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# A REVIEW OF OCEAN ZONING TOOLS AND SPECIES DISTRIBUTION MODELLING METHODS FOR MARINE SPATIAL PLANNING

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## Disclaimer

The analysis is produced in the frame of the LIFE+ Nature & Biodiversity project "Innovative approaches for marine biodiversity monitoring and assessment of conservation status of nature values in the Baltic Sea" (Project acronym -MARMONI). The content of this publication is the sole responsibility of the Baltic Environmental Forum and can in no way be taken to reflect the views of the European Union.

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## Contents

1 Introduction ... 4
2 Species distribution modelling ... 6
2.1 Predicting species distribution ... 6
2.2 Methods for species distribution modelling ... 7
2.2.1 GLM and GAM ... 7
2.2.2 CART ... 8
2.2.3 Random forest ... 8
2.2.4 MAXENT ... 8
2.2.5 Multivariate methods for community data ... 9
2.3 Model evaluation ... 9
3 Ocean Zoning in Marine Spatial Planning ... 10
3.1 Decision support tools ... 10
3.1.1 Atlantis ... 11
3.1.2 Cumulative Impacts Assessment Tool ... 13
3.1.3 Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) ... 14
3.1.4 Marine Protected Areas Decision Support Tool (MarineMap) ... 15
3.1.5 Marxan & Marxan with Zones ... 16
3.1.6 NatureServe Vista ... 17
3.1.7 Zonation ... 18
3.2 Discussion ... 19
3.3 Conclusions ... 21
4 Acknowledgements ... 21
5 References ... 22

# 1 Introduction

The marine environment has since prehistoric times been used as a critical provider of food and resources and as a means of waste disposal (MEA 2005, Kidd 2011). With a growing global population, anticipating to peak around 9 billion in 2050, humanity's relationship and dependency of upon the sea and the wide array of ecosystem services it provides are bound to increase in the future as well as the footprint of human activities (MEA 2005, Kidd 2011). Consequently, coastal and marine ecosystems suffer from pressures of increased use, climate change, natural hazards and erosions (MEA 2005, EC 2012) and are in many places subjected to more rapid change than ever in their history (MEA 2005). Further, their possibility to cope with rapid change, i.e. their resilience, decreases due to biodiversity loss (Worm et al. 2006). In order to secure sustainable growth and preserve coastal and marine ecosystems for future generations an integrated and coherent management is required (EC 2012, Day 2002). In the Marine Strategy Framework Directive (MSFD) the European Commission (EC) stress the importance of an ecosystem-based approach to the management of human activities while enabling a sustainable use of marine goods and services in order to achieve or maintain good environmental status (GES) of the marine environment, as well as to continue its protection and preservation, and to prevent subsequent deterioration (EC 2008). The ecosystem approach (EA) recognizes the need to handle conservation and environmental issues from an integrated perspective, for which closely combined interconnected economic and social considerations are crucial (Kidd 2011). Further, ecosystem-based management implies that the needs of the ecosystem are prioritized; starting with a view of the ecosystem requirements before addressing human needs (Kidd 2011). To further address the goals set by the MSFD, in 2012 the EC established a proposal for a framework for the effective application of Marine Spatial Planning (MSP) and Coastal Management (CM), again highlighting an ecosystem-based approach to marine and coastal management (EC 2012). The framework states that all EU Member States will be required to develop and implement coherent processes to plan human uses of maritime space and to ensure sustainable management of coastal areas. Today, most management of ocean resources for human activities is usually done on a sector-to-sector, case-by-case basis (Fernandes et al. 2005; Halpern et al. 2008a, Ehler and Douvere 2009) without much consideration of effects either on human activities or the marine environment (Ehler and Douvere 2009). Consequently, this has led to conflicts both among different human uses as well as between human uses and the marine environment (Ehler and Douvere 2009). Since all these sectors are interconnected they should also be managed together, i.e. as in ecosystem-based management (EBM), to yield a sustainable result. The central part of EBM is to restore and maintain the ecosystem services (Rosenberg & McLeod 2005; McLeod et al. 2005). For instance, terrestrial sources are responsible for almost 80 percent of the pollutant load reaching the oceans (Agardy 2010), highlighting the importance of integrating several sectors when managing ocean resources. Additionally, much of the fisheries management focuses on population metrics for single species instead of considering the factors affecting the population size (Halpern et al. 2008b). It is neither enough to consider single activities that affects the environment since activities can interact and lead to more severe effects. Halpern et al. (2008a) further explain different ways in which activities can interact, and how this can be accounted for.

Protected areas (MPAs) are one of the most efficient ways to prevent biodiversity loss (Possingham et al. 2006), hence they are a keystone of most conservation strategies (Soulé 1991). They range from "paper parks" (i.e. the conservation laws that the environment conservation areas are bound to force are non-existent), to multiple-use areas with varying degrees of protection, or no-take areas (Hughes et al., 2003). The functions of MPAs for modern conservation are: (i) conserving marine biodiversity; (ii) maintaining productivity; and (iii) contributing to social and economic wellbeing (McManus et al. 1998). To fulfil these functions, the planning of MPAs needs to incorporate their location in relation to biological and physical patterns, but also factors such as connectivity, size, replication, alignment of boundaries to e.g. watersheds (Margules & Pressey 2000), disturbance and present use. Additionally, it must not be neglected that protection of biodiversity whilst providing for reasonable use is required in order to achieve effective management (Day 2002). MSP offers a way to address conflicts and select appropriate management strategies to maintain and safeguard necessary ecosystem services (Ehler and Douvere 2009). Ocean zoning is not synonymous with, but a central component of MSP (Agardy 2010). It is basically a spatial planning tool that acts similar to a town planning scheme (Day 2002) and is used to implement marine spatial plans by using a set of regulatory measurements that specify allowable uses in all areas of target ecosystems (Agardy 2010). Marine spatial planners can use ocean zoning to integrate management of different activities, which often improves management at ground level (Agardy 2010). The integration of different activities can with advantage be done by using a decision support tool.

Further, spatial predictions of species distribution are a significant part of conservation planning (Austin, 2002), as ecological modelling might be a tool to locate the overlap between the ecosystems that people want and the ecosystems that can be obtained (Carpenter & Gunderson, 2001). The development of models that makes it possible to use environmental factors to predict ecological variables is a desirable goal, as it would increase our ability to manage resources in a sustainable way (Ellis et al. 2006). The quantification of species–environment relationships is the most important aspect of predictive geographical modelling in ecology (Guisan and Zimmermann 2000). The models are generally based on various hypotheses as to how environmental factors control the distribution of species and communities (Guisan & Zimmermann, 2000). The goal of species distribution models is to make detailed predictions by relating presence or abundance of species to environmental predictors (Elith et al., 2006). The selection of predictors depends on the ecological and biophysical processes thought to influence the distribution of the biota, as well as the purpose of the model (Austin 2007). A greater understanding of life-history characteristics, density information and biotic interactions could potentially lead to the development of more sensitive models of species distributions (Ellis et al. 2006). To use predictions of species distributions as input for management decisions, we must choose the environmental variables with great care.

