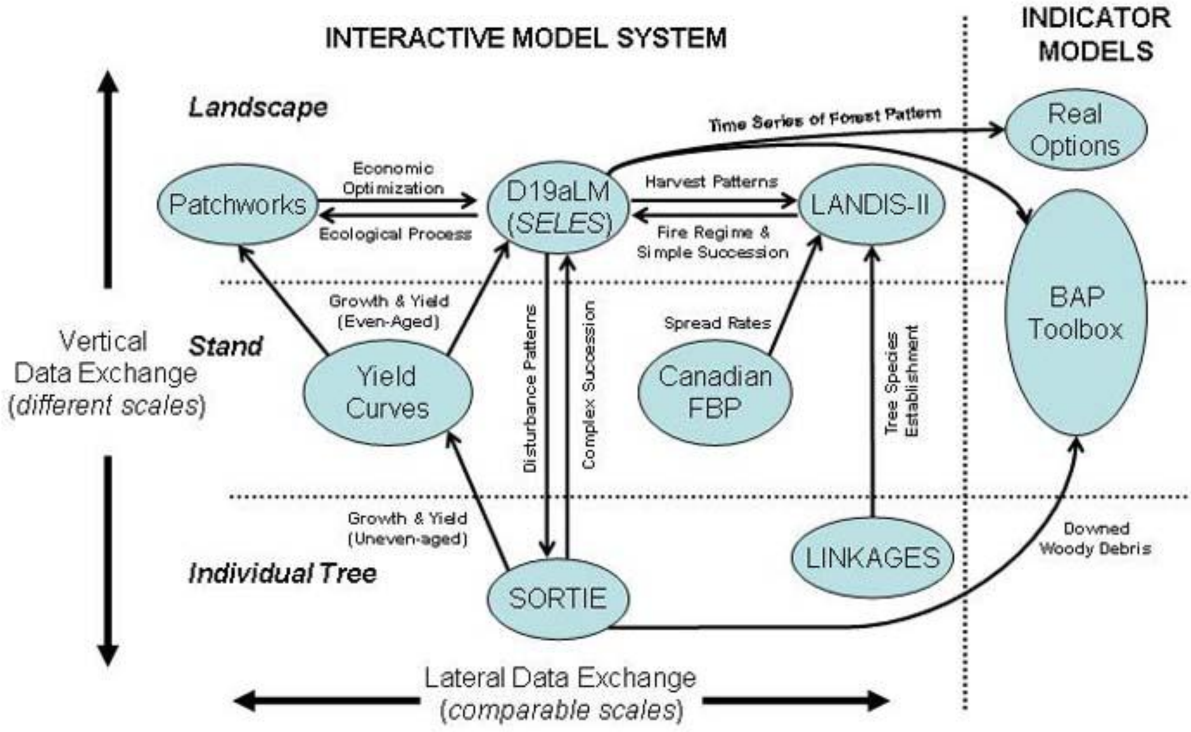

Fig 5. Information flow between models in SFM Toolkit (from Sturtevant et al., 2007)

3.1.1. Integration of Recreational Site Management Toolkit

To our knowledge, no recreational site management toolkit yet exists. InVEST toolbox does not address that issue either.

Comparing the number of issues identified by stakeholders with the number of models in the database, the best fulfilled needs seem in water, geological, economic and ecosystem subjects (Fig 6). Social and atmospheric issues are relatively poorly covered. As atmospheric issues, such a climate change and pollution are mostly large-scale problems, the database for local management does not specifically need such models. Lack of social models, however, may form a real gap.

Of various management areas, the best met information needs seem to be in forestry, agriculture & apiculture and aquaculture & commercial fishing (Fig 7). Most critical gaps appeared in 'tourism and access-based recreation', 'biodiversity conservation', and 'amenity areas'.

More detailed analysis revealed that the most critical gaps remain is issue items 'roads, transport, traffic, mobility', 'mining', 'waste management', and 'wastewater' (Annex 1). All of these issues were indicated at least eight times while no models addressed these issues.

