GIS tools for marine planning and management

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Authors Martin Snickars & Timo Pitkänen, Metsähallitus Natural Heritage Services, Finland With contributions from (in alphabetical order) Bergström, Lena, The National Board of Fisheries, Sweden Bergström, Ulf, The National Board of Fisheries, Sweden Boström, Minna, Metsähallitus Natural Heritage Services, Finland Ekebom, Jan, Metsähallitus Natural Heritage Services, Finland Feucht, Christiane, WWF Germany Herkül, Kristjan, Estonian Marine Institute, Estonia Kindström, Merit, County Admin Board of Stockholm Sweden Kotta, Jonne, Estonian Marine Institute, Estonia Lamp, Jochen, WWF Germany Lindblad, Cecilia, Swedish Environmental Protection Agency, Sweden Martin, Georg, Estonian Marine Institute, Estonia Mattisson, Anneli, County Admin Board of Stockholm Sweden Orav-Kotta, Helen, Estonian Marine Institute, Estonia Reker, Johnny, Danish Nature and Forest Agency, Denmark Sandström, Alfred, The National Board of Fisheries, Sweden Simm, Mart, Estonian Marine Institute, Estonia Sundblad, Göran, The National Board of Fisheries, Sweden Sørensen, Thomas, Danish Institute for Fisheries Research, Denmark Vestergaard, Ole, Danish Institute for Fisheries Research, Denmark	Date November 2007			
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0 PREFACE

The report covers aspects of marine nature conservation, the biophysical and socio-economical interests of the sea, the management through marine spatial planning and the assessment of management performance. The tools presented here are examples of the approaches and principles how these topics can be handled using GIS.

Twelve biophysical tools are described in detail as 'recipes', including how to delineate important habitats and species parameters. Socio-economical factors are presented in seven pressure tools, and two state tools, including potential pressures such as navigational activities, fishing and coastal development. One of the tools can be described as also having properties of a driving factor. The socio-economic state is exemplified for recreational values.

The same tools may be used as indicators for the assessment of management performance using biophysical, socio-economical and governance factors. The basic approach is that the analysis is conducted over time to reveal the temporal change of the feature or the differences among areas is analysed using a spatial approach.

The tools should be seen as a first generation of descriptions how to apply spatial information. All measures such as distance are based in literature references or judgements and not validated.

Knowledge of the link between various pressures and features is important, and the relationship between some of the tools is elaborated and a short section explains the central operations in the tools.

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Martin Snickars & Timo Pitkänen,

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Metsähallitus Natural Heritage Services, Finland

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1   *INTRODUCTION*

Marine Spatial Planning (MSP) aims at minimising the conflicts among different sea uses as well as their negative effects by allocating space and applying zoning for different uses. Geographic Information System (GIS) can be applied in several ways in the process.

Firstly, GIS tools can be used for delineation of features. The state of features (biogeophysical, socio-economical and governance) in a marine area is essential knowledge in an informative MSP process, and GIS can be an efficient tool for identifying, locating and visualizing the cover and spatial distribution of resources and uses in the form of maps.

Secondly, GIS tools can be used as indicators for the assessment of management performance. All management needs to be assessed concerning their efficiency and effects, both during the planning process and the implementation phase, thus covering the whole MSP cycle. GIS tools can be used as indicators of the effects management have on given biophysical, socio-economical and governance factors, whereof the latter are the main indicators for the planning process. Basically, the tools are used as indicators of the state compared in different areas or the change of state over time.

Thirdly, GIS tools can combine several types of spatial data. The process of the Pressure Evaluation Matrix (PEM), described in a parallel report, relates all uses and their effects in a marine area to the sensitivity of the habitats and species of that area. GIS can be combined with the PEM to visualise the relationship, *i.e.* by overlaying the spatial distribution of pressure factors and sensitive habitats. Hence, the applications of GIS in marine management are tightly interconnected and can be used synergistically.