Since there exist a vast number of technical possibilities for both species distribution modelling (SDM) and decision support tools for ocean zoning, this review seeks to provide its readers with an overview of some of them. We also discuss the usefulness of different decision support tools for ocean zoning in the LIFE+ Nature & Biodiversity project "Innovative approaches for marine biodiversity monitoring and assessment of conservation status of nature values in the Baltic Sea" (Project acronym -MARMONI).

# 2 Species distribution modelling

## 2.1 Predicting species distribution

The purpose of species distribution modelling (SDM) is to statistically relate empirical data on the spatial distribution of a species or habitat type (or any other response variable) to one or more environmental variables, thereby providing a basis for predictive mapping of species or biodiversity on a regional scale (Elith et al. 2006; Ferrier and Guisan 2006). The response can be measured as e.g. presence only (common in e.g. herbarium collections) presence/absence, percent cover or biomass. If the response is based on community data, it could be species composition or biodiversity indices. The statistical relationship can be used to predict the cover or occurrence of the response variable at locations where no measurements have been made. Spatial distribution models of species usually focus on predictors available as maps or interpolated layers, as the spatial distribution of the cover or probability of occurrence thus can be predicted for a whole area. The resulting prediction can be used in GIS to estimate e.g. the probability of presence, biomass or frequency of a species for each grid cell of the input maps.

Lehmann, Overton, & Leathwick (2002) and Lehmann, Overton, & Austin (2002) listed a number of criteria that methods used for making spatial predictions should meet:

i. Meaningfulness: the model should be precise and ecologically sensible
ii. Generality: They should be able to deal with a wide variety of attributes that need to be predicted.
iii. Objectivity: They should be data-defined and robust, in order to make predictions in an objective manner.
iv. Standardisation: They need to produce uniform results that can be expressed in a spatial framework.

Both species and environmental data are usually sampled during a limited period of time and/or in limited spatial context (Guisan and Thuiller 2005). Ecological organisation is however a result of the interaction of structures and processes that operate at different scales (Peterson 2000). For example, the general circulation models used for climate prediction operate on a much larger spatial and temporal scale than biotic interactions (Figure 1). To develop predictive models that are useful for management, in that they allow us to respond to the observed or predicted change, we must combine the different scales (Levin 1992).

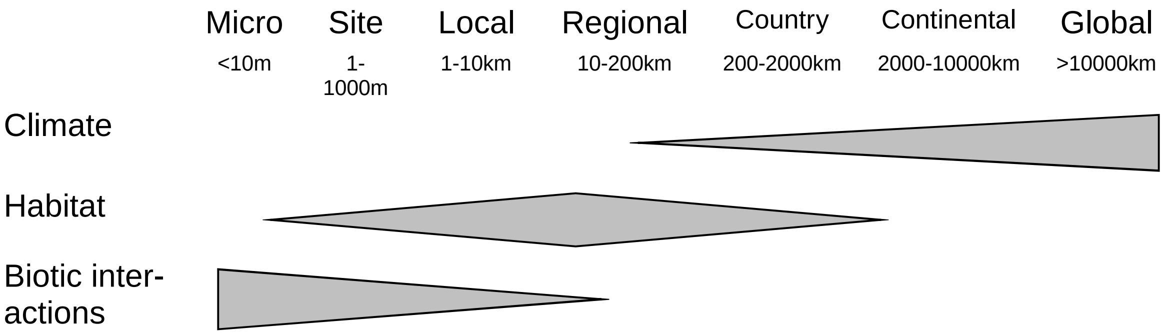


**Figure 1. Processes that control species distribution on different scales. Inspired by Pearson and Dawson (2003) and McGill (2010).**

## 2.2 Methods for species distribution modelling

Frequently used methods for the analysis of individual species include generalized linear models, GLM (McCullagh and Nelder 1989), generalized additive models, GAM (Hastie & Tibshirani, 1986; 1990) and classification and regression trees, CART (Breiman et al. 1984) and Random Forests (Breiman 2001). There are also methods that use presence data only like the Maximum Entropy method, Maxent (Phillips et al. 2004, 2006). Ordination methods are widely used for community analysis (ter Braak and Prentice 1988; Kent and Coker 1992; Legendre and Legendre 1998; Clarke and Warwick 2001).

### 2.2.1 GLM and GAM

Generalized linear models (GLM) are a generalisation of least square regression that do not force data into unnatural scales, and thereby allow for non-linearity and non-constant variance structures in the data (Hastie & Tibshirani, 1990). GLMs are based on a link function, which is an assumed relationship between the mean of the response variable and the linear combination of the explanatory variables, and data may be assumed to be from several families of probability distributions. GAMs are non-parametric extensions of GLMs. While GLMs allow the application of classical regression to extend into non-normal statistical distributions, the GAM analysis uses non-parametric, data-defined smoothers to fit non-linear response curves. GAMs also use a link function, but in this case it describes the relationship between the mean of the response variable and a smoothed function of the explanatory variables instead of a linear combination (for review c.f. Guisan et al., 2002; A. Lehmann et al., 2002; Elith et al., 2006). GAMs are sometimes referred to as data-driven rather than model-driven, because the data itself is used to determine the shape of the response curves, rather than assuming some form of parametric relationship. GAMs are able to deal with non-linear relationships between the response and the explanatory variables (Guisan et al., 2002) and allow a wider range of response curves to be modelled than GLMs, which are not always flexible enough (Yee & Mitchell, 1991). GLMs generate a formula that can be used directly in GIS using map algebra, whereas GAMs require more sophisticated methods such as lookup tables to translate the outcome into spatial predictions. One such method is GRASP (generalized regression analysis and spatial prediction). It is a modelling tool, that first model a species' realised environmental niche based on the input data, and then it predicts its spatial distribution into geographical space (Lehmann et al. 2003). The response curve of species can only be properly determined if the sampled environmental gradient clearly exceeds the upper and lower limits of the species occurrence (Austin 2007). As GLMs and GAMs model the realised niche, i.e. where the species exists, rather than the possible distribution expressed by the fundamental niche (Austin 1985; Guisan et al. 2002), the models can not easily be extrapolated outside the limits set by the environmental data that were used to build the model. Thus, using these models to predict outside the environmental range found in the input data, in either space or time, must be subject to great care (Lehmann et al. 2003; Elith et al. 2010)

While these techniques are not new, they have rarely been applied to marine systems (Ellis et al. 2006). However, in very recent years, a number of marine species distribution models have been published (e.g. Bekkby et al. 2008; Soldal et al. 2009; Sundblad et al. 2009; Snickars et al. 2010) + Nyström Sandman et al 2012 indicating that these techniques now are becoming commonly used also for marine applications.