3.2. Software gaps

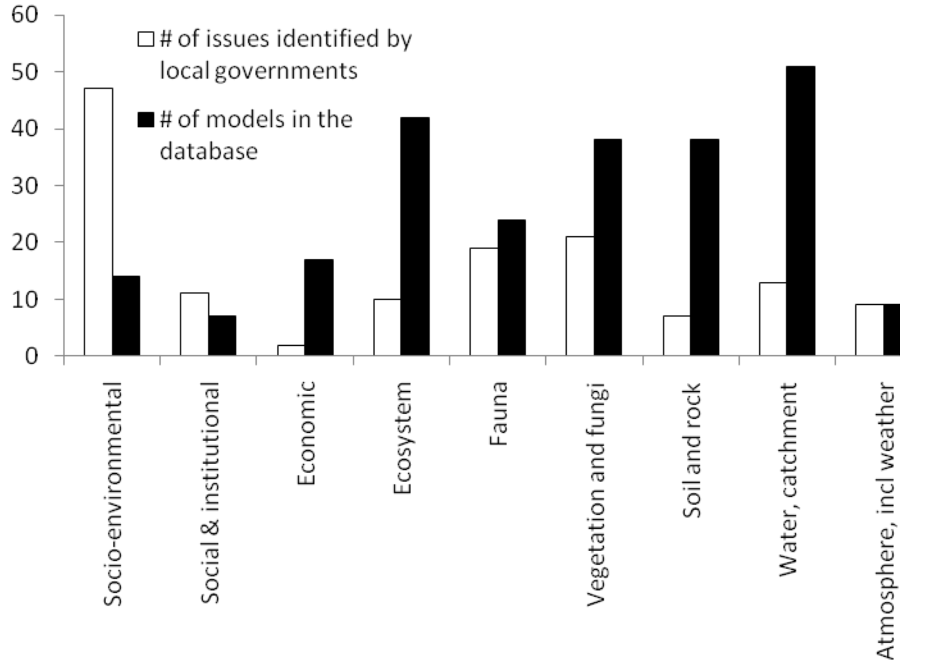

Fig 6. Supply of stakeholder needs for environmental information along various subject fields

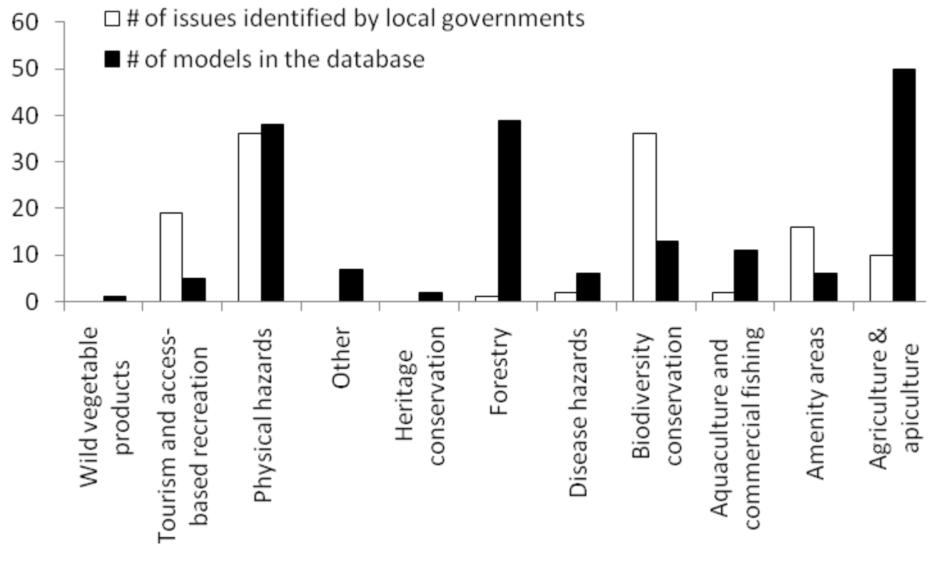

Fig 7. Supply of stakeholder needs for environmental information along various management areas

3.2.1. **Field Health Software gaps.**

DSSAT and its GIS-solution Apollo, globally the most widely used agricultural DSS, has been used to model the effects of irrigation and no-till farming to crop productivity and nutrient leaching (Dillon & Shockley, 2010). Also, DSSAT has been used to model long-term effects of changes in soil organic carbon (Jones et al., 2003). However, according to our knowledge, DSSAT has not been used for the management of buffer strips, pollinators, GMOs, or biocontrol agents. Hence, DSSAT lacks sufficient environmental character to classify as comprehensive 'field health software'.

MICROLEIS DSS is more targeted to environmental and sustainability issues (Rosa et al., 2003). The main focus is not on crop productivity but rather on the quality of soil and agricultural land. Drivers of soil quality include also rooting depth, tillage operations, treatment of residues etc. The main indicators of land quality are plant water use efficiency, water- and air-filled pore space, nutrient availability, plant root penetration, water infiltration, and crop growth. The DSS pays much attention to land vulnerability, analysing runoff and leaching potential, erosion resistance, soil structure, cover protection, pesticide absorption and mobility, and subsoil compaction. The model also addresses restoration of marginal areas. Arena and Pantana expert systems assess field contamination.

MICROLEIS, however, is designed primarily for Mediterranean fields. In other European ecoregions, it may work less well.

InVEST Pollination model focuses on the resource needs and flight behaviors of wild bees, the most important group of pollinators. The model uses information on the availability of nesting sites and flower resources, as well as flight ranges of bees, to map an index of bee abundance across the landscape. In a second step, the model uses this map and bee flight ranges again to predict an index of the number of pollinators likely visiting crops in each agricultural cell on the landscape. If one opts to also estimate value indices, the model then takes a third and fourth step. In the third step, it uses a simplified yield function to translate bee abundance into crop value on each agricultural cell. And in the fourth step, it attributes these cell values back to cells "supplying" these bees.

However, InVEST model does not yet consider other pollinators such as birds, bats, moths and flies. InVEST neither considers other mobile agents providing services for agricultural production, especially biocontrol agents (enemies of pests). Above all, InVEST is an extremely simple model which does not consider population dynamics of the bees, sizes of their habitats, existence of small habitats etc.