Identification of marine features, uses and activities
Biological, geological and physical information and the mapping of the ecosystem is the first step of MSP and the base for the whole planning. An ecosystem-based approach to resource management suggests that the ecosystem health must not be compromised, and implies that all activities *e.g.* in coastal and marine areas should always consider what effects the use induces on the ecosystem. According to Belfiore et al. (2006), the biophysical components can be divided in three categories.

- The organisation of an ecosystem is the fundamental ecological structure, *i.e.* species diversity and composition as well as the spatial distribution of species assemblages.

- The vigour or level of function of an ecosystem is *e.g.* predator-prey interactions, the trophic structure expressed as food-web properties and productivity.

- Water and habitat quality are the physical and chemical properties of an ecosystem.

The goals and objectives for a sustainable use of the ecosystem can be identified first after the ecosystem components of an area are known, *i.e.* identified and mapped to a sufficient level. Real data and proxies should cover elements from the three ecosystem categories (Belfiore 2006). Habitats maintain and support a variety of biological communities and species. Some communities can be found in several habitats and others are more habitat-specific. Measures of species, which can be helpful in defining communities, include richness and diversity. Examples of habitats to consider in spatial planning in the Baltic Sea are; important habitats for focal species, Habitats Directive Annex I habitats, EUNIS habitats, important recruitment habitats and other key habitats, regionally rare habitats, vulnerable habitats and target habitats. The identification and location of these habitats and species is crucial for a successive management, both legally and ecologically.

The availability of real data concerning the distribution of species and habitats is often scarce and problem may arise when trying to choose appropriate management targets without having spatially extensive biophysical data from field inventories to meet the targets with (*e.g.* Ardron 2002). Management decisions have to be made regardless of whether or not comprehensive data are available to support the decision making process (Stanbury & Starr 1999).In such situations, proxies, such as suitable environmental conditions, for any given feature may be needed in order to make it possible to make management decisions based on spatial data. Fortunately, it is possible, to a certain extent, to predict the biodiversity based on environmental conditions. A powerful tool for the purpose is GIS technology that enables analyzing and combining of data sets to produce estimates of *e.g.* benthic biodiversity (Ardron 2002; Burne & Parvey 2002).

Similarly, the socio-economical uses need to be identified in any given area. Whereas most of human activities occur on land, it is necessary to include activities both on land and water in the coastal and marine management. Management of coastal and marine areas should be assessed against any objective of the zone category and consider all relevant socio-economic uses and activities inside as well as outside the zone. Central considerations of the Water Framework Directive and the proposal for EU-Marine Strategy Directive are that an efficient management must identify anthropogenic pressures on the environment and assess their potential effects. Hence, biophysical features and socio-economic use of coastal and marine areas are closely interconnected.

The concepts of both sustainable use and an ecosystem approach to resource management recognise the relationship in declaring that a healthy ecosystem and a sustainable socio-economy in many ways are interdependent. For example, a marine resource such as a productive fish stock, which supports many sea uses, is a crucial part of healthy ecosystem. The ecosystem stays healthy as long as the uses, such as fishing, are conducted on a sustainable level. The PEM can be applied in evaluating the linkage between sea uses and conservation aspects. Such information is important for the safeguarding of the sustainable use of marine areas, and may form a basis for management decisions.

Whereas most of human activities occur on or originates from land, it is necessary to include activities both on land and water in the coastal and marine management. The dominant socio-economic drivers and potential pressure differ dependent on the area of the MSP. In coastal, near shore areas the main socio-economic factors are tourism, fish-

eries, transportation, shoreline exploitation and data related to land borne input, such as nutrients and toxic substances). Nutrient load, shipping and especially the commercial fishing are main socio-economic data in offshore areas. Here also the data on exploitation by dredging and dumping activities, wind park plans, and military use can play important roles (Table 1).