### 2.2.2 CART

Classification and regression trees (Breiman et al. 1984) are tree-building algorithms that determine logical splits in the data (if the value of the predictor is larger than e.g. 2 then the dependent variable belongs to group A otherwise to group B). Classification trees are used to predict values of a categorical dependent variable from continuous and/or categorical predictor variables, while regression trees predict the values of a continuous variable. Advantages of tree methods are that the results are easy to interpret, and the tree methods are nonparametric and nonlinear.

### 2.2.3 Random forest

Random forest (Breiman 2001) is a further development of classification or regression trees. Random forests grows a huge number of trees, each using a subsample of the original data. For the response variable, a training dataset is randomly sampled (with replacement), and for each node a small subset of the environmental variables is selected at random. The number of cases in the training dataset, as well as the number of environmental variables sampled at each node is held constant when growing the forest. Each tree gives a classification, a vote, and the forest chooses the classification having the most votes based on all trees in the forest. Random Forests is known to perform well compared to other methods (Caruana et al). The method is also efficient for large datasets and/or many environmental variables (breiman).

### 2.2.4 MAXENT

Among methods that use presence only, the Maxent method (S. J. Phillips et al., 2004; S. J. Phillips et al., 2006) has been shown to perform well (Elith et al., 2006). "Presence only"-methods are especially of interest when the data has been recorded without planned sampling schemes, e.g. when derived from in museum or herbarium collections (Graham et al., 2004; Soberón & A. T. Peterson, 2005). (Stockwell 2006 http://landshape.org/enm/phillips-et-al-maxent/): The Maxent principle is to estimate the probability distribution, such as the spatial distribution of a species, that is most spread out subject to constraints such as the known observations of the species. Maxent estimates a probability distribution over every pixel in the study area which means the probability in all pixels sums to 1. Rather than individual probabilities of 0.8, 0.9, etc. representing the suitability of each pixel for a species, the probabilities are each very small. To get around this, Maxent assigns a "cumulative" probability to each pixel which is the sum of the probabilities for all pixels with lesser probability.

### 2.2.5 Multivariate methods for community data

Generally, the focus of predictive distribution modelling has been on individual species, but the relationships between species and environment can also be modelled using community data (De'ath 2002; Ferrier and Guisan 2006) (ter Braak and Prentice 1988; Kent and Coker 1992; Legendre and Legendre 1998; Clarke and Warwick 2001). Spatial modelling of biodiversity at the community level may be a better choice when large numbers of species are of included. The changes in the community composition or the species richness might reflect anthropogenic disturbances better than analysis using only a single species. The community approach increases the possibility to detect environmental responses of rare species (Ferrier and Guisan 2006). In order to predict multivariate responses several species predictions can be summed to obtain community composition or species richness (Lehmann, Overton, & Leathwick, 2002). Other methods are multivariate regression trees, MRT (De'ath 2002), Multivariate adaptive regression splines, MARS (Friedman 1991) and Boosted Regression Trees, BRT (Leathwick et al., 2006c). Multivariate regression trees (MRT) is an extension of univariate regression trees, where the univariate response is replaced by a multivariate response. MRT analyses community data, and makes no assumptions about the form of relationships between species and their environment. (De'ath, 2002). Multivariate adaptive regression splines, MARS, fits a model describing relationships between multiple species and their environment. This allows a model to be fitted that simultaneously relates variation in the occurrence of all species to the environmental predictors in one analysis. It is a technique in which non-linear responses between species and an environmental predictor are described by linear segments. The slope of the segments and breaks between them are defined by a model that initially over-fits the data, and which is then simplified to identify terms to be retained in the final model (Friedman, 1991; Leathwick et al., 2006a). In boosted regression trees (BRT), an iterative process progressively add trees, while re-weighting the data poorly predicted by the previous tree. Simple trees, fitted in a forward, stagewise fashion leads up to the final BRT model (Leathwick et al., 2006, Elith et al., 2008).

## 2.3 Model evaluation

Validation of models can be internal or external. In internal validation, a subsample of the data used in the analysis is then used to validate the model. External validation is based on datasets not used in the modelling process. The statistical relationship fitted in the model is used to predict the response in the points of the external dataset, based on the information in the environmental variables. The difference between the prediction and the actual data is then evaluated. Uncertainty, expressed as e.g. confidence intervals or prediction error, could be visualised as part of a suite of maps describing species distribution and used to inform decision-makers about error (Elith et al. 2002).

The outcome of most presence/absence models is a probability of the species to be present at a specific location. In a presence/absence model there are two possible prediction errors: false positives, i.e. true absences that are classified as presences (Type I error), and false negatives which are actual presences that are classified as absences (Type II error) (c.f. Fielding & Bell, 2002). AUC is an evaluation method that gives the goodness-of-fit of the model regardless of threshold for presence/absence, and the values can be interpreted as the probability that, when a site where a species is present and a site where the species is absent are drawn at random from the population, the presence site will have a higher predicted value than the absence site (Zweig & Campbell, 1993; Elith et al., 2006). Statistical evaluation is of importance to find the best model, but the models have to be ecologically reasonable. Thus, the shape of the response curves and their interpretability, as well as the resulting spatial predictions, has to be considered as well (Maggini et al. 2006).

## 2.4 Discussion

In a comprehensive comparison of methods by Elith et al. (2006) using presence only data, MAXENT turned out to be among the top performing modelling approaches. Among the methods with univariate response using both presences and absences, GAM, GLM and Random Forest have shown to perform well. For comparisons see for example Elith et al. (2006) and Reiss et al. (2011). In Random Forest it is also possible to use a response variable containing multiple classes. GAM, MAXENT and Random Forest also have been successfully used in assemble modelling (Bergström et al., 2013). For multivariate data, BRT (see Elith et al., 2006) and MARS (see Reiss et al., 2011) both perform well. Depending on the issue at hand, output from all these models could be used as an input for ocean zoning tools.

# 3 Ocean Zoning in Marine Spatial Planning

Ocean zoning should be based, not only on conservation targets but, on socio-economic considerations (Teh & Teh 2011). This can be done by incorporating human uses early in the progress, e.g. by optimization algorithms (Teh & Teh 2011). The decision support tool must be able to: (i) combine quantitative and qualitative variables; (ii) handle estimates and uncertainties in human judgement; and (iii) be easy to use and attractive for both stakeholders and managers (Teh & Teh 2011). Teh & Teh (2011) argues that these criteria are not always met in the decision support tools, since many of them use Boolean operators which only deal with true and false scenarios. Nevertheless, the social and political decisions of which areas to protect are complicated by the tradeoff between the economic and the biodiversity value of certain areas. The tradeoff between biodiversity gain and opportunity costs can be incorporated in the model or managed with other software, e.g. Target (Margules & Pressey 2000; Faith & Nicholls 1996). This tradeoff is an important step in the planning process in order to make the result sustainable.