GMO risk models. GMO cross-pollination risks have been considered in non-toolboxed isolated software solutions. For instance, **MAPOD** model (Matricial Approach to Pollen Dispersal, Klein et al., 2008) predicts cross-pollination between GM and non-GM maize. **GeneSYS** model has been used to evaluate the influence of cropping systems on transgene escape from rapeseed crops to rapeseed volunteers (Colbach et al., 1999).

Information supply gaps. Of field health issues, the most critical supply gaps appeared for hogweed (and presumably other noxious plants, as well as animal pests) and soil protection & erosion prevention (table 2). Although some agricultural models may indirectly consider these, none of the models provide specific decision support in these issues. Similarly, the database has failed to address land use, livestock & impacts hereof, quality of soil for farming community, hedge management, animal pests, lopping of olive trees, horticulture rehabilitation and development, plantations, playing fields for agricultural circuit, and burning of agricultural residues. The models are focussed primarily on productive services in agricultural ecosystems.

Table 2. Gaps in supplying models about field health issues identified by local stakeholders (issues extracted from Hodder at al., 2009, see also Annex I)

🟢 At least as many models as issues 🟡 At least one model 🔴 No models

Issue	# of issues	# of models	Supply rate
Hogweed	5	0	🔴
Soil protection, erosion prevention	4	5	🟢
Agricultural changes	3	50	🟢
Impact of agriculture & industry changes in land use on environment/people	3	4	🟢
Impact of agriculture on environment	2	51	🟢
Land use	2	3	🟢
Livestock and impacts hereof	2	2	🟢
quality of soil for the farming community	1	3	🟢
Gardens restoration	1	1	🟢
Animal pests (mammals, birds, insects)	1	0	🔴
burning of agricultural residues in the fields	1	0	🔴
Hedge management- cutting, laying (costs, impacts)	1	0	🔴
Horticulture rehabilitation and development	1	0	🔴
Lopping of olive trees/burning of agricultural residues in the fields	1	0	🔴
Plantations	1	0	🔴
playing field for agricultural circuit	1	0	🔴

3.2.2. Forest Health Software gaps.

SFM Toolkit addresses most of forest health issues including prediction of fire spread and behaviour (with FBP model, Forestry Canada Fire Danger Group, 1992), disturbance impacts on various tree species, effects of wind storms and pathogens (with LANDIS-II, Scheller et al., 2007 and SORTIE model, Coates et al., 2003), biodiversity issues (with BAP toolbox, Doyon and Duinker, 2003). BAP Toolbox comprises following criteria and indicators of sustainable forest management:

- Conservation of Biological Diversity
- Maintenance and Enhancement of Forest Ecosystem
- Condition and Productivity
- Conservation of Soil and Water
- Forest Ecosystem Contributions to Global Ecological Cycles

Socio-economic criteria and indicators focus on the last two titles:

- Multiple Benefits to Society;
- Accepting Society's Responsibility for Sustainable Development (CCFM, 1995)

Bio-indicators used in the analysis of ecosystem diversity are:

- Area-weighted Stand Age
- Tree Species Distribution
  - Species distribution by broad habitat type
  - Species presence
  - Species dominance
- Habitat Diversity

These three indicators enable BAP to track the changes in forest composition due to management practices being projected.

SFM Toolkit and BAP Toolbox have been effectively used in Canada. However, adaptation of it to the European conditions, particularly to non-boreal regions, might appear challenging.

Information supply gaps. SFM Toolkit does not address deforestation (Table 3).

Table 3. Gaps in supplying models about forest health issues identified by local stakeholders (issues extracted from Hodder at al., 2009, see also Annex I)

🟢 At least as many models as issues 🟡 At least one model 🔴 No models

Issue	# of issues	# of models	Supply rate
Deforestation	2	0	🔴
Forest fire prevention	1	8	🟢
Afforrestation	1	1	🟢
FOREST EXPANSION	1	0	🔴

3.2.3. Recreational Site Management Software gaps

The database comprises only six models, reported for the management of tourism and access-based recreation (Fig 8). Such a low number comprises a clear gap in the context of high demand for such information by local managers (Kenward *et al*., 2010; Hodder *et al*., 2009).

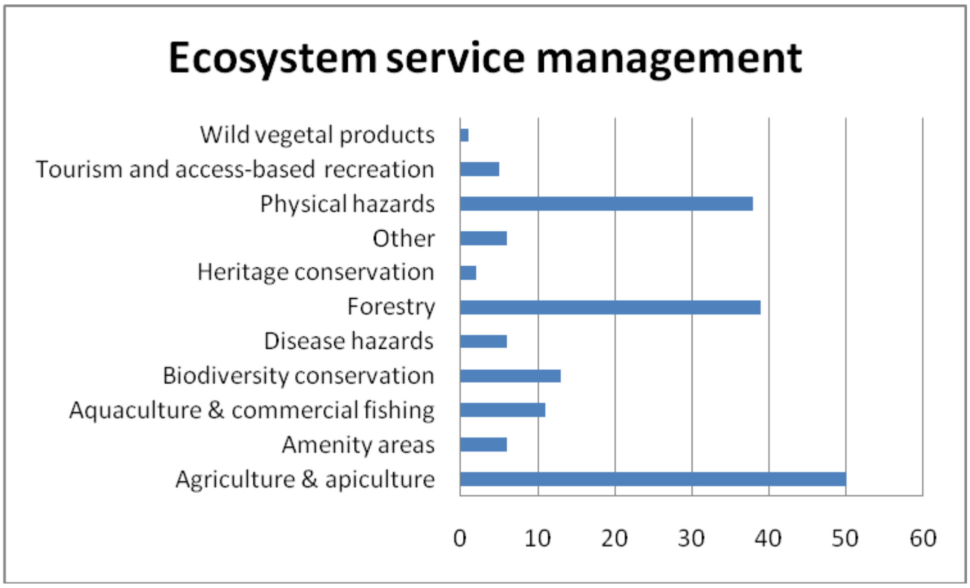

Fig 8. Number of models in the database according to different ecosystem service management areas

Recreational Behaviour Simulator (RBSIM)

RBSim is a computer program that simulates the behaviour of human recreators in high use natural environments. RBSim developed as a synthesis of work over a ten year period by researchers in the U.S. and Australia. Randy Gimblett, an Associate Professor of Landscape Architecture in the School of Renewable Natural Resources, The University of Arizona has been studying recreation behaviour in forest land in the western U.S. Specifically RBSim uses concepts from recreation research and Artificial Life and combines them with geographic information systems to produce an integrated system for exploring the interactions between different recreation user groups within real geographic space. RBSim joins two computer technologies:

- Geographic Information Systems to represent the environment
- Autonomous Human Agents (see text box) to simulate human behaviour within geographic space.

RBSim is experimental at this stage, but demonstrates the potential of combining the two technologies to explore the complex interactions between humans and the environment. The implications of this technology should also be applicable to the study of wildlife populations and other systems where there are complex interactions in the environment.

The main output of RBSIM is movement, location and concentration of visitors. However, RBSIM does not yet simulate environmental impacts. Further information about the model can be found at www.srnr.arizona.edu/~gimblett/rbsim.html

An autonomous agent is a computer simulation which is based on concepts from Artificial Life research. Agent simulations are built using object oriented programming technology. The agents are autonomous because once they are programmed they can move about the landscape like software robots. The agents can gather data from their environment, make decisions from this information and change their behavior according to the situation they find themselves in. Each individual agent has it's own physical mobility capabilities, sensory capabilities, and cognitive capabilities. This results in behavior that echo's the behavior of real animals (in this case humans) in the environment.

The process of building an agent is iterative and combines knowledge derived from empirical data with the intuition of the programmer. By continuing to program knowledge and rules into the agent, watching the behavior resulting from these rules and comparing it to what is known about actual behavior, a rich and complex set of behaviors emerge. What is compelling about this type of simulation is that it is impossible to predict the behavior of any single agent in the simulation and by observing the interactions between agents it is possible to draw conclusions which are impossible using any other analytical process.

Simulation of Disturbance Activities (SODA)

With conservation awareness and the demand for wildlife preservation increasing, ecotourism and outdoor recreational activities are becoming more popular. If such activities go unmanaged, the disruption to many species may have implications on their breeding success, survival and abundance and these, in turn, may have cascading ecosystem effects. By developing management strategies, through the application of simulation models, to simultaneously maintain recreational opportunities and sustain wildlife populations, these detrimental impacts can be minimised. Simulation of Disturbance Activities (SODA; Bennett et al., 2009) is a spatially explicit individual-based model designed as a flexible and transferable practical tool to explore the effects of spatial and temporal patterns of anthropogenic disturbance on wildlife.

SODA is a tool designed specifically to explore the repercussions (for example, variations in foraging rate, sleep deprivation, increased energy expenditure and decreased time spent feeding or in contact with young) of ecotourism and other outdoor recreational activities (such as dog-walking, bird watching, mountain-biking, snowmobiling and kayaking) on wildlife (Fig 9). As such, SODA makes predictions regarding the implications of wildlife behavioural rules in novel circumstances (e.g. alternative pathway locations within a park). The model can therefore be used to provide insight into the relative impacts of alternative strategies for human recreation (spatial configurations and/or intensity of human activities) upon habitat use by wildlife (e.g. breeding, foraging and sleeping) in diverse settings (such as pedestrians in urban parks and off-road vehicles in national forests).