## 3.1 Decision support tools

As mentioned above, systematic conservation planning is effective since it reaches conservation goals by including limited resources (Margules & Pressey 2000). Additionally, it challenges land uses and allows for review and adaption (Margules & Pressey 2000). The tools described below all aims to reduce conflicts between different activities and between the activities and the ecosystems and in that way make marine space and resources more efficiently used (Coleman et al. 2011). In order to achieve this, the tools must be able to:

i. incorporate data from ecological, economic and social systems;

ii. incorporate ecological data produced through species distribution modelling

iii. incorporate ecological element's sensitivity to activities;

iv. assess management alternatives and trade-offs in a transparent manner;

v. involve stakeholders; and

vi. assess development to management objectives

Seven tools that suit these criteria were found: Atlantis, Cumulative impacts assessment tool, Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST), Marine Protected Areas Decision Support Tool (MarineMap), Marxan & Marxan with Zones, NatureServe Vista and Zonation. Below each tool is described shortly (in alphabetical order), and thereafter compared more in detail in the discussion.

### 3.1.1 Atlantis

Atlantis was developed by the Commonwealth and Industrial Research Organisation (CSIRO), Marine and Atmospheric research. It was made as an ecosystem simulation model which considers the biophysical, economic and social parts of the ecosystem (Link et al. 2010). It is based on the Management Strategy Evaluation (MSE) approach (Link et al. 2010), which aims to provide the decision maker with information upon which the decision can be based and not a decision in itself (Smith 1994). Atlantis has a sub-model for each step in the management cycle; the marine environment, industrial activities, monitoring and assessment processes of fishery, management actions and implementation, Figure 2 (http://www.csiro.au/science/ps3i4#a1 21/5-12). It includes dynamic, two-way coupling of all these system components. The modelling framework includes many alternative model formulations for each major process and model component included. The formulation is application-specific decision made by the user, who has the freedom to set complexity at any desired level (Fulton 2011). It has mostly been applied in the temperate regions of the USA and Australia (http://www.csiro.au/science/ps3i4#a1 21/5-12), and has mostly been used in fisheries management, but can also handle questions related to marine biodiversity, habitat and nutrients (Coleman et al. 2011).

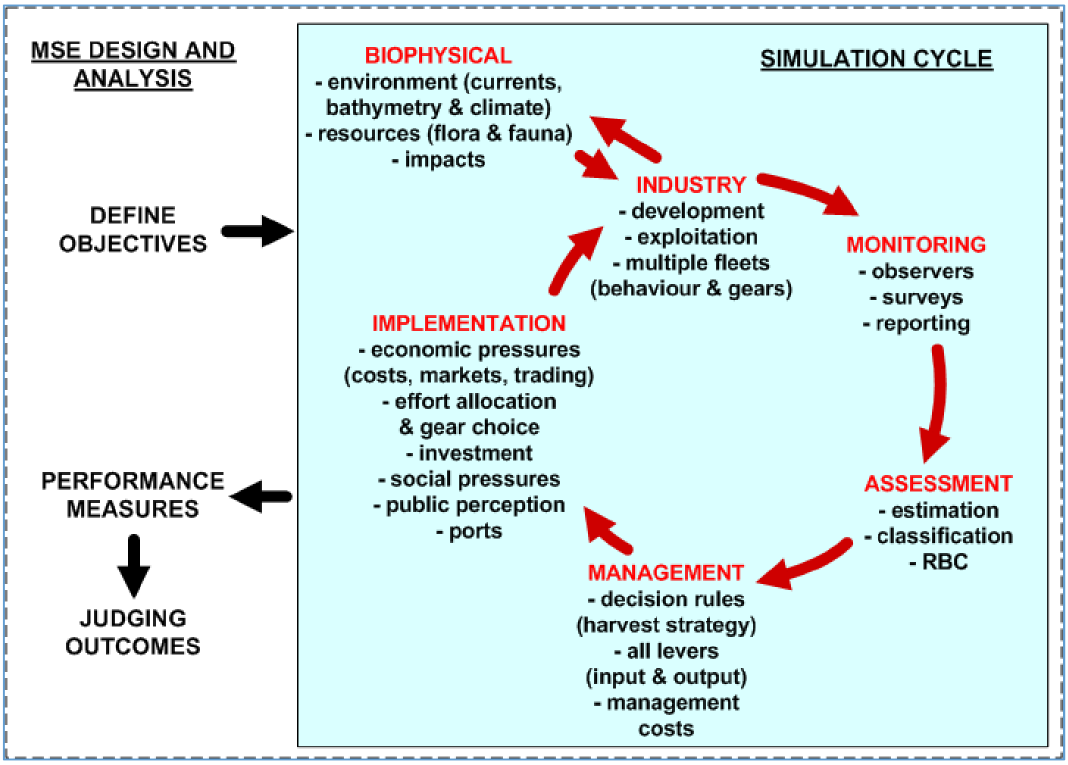


**Figure 2. Atlantis model structure - based on the management strategy evaluation cycle (http://atlantis.cmar.csiro.au/ 29/5-13).**

Atlantis makes is possible to test depictions of complex ecosystems against management policies and assessment methods. It incorporates ecological, chemical, physical and fisheries dynamics. There are also sub-models that simulate marine ecosystem dynamics in terms of hydrographical processes such as nutrient fluxes, biogeochemical factors, food web relationships, habitat interactions and fishing fleet behaviour (Coleman et al. 2011). The ecological and fishing fleet dynamics models are flexible in the sense that different functional relationships are available for selection (Coleman et al. 2011).

The main ecological processes modelled with Atlantis are production, consumption, predation, migration, recruitment, mortality, habitat dependency and waste production (atlantis.cmar.csiro.au 11/5-12). The food web relationships are in general modelled at the functional group level, where invertebrates embody biomass pools and vertebrates are represented by an explicit age-structured formulation (Link et al. 2010). The physical environment is represented by a set of linked polygons matched to the bioregional and geographical characters (Link et al. 2010). The dynamics of fishing fleets are modelled with a detailed exploitation sub-model which also treats impacts of pollution, coastal development and environmental change (Link et al. 2010).

Atlantis is primarily supported by free support software, i.e. tools to make parameter files. But the developer can be requested for consultation and there is a user manual under development (www.ebmtools.org, 11/5-12). The working assumptions for Atlantis are not stated clearly and cannot be supplied by the user, but the assumptions are expressed in the modelling equations or the software code (Coleman et al. 2011). Atlantis was rated to be the best DST in the world by FAO in year 2007 (http://www.csiro.au/science/ps3i4#a1 21/5-12), but the objective of the analysis should always be kept in mind when choosing which tool to use.

### 3.1.2 Cumulative Impacts Assessment Tool

The Cumulative Impacts Assessment tool was developed by the National Center for Ecological Analysis and Synthesis (NCEAS), University of California Santa Barbara and Stanford University (Coleman et al. 2011). It was developed to support MSP and EBM by identifying vulnerable regions, main stressors to diminish in certain areas, compatible and incompatible uses based on ecosystem vulnerability, map which areas are most and least protected within a region, and to assess how the overall ecosystem condition is affected by the stressors (Coleman et al. 2011).  In summary, it evaluates and visualises the human impacts to marine ecosystems (Halpern et al. 2008a; Halpern et al. 2008b), Figure 3.