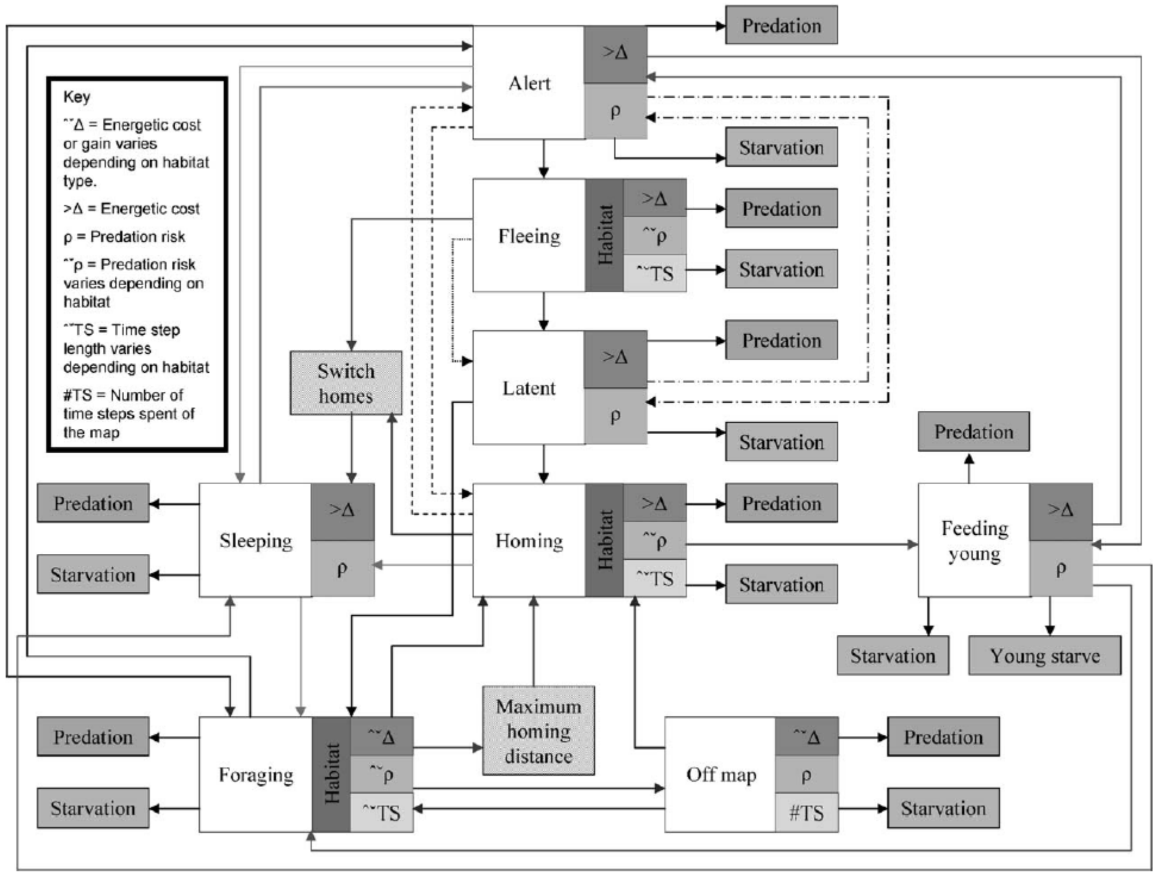

Fig 9. Conceptual delineation of the main wildlife processes employed by SODA to simulate the interactions between wildlife individuals, human recreationalists and habitats. It includes the eight different behaviour modes exhibited by wildlife mobile objects, movement patterns with and without disturbance, energetic status and predation potential. (From Bennett et al., 2009)

SODA has been applied: (1) to explore the effect of potential park designs on a nesting population of yellow-headed blackbirds (*Xanthocephalus xanthocephalus*) in Calumet, Illinois, USA (Bennett et al., 2009); (2) to investigate the influence of visitor frequency on the breeding success of barbastelle bats (*Barbastella barbastellus*) in the south west of England (Bennett et al., 2009).

Other recreational models

TourSim (Johnson & Sieber, 2009), is software which considers capacity of recreational objects to accommodate tourists. However, it does not simulate the environmental impacts.

Wilderness (Smith et al., 1976) is Spanish model which represents the travel behaviour of wilderness recreationists. The model shows the relationship between the natural, undisturbed purity of a wilderness and the human influence that affects it. However, the model has not been modernised.

WUSM (Wilderness Use Simulation Model; Underhill et al., 1986) was designed to make management decisions for peak season boating. However, the model does not address environmental impacts.

Landscape Management Checklist (Lindenmayer et al., 2008) assesses six major themes in the ecology and conservation of landscapes. The checklist identifies 13 important issues that need to be considered in developing approaches to landscape conservation. They include recognizing the importance of landscape mosaics (including the integration of terrestrial and aquatic areas), recognizing interactions between vegetation cover and vegetation configuration, using an appropriate landscape conceptual model, maintaining the capacity to recover from disturbance and managing landscapes in an adaptive framework.

Cudgen Lake Bn (Ticehurst et al. 2007) is a **Bayesian network (Bn)** for the management of small lakes. Bns were used to assess the sustainability of eight coastal lake-catchment systems, located on the coast of New South Wales (NSW), Australia.