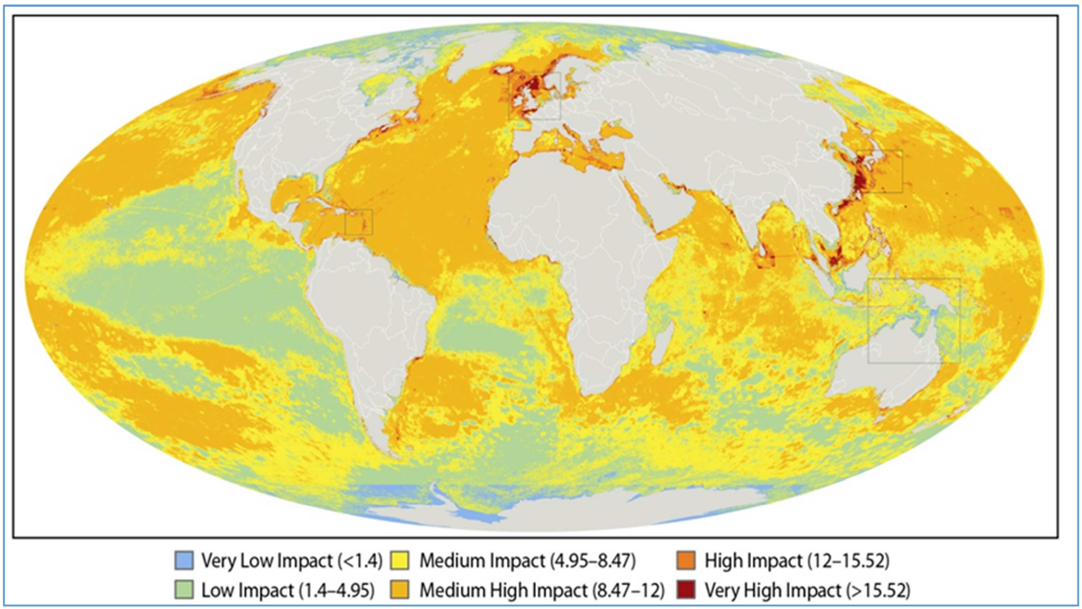


**Figure 3. A Global map of cumulative human impacts across 20 ocean ecosystem types (Halpern et al. 2008 a).**

Cumulative Impacts predicts a cumulative impact score for each pixel by using spatial data together with weighted expert opinions (Coleman et al. 2011; Halpern et al. 2008 b). The impact score is based on the type of anthropogenic drivers and their intensity, which type of ecosystems that are present, and the weighted impact assigned for each anthropogenic driver on a certain ecosystem (Coleman et al. 2011). The model assumes an additive accumulation of impacts and that the presence of an anthropogenic driver has a negative impact (Coleman et al. 2011).

Human activities that directly or indirectly have impact on the ecological communities in the ecosystems chosen can be mapped by Cumulative Impacts (Halpern et al. 2008 b). This tool is supportive to the increasing application of MPAs, ocean zoning and EBM to help to decrease human influence and biodiversity loss (http://ebmtoolsdatabase.org/tool/cumulative-impacts-assessment-tool, 23/5-12).

The majority of the applications of the Cumulative impacts assessment tool have been to set conservation and management priorities and to assess the most vulnerable locations in a region (Coleman et al. 2011). It has also been used as a base for environmental impact assessments of state agencies (Coleman et al. 2011). The Cumulative Impacts assessment tool has mostly been used in tropical environments (Halpern et al. 2008 b).

There is technical support available (Coleman et al. 2011), but it seems rather limited. The working assumptions for Cumulative impacts are stated clearly but cannot be supplied by the user and are not expressed in the modelling equations or the software code (Coleman et al. 2011).

### 3.1.3 Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST)

InVEST was developed by The Natural Capital Project which is driven by Stanford University, World Wildlife Fund, the Nature Conservancy and the University of Minnesota. The tool aims to estimate how the production and value of terrestrial and marine ecosystem services are affected by human activities and climate change (Nelson et al. 2009). It identifies where ecosystem services are provided and where they are consumed (Coleman et al. 2011; Nelson et al. 2009). Further it can reveal relationships and identify trade-offs among several ecosystem services and biodiversity (Coleman et al. 2011, Link et al. 2010). It also identifies how several aspects of the economy, human well-being and the environment are affected by resource management decisions (Coleman et al. 2011). InVEST includes models based on economic valuation methods and ecological production functions, with biophysical and economic information about the ecosystem services which is incorporated to conservation and natural resource management (Tallis & Polasky 2009). The models not only accounts for service supply (e.g. living habitats as buffers for storm waves), but also include the location and activities of people who benefit from services (e.g. location of people and infrastructure potentially affected by coastal storms) (http://naturalcapitalproject.org/InVEST.html 28/5-13). Further there are models for ecosystem services which include carbon storage, wave energy, recreation, fishery production, erosion control, habitat quality, crop pollination and timber production (Coleman et al. 2011). The user can define alternative scenarios which are translated into changes in ecosystem services and values, provided by the process models in InVEST's ecological production function approach (Tallis & Polasky 2009), Figure 4. Scenarios are critical inputs in all InVest models and typically include maps of potential future land use or land cover and/or marine habitats and ocean uses (http://naturalcapitalproject.org/InVEST.html 28/5-13). InVEST has been used for MSP in Belize and Canada (Coleman et al. 2011).

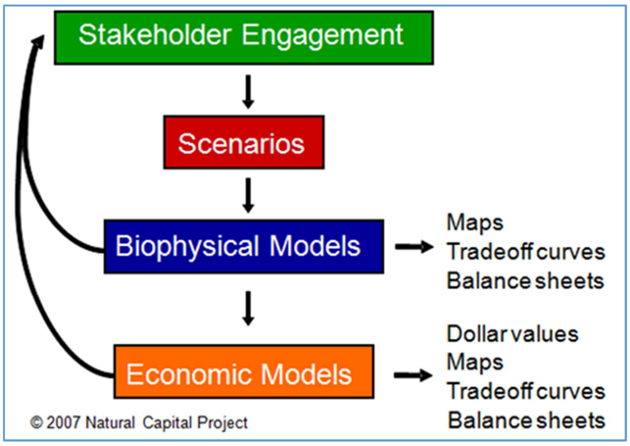


**Figure 4. A conceptual framework for how InVEST works, http://www.naturalcapitalproject.org/InVEST.html.**

The models can be run independently (http://naturalcapitalproject.org/InVEST.html 28/5-13), or as a toolbox in ArcGIS (Coleman et al. 2011) designed to be flexible but still scientific (Tallis & Polasky 2009). The outputs can be both economic and biophysical (Tallis & Polasky 2009) and can be viewed using GIS-software such as QGIS or ArcGIS (http://naturalcapitalproject.org/InVEST.html 28/5-13). Running InVEST effectively does not require knowledge of Python programming (http://naturalcapitalproject.org/InVEST.html 28/5-13). However, it requires a quite deep GIS-knowledge and feedbacks between ecosystem services are limited (http://ebmtoolsdatabase.org/tool/invest-integrated-valuation-ecosystem-services-and-trade-offs, 23/5-12).