Table 4. Gaps in supplying models about recreational site management issues identified by local stakeholders (issues extracted from Hodder at al., 2009, see also Annex I)

(Green) At least as many models as issues (Yellow) At least one model (Red) No models

Issue	# of issues	# of models	Supply rate
Amenity areas	6	7	Green
Public access	6	1	Yellow
impact of tourism and recreation	3	5	Green
Impact of camping on environment	3	1	Yellow
Impacts of resort, holiday and business properties	2	0	Red
Visual Impact on Environment	1	8	Green
Recreational areas and routes	1	7	Green
Relative values of different habitats for wildlife and humans	1	4	Green
Impact of recreational/housing/business building development on environment	1	1	Green
Trails and exposure to wear on nature areas	1	1	Green
Ecotourism development	1	0	Red
Green area maintenance (cost, impact)	1	0	Red
Impact of holiday/residential/business properties	1	0	Red
Impact of skiing slope on habitats of protected species	1	0	Red
Permanent damages related to horses left uncontolled	1	0	Red
The negative effect from permanent residential buidings for recreation and tourism	1	0	Red

ALMaSS (Topping et al., 2010) evaluates demographic constraints of grey partridge *Perdix perdix*, a valuable game bird in many European countries. The model integrates agriculture, predation, hunting and weather as drivers. Management of its population, hence, depends on land use changes and hunting.

Information supply gaps. The database has failed to address over 30 issues identified by local stakeholders (Table 4 and see also Annex I). Of these issues, the most wanted were public access as well as impact of camping, resorts, holiday and business properties.

Conclusion

The existing models for recreational site management are relatively patchy, not integrated. The most promising heart for the envisaged Recreational Site Management Toolkit might be a combination of RBSIM and SODA. As RBSIM simulates location and concentration of visitors, it might be technically relatively easy to add environmental impacts of these visitors.

3.3. Knowledge gaps

From the analysis of the existing toolkits and independent software models, we conclude that forest health management has no dramatic software gaps although they might appear during adaptation of the existing tools to e.g. Mediterranean forests. In field health management, the biggest gap seems to be effects of ecosystems surrounding a field. In recreational site management, there are many critical software gaps. To bridge the software gaps, these effects and relationships may need to be found in published material. However, research literature may also contain gaps in describing these problems. Here we present results from such literature survey.

3.3.1. Effects of surrounding ecosystems to long-term crop yields

The concept of 'field health', adopted by the TESS project, appears relatively new in the context of decision support. The existing concepts are mostly limited to 'soil health', which is defined as the continued capacity of soil to function as vital living system, within ecosystem and land-use boundaries; to sustain biological productivity; promote the quality of air and water environments; and maintain plant, animal, and human health (Doran et al., 1997). Rosa & Sobral (2008) use term 'soil quality' which consists of soil health (dynamic soil quality) and soil suitability (inherent soil quality). However, for sustainable management of arable land, such approach seems still too narrow. For instance, in addition to soil quality, long-term crop production depends also on grassy field margin, pollinators, biocontrol agents and other biota which inhabit green areas near the fields. Except for the very simple pollination model of the InVEST toolkit, the existing reports ignore services of these surrounding ecosystems. Hence, a comprehensive decision support tool for managing ecosystems above the soils is still missing.

The existing information on services provided to agricultural fields by surrounding ecosystems, remains far from being a comprehensive quantitative model. However, most agricultural crops are dependent on insects which pollinate crops and control pests (an overview in Kremen & Chaplin-Kramer, 2007). MABES, a conceptual model (*mobile-agent-based ecosystem service*; Kremen et al., 2007) describes the effects of land-use changes to animal-mediated pollination and other ecosystem services provided by mobile agents. Ricketts et al. (2008) attempted to quantify the decline of crop yields with distance from natural/semi-natural habitat. They also quantified the effects of size of such habitat patch. However, the long-term effects of changes in these habitats on crop productivity still remains unclear as there are substitutes for wild pollinators and pollinator-dependent crops (Balmford et al., 2008). Their report admits that there is not enough empirical data on which to base a global model to evaluate how biological control services are affected by changes in wild nature. This model could be obtained following the same lines as for pollination (probably with leadership by the same group) but they suspect this would not be possible within the near future. They nonetheless recommend that further advice is obtained from experts on the feasibility of this particular task.

A solution to this gap might be non-quantitative decision support: either dialectic approach, reasoning support, expert system or any other alternative.

3.3.2. Management of recreational small lakes

Apparently, one economically viable sector of tourism in Europe is angling (see e.g. Steinback, 1999; Smith et al., 1999). However, as waterbodies and angling sites are very different while their management depends on diverse factors, including much uncertainty, a comprehensive model will remain missing in the near future. A solution to this gap might be also non-quantitative decision support: either dialectic approach, reasoning support, expert system or any other alternative. For instance, Ticehurst et al. (2007) proposed to apply Bayesian networks. Such approach has been widely applied recently (an overview in Castelletti & Soncini-Sessa, 2007).

3.3.3. Ecological implications of harvesting forest fruits

Sustainable harvesting of non-timber forest products has been addressed by many research papers (an overview in Ticktin, 2004). Ticktin (2004) indicated a large data gap in that ecological sector, calling for further long-term monitoring. In addition, very few studies have assessed the effects of harvest on genetic structure and diversity of harvested populations. Also, we have little information to date on the mechanisms underlying the observed effects of harvest.

3.4. Mismatches

In the classification of models (Aruvee & Piirimäe, 2010), it was concluded that computationally all models might break into eight clusters according to graphical mapping technology, time horizon and simulation technology. Non-GIS, non-spatial and steady-state or static models fell simultaneously into more than one cluster.

As all the discussed cartographic models as well as InVEST toolbox work in ESRI ArcGIS, their spatial integration might be relatively easy.