There is a user manual for InVEST, an online forum, frequently asked questions for problems in ArcGIS and trainings at set (or requested) times and locations (www.ebmtools.org, 11/5-12). The working assumptions for InVEST are stated clearly and can be supplied by the user, but the assumptions are not expressed in the modelling equations or the software code (Coleman et al. 2011).

### 3.1.4 Marine Protected Areas Decision Support Tool (MarineMap)

MarineMap (previously named Doris) was developed by the MarineMap Consortium, University of California Santa Barbara, the Nature Conservancy and Eco-Trust. MarineMap aims to: (i) protect marine life, habitat, ecosystems and natural heritage; (ii) improve recreational, educational and research services provided by marine ecosystems; and (iii) minimise the economic impact to fisheries and coastal communities (Coleman et al. 2011). Further, it allows stakeholders to access large amounts of reliable geospatial information, and to outline legal boundaries of MPAs (Coleman et al. 2011).

MarineMap is a web-based application, the latest version has new functions including (i) a spatial data viewer; (ii) design tools allowing users to draw shapes; (iii) group management software allowing users to share their proposals either privately or publicly; and (vi) analytical tools allowing users to evaluate their proposals against the primary goals set (Coleman et al. 2011). MarineMap requires customisation to meet the needs for specific areas; this means the codes have to be changed. The codes are open source but editing requires substantial knowledge in Java, Python (http://ebmtoolsdatabase.org/tool/marinemap-marine-protected-areas-decision-support-tool, 14/5-12).

MarineMap was first used to make the design and evaluation of MPAs easier (marinemap.org, 25/5-12). It functions as an open-source platform where managers easily can assess and understand spatial information (marinemap.org, 25/5-12). No deep GIS-knowledge is needed to use this tool since spatial concepts and science based guidelines for MPA-design are simplified (marinemap.org, 25/5-12). The stakeholders have a central position in MarineMap and it is easy to use since no spatial training or assistance is required (marinemap.org, 25/5-12). With MarineMap it is possible to illustrate, assess and discuss future MPAs (marinemap.org, 25/5-12).

A user manual and online help are available as well as training sessions, consultation and webinars (www.ebmtools.org, 11/5-12). The working assumptions for MarineMap are stated clearly and are understandable by all users but cannot be supplied, they are not expressed in the modelling equations or the software code (Coleman et al. 2011).

### 3.1.5 Marxan & Marxan with Zones

Marxan was developed by the University of Queensland's Ecology Centre, Spatial Ecology Lab. It aims to find a network of areas that meet biodiversity targets and are relatively socially and economically cost-effective for conservation management (Coleman et al. 2011). It delivers solutions that have achieved a minimum set of biodiversity features to the lowest cost (Klein et al. 2009; Possingham et al. 2006), Figure 5.

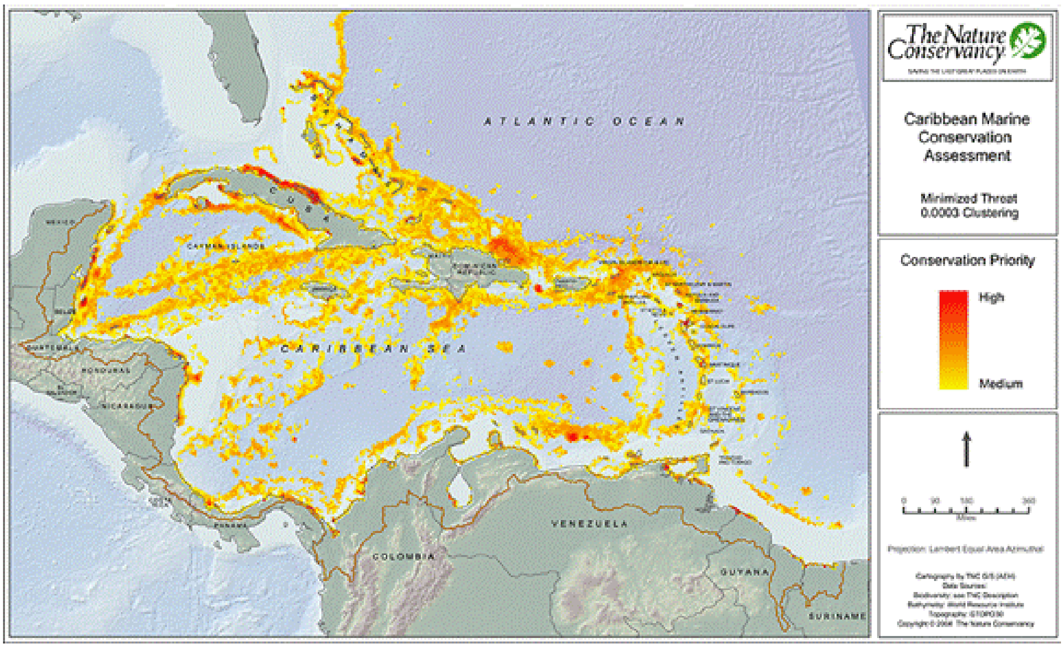


**Figure 5. Result of the MARXAN marine assessment for the Greater Caribbean Basin. More red areas have higher conservation priority based on e.g. human impacts, biodiversity conservation targets and conservation values (http://edcintl.cr.usgs.gov/ip/macga/tnc.php).**

Marxan works by stepwise algorithm that identifies combinations of sites that meet targets set for biodiversity or other features, while minimizing the sum of costs for protecting each of those areas. Inputs needed for the calculations include user-supplied GIS layers of (1) socioeconomic values (e.g. human activities that affect the object of protection and are affected by the resulting management), (2) a weighting value for biodiversity features (e.g. species distribution maps or biological value maps), and (3) a boundary length modifier value to account for the "clumpiness" of a reserve (Coleman et al. 2011). When penalties are too high, the spatial solution changes by replacing "high-cost" solutions with "lower-cost" solutions. Marxan was originally developed based on the principle of complementarity, such that sites that are most similar to other sites in their composition of features, such as species, are selected together (Coleman et al. 2011).

In addition to Marxan, Marxan with Zones was developed to make it possible to incorporate several types of zones allowing different activities, contributing to different management targets, having different costs in different locations with different biodiversity benefits (Coleman et al. 2011; http://www.uq.edu.au/marxan/index.html?page=77640&p=1.1.2.1, 16/5-12). Marxan with Zones can also incorporate interactions between different zones (Coleman et al. 2011). It creates a zone scheme which allocates resources across an array of several activities; at least two zones with different targets are identified (http://www.uq.edu.au/marxan/index.html?page=77640&p=1.1.2.1, 16/5-12).