As the **Sustainable Forest Management Toolkit** (SFM) is already operational, it cannot suffer from serious mismatch problems. However, the current InVEST works as a simulation system while SFM provides different types of decision aid, such as teaching. Consequently, an attempt to pipeline InVEST and SFM would require rebuilding of InVEST on a more flexible basis.

For a **Field Health Toolkit**, InVEST, DSSAT, Apollo and MicroLEIS might be integrated as well as extended by GMO models (MAPOD, GeneSYS) and DSSs addressing ecosystem services of surrounding areas. Apollo has already integrated DSSAT. All cartographic models in this list use raster-GIS and prefer ESRI ArcGIS software. MicroLEIS DSS is a loosely connected toolkit system which could possibly involve DSSAT and Apollo as one component. All these models run in MS-Windows. From an integration perspective, we therefore do not see any commensurability or principal mismatch issue. However, similarly with forestry issues, MicroLEIS and InVEST contradict conceptually: while MICROLEIS provides a wide spectrum of various tools, including expert systems, neural networks and optimisation tools, InVEST provides a broader concept of ecosystem services. Their pipelining would require rebuilding of InVEST on a more flexible basis.

A **Recreational Site Management Toolkit** has been proposed by combining RBSIM and SODA. RBSIM is a stochastic autonomous agent-based model which has reported flexibly working in any GIS format. SODA, written in C++, runs in time steps between 5 min and 6 h. Both are individual-based models. Although we have not found any incommensurability or technical mismatch, both models are relatively narrowly built. Hence, challenges in pipelining these two models would need further assessment.

4. Conclusions

The InVEST project has provided a good integral framework for the development of a comprehensive ecosystem management toolbox. However, the first version of the toolbox provides little practical decision support. This gap has partly been bridged by some more specialised toolkits.

The existing crop management toolkits cover soil health issues well but remain very limited in wider field health issues such as ecosystems around the fields (grassy field margin etc.) providing biodiversity, biocontrol agents, pollinators and other services. An existing Sustainable Forest Management Toolkit addresses forest health issues well. However, it has been applied mostly in Canada. Hence, adaption to the European conditions might appear challenging. There's no comprising recreational site management toolkit yet (Fig 10). Thus, such a toolkit needs to be created. The core models for that might be RBSIM and SODA.

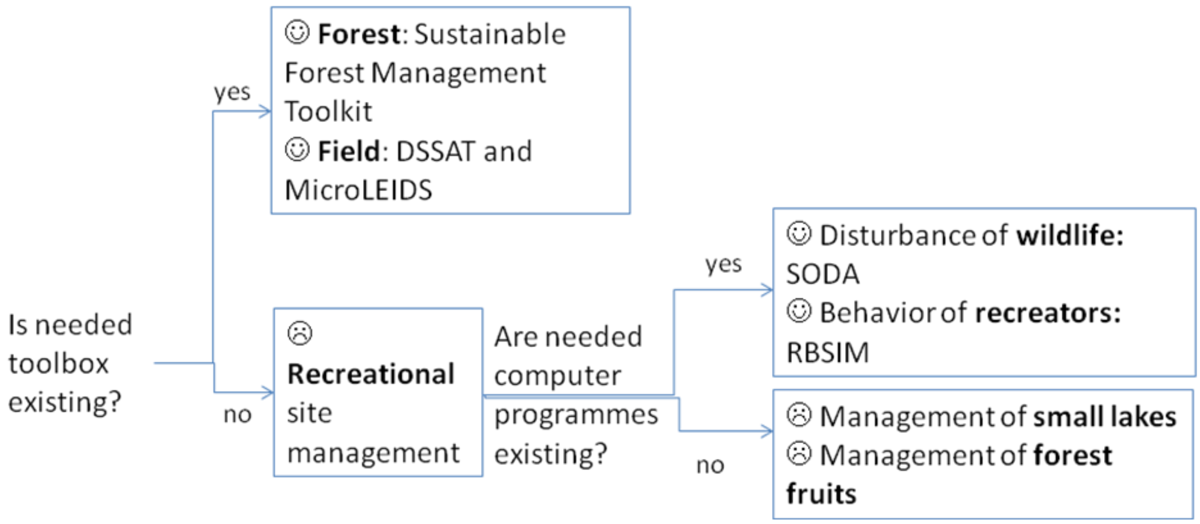

Fig 10. Results of vertical gap search

Considering the need for information for the management of various types of ecosystem services (Hodder et al., 2009; Kenward et al., 2010), the database seems adequately to provide models about some provisioning and supporting services (Table 5). The serious gaps have been identified for biodiversity, regulating and cultural services. However, a search of all 2400 models scanned, of which only the 165 considered fit for the 3 pre-selected toolkits were added to the meta-database, might fill some of these gaps.

Table 5. Results of thematic gap search

Ecosystem service type	Information demand	Information supply	Conclusion
Biodiversity	high	low	thematic gap!
Provisioning	low	high	ok
Regulating	medium	low	thematic gap!
Supporting	medium	high	ok
Cultural	medium	low	thematic gap!