Marxan with Zones is different from Marxan since it provides multiple zones instead of being limited to including or excluding, but also since it can minimize several types of zoning costs: reservation, management, opportunity costs and other constraints (http://ebmtoolsdatabase.org/tool/marxan-zones, 16/5-12). These properties make it possible to address a variety of questions associated with spatial planning (http://ebmtoolsdatabase.org/tool/marxan-zones, 16/5-12). Each zone can have certain actions, objectives and constraints tied to it which might be biological, cultural, economic or social (http://ebmtoolsdatabase.org/tool/marxan-zones, 16/5-12). Klein et al. (2009) describe how Marxan with Zones was developed and assess the difference in socio-economic advantages between Marxan and Marxan with Zones. Further, Klein et al. (2009) investigate tradeoffs associated with the representation of biodiversity features and impacting fisheries. According to Coleman et al. (2011), Marxan with Zones essentially operates as a multi-layered version of Marxan.

In summary, this tool can be applied to biosphere reserves, multiple-use marine parks and off-reserve marine planning (http://www.uq.edu.au/marxan/index.html?page=77640&p=1.1.2.1, 16/5-12).

It is recommended to work with Marxan before learning to work with Marxan with Zones (http://ebmtoolsdatabase.org/tool/marxan-zones, 16/5-12). There is a user manual available as well as training courses and to a small extent also consultants (www.ebmtools.org, 11/5-12). The working assumptions for Marxan and Marxan with Zones are not stated clearly and cannot be supplied by the user, neither are the assumptions expressed in the modelling equations or the software code (Coleman et al. 2011). Recently, a marine version of the tool was developed; Marine InVEST (http://www.naturalcapitalproject.org/marine/MarineInVEST_Apr2010.pdf).

### 3.1.6 NatureServe Vista

NatureServe Vista was developed by the non-profit conservation organisation NatureServe, which aims to provide the scientific basics to achieve effective conservation. It is a conservation planning support tool, which runs on the ESRI platform of products (ArcMap/ArcInfo) (CRWVPP 2008) and can be used for impact assessments or conservation purposes (http://ebmtoolsdatabase.org/tool/natureserve-vista, 1/5-12). The most well adapted application is biodiversity conservation but other features can also be included, such as historic or hazardous areas etc. as well as the balancing of competing uses (www.ebmtools.org, 1/5-12). By working with other software tools it considers economics, land use, ecological and geophysical modelling (www.natureserve.org/prodServices/vista/overview.jsp, 11/5-12). NatureServe Vista is compatible with Marxan (chapter 2.1.5) through a wizard that prepares input for Marxan and, after running Marxan, imports the resulting scenarios back into NatureServe Vista (www.natureserve.org/prodServices/vista/overview.jsp, 11/5-12; http://www.natureserve.org/prodServices/vista/kf_generate.jsp, 11/5-12). NatureServe Vista includes element (species or community) location and runs analyses utilizing information on the element’s sensitivity to different types of disturbance and on each occurrence’s (individuals, populations) known or estimated condition. Further it handles assertions of confidence in the existence of each occurrence entered in the system. Background data (e.g. hydrology, land use, zoning, political subdivisions and protected areas) is used by the application to produce maps, frame the information and carry out some of the analyses (CRWVPP 2008). Central functions are (i) the production of indices for the regions' conservation values which makes it possible to early identify areas important for conservation; (ii) the importation of land use scenarios which can be evaluated against the conservation motives at hand; (iii) the interoperating with other conservation optimization tools such as Marxan (www.ebmtools.org, 1/5-12). Data inputs may be in both vector and raster format. The outputs are predominantly in raster (CRWVPP 2008). There is a user manual available (www.ebmtools.org, 1/5-12), but according to the CRWVPP 2008, the NatureServe Vista application is complex and beginning users will require technical support. Such is provided via Internet or by phone by NatureServe a year after product installation as well as through a knowledgebase page (http://support.natureserve.org/vista/) and a listserv (Vista-users@lists.natureserve.org) that provides a way to access topics recently discussed by other list members (CRWVPP 2008).

### 3.1.7 Zonation

Zonation was developed by the Metapopulation Research Group at the University of Helsinki (www.ebmtools.org, 1/5-12). It aims to achieve long-term persistence of species by identifying areas important for retaining habitat quality and connectivity for multiple species (www.ebmtools.org, 1/5-12). In contrast to most other conservation planning methods, Zonation is based on the specification of tool is intended for using species distribution predicted on large grids and priorities and connectivity responses for biodiversity features (Moilanen 2007, Leathwick et al. 2008) rather than on setting conservation targets (Sarkar et al. 2006, Leathwick et al. 2008). This produces a hierarchical prioritization of the conservation value of a landscape. The Zonation algorithm works by removing cells one by one from the landscape, using minimization of marginal loss as a criterion to decide which cell is removed next (Moilanen 2007), resulting in a landscape zoning with the most important areas remaining last (Moilanen et al. 2005). By removing cells instead of adding them the tool enables analysis of connectivity of species, habitats or ecosystems. The initial landscape includes all clusters with maximal possible connectivity, and cell removal proceeds in a manner that maintains maximal value and connectivity for remaining areas (Moilanen 2007). The order in which cells are removed is recorded to allow identification of the landscape zoning (Moilanen et al. 2005). Consequently it is possible to identify multiple spatially distinct important regions at any given fraction of cell removal (Moilanen 2007). The definition of marginal loss (the cell removal rule) is crucial for the Zonation algorithm to work properly (Moilanen 2007). According to Moilanen (2007) it should be seen as a separate component (and not be confounded with the Zonation meta-algorithm) with several alternatives that have different interpretations (Leathwick et al. 2008). Furthermore it allows species weighting and species-specific connectivity considerations to be applied (Leathwick et al. 2008). The Zonation tool can be used for the expansion of existing reserve networks, to find optimal areas for new reserve networks, to assess proposed reserve networks or as conservation decision support by priority ranking (www.ebmtools.org, 1/5-12). The output of Zonation can be imported to GIS software in order to visualise or further analyse the results (http://www.helsinki.fi/bioscience/consplan/software/Zonation/Introduction.htm l, 4/6-12). Zonation can also yield output in terms of diagrams showing the decrease of selected features, e.g. proportion of original species distribution, depending on the area of conserved land included (http://www.helsinki.fi/bioscience/consplan/software/Zonation/Introduction.html, 4/6-12), Figure 6.

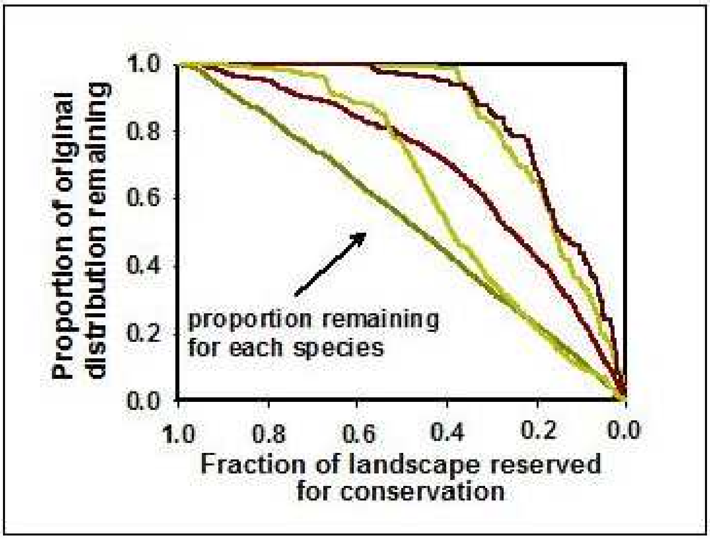


**Figure 6. Zonation produces detailed information about the decrease in species distributions (or other features) as landscape is lost, http://www.helsinki.fi/bioscience/consplan/software/Zonation/Introduction.html.**

Zonation has a direct workflow between GIS and statistical species distribution modelling (SDM) and has the ability to work with large datasets (www.ebmtools.org, 11/5-12). Zonation can also model species interactions and do uncertainty analysis to find robust reserve solutions (www.ebmtools.org, 11/5-12). It cannot work with vector data and it only allows a limited set of interactive planning analyses (http://www.helsinki.fi/bioscience/consplan/software/Zonation/zv3_leaflet_120306.pdf, 15/5-12). Available support includes user manuals and tutorials (http://www.helsinki.fi/bioscience/consplan/software/Zonation/References_new.html, 14/5-13).

## 3.2 Discussion

All the tools described above are based on the foundations of ecosystem based management, i.e. considering the whole ecosystem; humans and the environment. Further, the use of an adaptive management approach, i.e. that management can be adapted to changing circumstances, is essential for all these tools (www.ebmtools.org, 11/5-12). Other aspects to consider before deciding which tool to use is how steep learning curve the tools has, if support is available, how up-to-date the tool is i.e. if it is frequently used and updated, if the assumptions are transparent and how time consuming the analysis is. These aspects are difficult to assess without having tested the tools. Albeit, after reviewing the literature it can be concluded that these tools are specialised in different subjects, e.g. the fishery industry (Atlantis), impacts assessment (the Cumulative Impacts Assessment Tool) etc. The tools have common grounds, and to a certain extent also common input data, they are also more or less adaptable to better serve local regulations, goals, limitations, species, habitats etc.

Compared to the other tools, MarineMap is different since it is more adapted for stakeholders by being simplified, possibly too simplified for the purpose of MARMONI. Even though adaptations are possible, MarineMap requires knowledge about Python programming, which not always is at hand. Further, it works as a web-based tool, not having the analysing advantages of GIS-software. The tool Atlantis, on the other hand, is more advanced with a sub-model for each step in the management cycle (http://www.csiro.au/science/ps3i4#a1 21/5-12). It has a good reputation after being elected to the best DST in the world by FAO in year 2007 (http://www.csiro.au/science/ps3i4#a1 21/5-12). It is applicable for biodiversity conservation and ocean zoning but, after all, most well adapted to fisheries management. Additionally, since it mostly has been applied in tropical environments its possibility to assess the Baltic Sea is unknown.

Another tool mostly applied in tropical environments is InVEST. This tool does not assess fisheries management but ecosystem services, which could be set to e.g. biodiversity to fulfil the goals of MARMONI. But the sensitivity for disturbance, such as the building of wind power plants, could be more difficult to assess with InVEST, although not impossible since ecosystem services should be a function of e.g. the biodiversity after exposure to disturbance. However, the analysis tends to get complicated; therefore the Zonation tool is ranked higher for the purpose of MARMONI. The strengths of Zonation are its ability to work with both GIS and statistical species distribution modelling, as well as connectivity responses for biodiversity features. The downside is its inability to work with vector files, further; it is primarily developed to design marine reserves and not combined planning of human activities and marine protection.

Left are three strong candidates, in alphabetic order; the Cumulative Impacts Assessment Tool, Marxan, its sibling Marxan with Zones and NatureServe Vista. The Cumulative Impacts Assessment Tool has a possibility to assess the impacts of different activities to different ecosystems by identifying vulnerable regions and important impact factors. Another important property is its ability to assess compatible and incompatible uses based on vulnerability. Further, it supports ecosystem based management. These are all features matching the MARMONI objectives. The downside, however, is the fact that is has most been applied in tropical environments and perhaps that it assumes all impacts to be negative and additive accumulative. The most well-known and possibly therefore most widely used Marxan with Zones on the contrary offers the possibility to set each activity’s cost or contribution to different management targets, enabling consideration not only to the cost of activities, but also to their possible biodiversity benefits. This and its ability to incorporate several layers of ecological elements (e.g. species, habitats, and/or biological values) and pressures makes it seem to be the most suited tool for ecosystem based management and MARMONI purposes. However, Marxan with Zones are somewhat limited in its possibilities to incorporate interactions between areas that are spatially separated by each other (Leathwick et al., 2006b), therefore inhibiting consideration to corridors for dispersal of species. This could perhaps, if technically possible, be addressed by a combination of Marxan with Zones and Zonation, which is designed to consider connectivity.

Finally, NatureServe Vista is confirmed compatible with both ArcGIS and Marxan, meaning it has the possibility to prepare input for Marxan and then transport the results back into NatureServe Vista. This quality gives it the powerfulness of Marxan and user-interativeness of NatureServe Vista. NatureServe Vista also has the ability to evaluate land use scenarios against conservation, which suits with the requirements for the tool to be used in MARMONI.

After all, the most well adapted tool for the objectives of MARMONI seems to be Marxan with Zones, possibly in combination with NatureServe Vista or Zonation followed by the Cumulative Impacts Assessment Tool.

## 3.3 Conclusions

- The most well adapted tool for the objectives of MARMONI seems to be Marxan with Zones due to its capability to incorporate several types of zones allowing different activities, contributing to different management targets, having different costs or benefits in different locations with different biodiversity benefits.
- NatureServe Vista and Zonation does not independently fully meet the objectives of MARMONI in regards to management of uses, but could be useful in a combination with Marxan with Zones.
- Cumulative Impacts Assessment Tool is ranked as individually second best suited for the objectives of MARMONI because of its ability to assess the impacts of different activities to ecosystems and compatible and incompatible uses based on vulnerability. However, the fact that it assumes all impacts to be negative and additive accumulative makes it seem less applicable then Marxan with Zones.
- MarineMap is targeted against viewing, changing and evaluation MPAs and is probably either too simplified to fit the purposes of MARMONI (if used in its original state) or to demanding in regards to requirements Python programming skills. Further, it works as a web-based tool, not having the analysing advantages of GIS-software.
- Atlantis offer good possibilities to incorporate each step in the management cycle into the MSP and considers biophysical, economic and social components of the ecosystem. However it's heavy adaption to fisheries management still push it below Marxan with Zones and Cumulative Impacts Assessment tool in the prioritizing for the purposes of MARMONI.
- InVEST assess the impacts on ecosystem services caused by different scenarios which could be set to fulfil the goals of MARMONI, but tends to be too complicated in regards to analysis of the sensitivity for disturbance.

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