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6. Annex I. Supply of models to provide environmental information about issues identified by stakeholders (Hodder et al. 2009)

🟢 At least as many models as issues 🟡 At least one model 🔴 No models

Issue	# of issues	# of models	Supply rate
Roads, transport, traffic, mobility	27	0	🔴
Flood prediction and risk assessment	13	2	🟡
Mining	9	0	🔴
Waste management	9	0	🔴
Wastewater	8	0	🔴
Drainage systems	7	1	🟡
Biodiversity conservation	6	13	🟢
Amenity areas	6	7	🟢
Public access	6	1	🟡
Conservation of trees	6	0	🔴
Roadsides	6	0	🔴
Hogweed	5	0	🔴
Landfills, communal waste deposite	5	0	🔴
The weather and damages	5	0	🔴
Species conservation	4	13	🟢
Soil protection, erosion prevention	4	5	🟢
Common land	4	0	🔴
Heritage sites	4	0	🔴
Rivers and streams	3	51	🟢
Agricultural changes	3	50	🟢
impact of tourism and recreation	3	5	🟢
Impact of agriculture & industry changes in land use on environment/people	3	4	🟢
Contaminated land	3	4	🟢
Impact of camping on environment	3	1	🟡
Water supply	3	1	🟡
dredging, cleaning of riverbed (Bitva stream) Regional Water Management Directorate	3	0	🔴
noise and air pollution	3	0	🔴
Impact of agriculture on environment	2	51	🟢
Environmental issues in general	2	42	🟢
ground water	2	7	🟢
Land use	2	3	🟢
Livestock and impacts hereof	2	2	🟢
Protected areas	2	2	🟢
contamination of groundwater	2	1	🟡
Landslide risks	2	1	🟡
Polluted soils	2	1	🟡
Deforestation	2	0	🔴
Impacts of resort, holiday and business properties	2	0	🔴
EIA, incl. habitats and protected species	2	0	🔴
Impact on archaeology	2	0	🔴
Infrastructure	2	0	🔴
Planning for windmillparks	2	0	🔴
Powerstation	2	0	🔴
rubbish	2	0	🔴
Smells	2	0	🔴
Water and sewage issues	2	0	🔴

water quality; fisheries resources	1	51	
Information regarding habitats on regional scale	1	17	
Demographic	1	14	
Fauna and Flora	1	13	
Forest fire prevention	1	8	
Visual Impact on Environment	1	8	
Recreational areas and routes	1	7	
Relative values of different habitats for wildlife and humans	1	4	
quality of soil for the farming community	1	3	
special nature surveys, land use planning, building	1	3	
fishing restrictions, land use planning	1	2	
Gardens restoration	1	1	
Afforrestation	1	1	
Impact of recreational/housing/business building development on environment	1	1	
Trails and exposure to wear on nature areas	1	1	
Historical Issues	1	1	
Impact of building development & urbanization on people, environment and transport	1	1	
Impact on Bird Species	1	1	
quality of sea water	1	1	
The development of specific areas (eg. A belt of green spaces)	1	1	

Animal pests (mammals, birds, insects)	1	0	
burning of agricultural residues in the fields	1	0	
Hedge management- cutting, laying (costs, impacts)	1	0	
Horticulture rehabilitation and development	1	0	
Lopping of olive trees/burning of agricultural residues in the fields	1	0	
Plantations	1	0	
playing field for agricultural circuit	1	0	
FOREST EXPANSION	1	0	
Ecotourism development	1	0	
Green area maintenance (cost, impact)	1	0	
Impact of holiday/residential/business properties	1	0	
Impact of skiing slope on habitats of protected species	1	0	
Permanent damages related to horses left uncontolled	1	0	
The negative effect from permanent residential buidings for recreation and tourism	1	0	
Allotments	1	0	
Communal waste transportation problems	1	0	
Control of Heracleum montegazzianum	1	0	
Drinking water quality	1	0	
Dumping rubble (boulders, rocks and soil) in valley streams	1	0	
Environmental management of energy supply	1	0	
eskers	1	0	
Fakia River - construct a supportive wall	1	0	
Geology	1	0	
green energy (solar, wooden chips and so on)	1	0	
ground water areas	1	0	
Gully maintenance – when and how often	1	0	
Gutter keeping - when and how often	1	0	
habitats according to the forest act (protected)	1	0	
Homeless animals	1	0	
Impact of building, housing, vacation, business	1	0	
Impact of domestic animals (dogs, cats, horses)	1	0	
Impact of housing and urban development transport, mobility of people and environment	1	0	
Impact of the industry nearby, air polution, smells	1	0	
Impact on designated sites	1	0	
Information about communities	1	0	
invasive plants	1	0	
Maintenance of sewing systém	1	0	
Maintenance of water courses and gullies	1	0	
MITIGATION OF WILD MAMMALS ROAD CASUALTIES	1	0	
Overfishing	1	0	
Pollution of lakes	1	0	
Regulation of populations of wild species (polecat, wild boar)	1	0	
Renewable energy	1	0	
River and lake restoration	1	0	
Settlements in nature areas	1	0	
Values of natural resources	1	0	
water protection and restauration; assistance to voluntary associations	1	0	