Table 1   Example of socio-economic data that may be relevant for MSP

Data	What may it be used for?/Maps
Protected areas	Reserves, Natura 2000 sites, BSPA
Areas with restricted use	Fishery restrictions Safety zones.
Military areas	Closed areas for exercises
Cultural/Natural heritage sites	
Shipping lanes and boating routes	Important areas for navigational activities, areas with potential disturbance by traffic
AIS / VMS data with area/temporal distribution	identify ship traffic and rarely frequented zones; identifying areas with potential disturbance by traffic
Harbours, marinas, piers and jetties	Identifying the positions for shoreline use
Shoreline buildings, including detailed attribute data	Identifying exploitation and the positions for shoreline use
Categorised data on local enterprises (companies) including attribute data	Socio-economical value of marine areas
Demographic data Population density	By analysing geo-referenced population abundance & structure data can several pressure indicators be defined, related to urban & settlement sprawl
Abundance of leisure boats, snow mobiles	Identifying areas with potential disturbance by traffic
Tourism density	Disturbance and value of marine areas
Fishing areas incl. real trawl lines where possible	Areas important for commercial fishing
Areas for standing fishing gear	Areas important for commercial fishing
Fishing activities	Fishing grounds, amount of catch in a certain area
Mariculture (fishfarms, mussel-cultivation)	Socio-economical value of marine areas. Local pollution. Space demand
Harvesting activities	Socio-economical value of marine areas Habitat disturbance, socio-economical value
Sand & gravel extraction	Habitat disturbance, socio-economical value
Oil & gas extraction	Space demand, safety area, socio-economical value
Cables and pipelines Dredging, dumping, drilling/exploration activities	Identify threats and status quo, space demand
Wind farm sites existing and proposed	Space demand, safety area, socio-economical value
Research and reference sites	Important areas for science, reference base-line

1.1 *Indicators in the Assessment of Management Performance*

The need of management would not exist if only unaltered natural conditions existed and there would not be any pressure on the ecosystem at any scale. Management *per se* seldom is effective and therefore needs to work against goals and measurable targets in order to perform well. Marine and coastal areas are under pressure from multiple human activities, which imply that the assessment of management performance needs several types of indicators that are able to measure this broad range of factors. The tools described here can be used as indicators quantifying the maintenance and change of ecosystem components over space and / or time against the distribution of relevant pressure factors. The indicators that measure specific objectives should result in improved management and understanding of the environment, whereas *e.g.* temporal change (to the worse) such as the likelihood of a community to persist over time in an area would imply an inefficient management.

Indicators of ecosystem components are commonly named biological, biophysical, ecological, ecosystem and environmental indicators. In this report we use the name Biophysical indicators. Indicators are any measured component that provides straightforward information of a more complex system. The main criteria of indicators are that they should communicate with an audience by simplifying and quantifying the state and change of component. The purpose of an indicator should be widely accepted so that also the complex underlying structure and function of a system is communicated and easily understood. The information from indicators should help in maintaining and restoring *e.g.* a certain ecosystem.

> An example of the use of a quantifiable indicator measuring the state of vulnerable Coastal lagoons:
>
> Should the analysis indicate that over 40 % of all investigated sites belong to the highest classes on a 1-5 scale of vulnerability (1 indicating a natural condition with no impact from human influence, there may be a demand for management actions to guarantee a favourable condition.

Indicators can be conceptualised in the DPSIR framework (EEA 1999, Elliot 2002) as a chain of driver, pressure, state, impact and response factors. Drivers are the underlying large-scale cause of the chain, which can be of natural or anthropogenic origin. The drivers result in pressure factors, which have impact the environment, via change of state. The response to these circumstances can be assessed. Coastal development is an example of a driver factor in coastal and marine areas, expressed as multiple pressure factors and an increased demand on space which may result in unspecific habitat deterioration. The postglacial land uplift in the northern Baltic Sea is a major process that

can be viewed as a natural driving force that continuously changes the environmental conditions, especially in shallow coastal areas, which put ongoing (natural) pressure on organisms in the slow succession process where sea becomes land. The occurring gradient of salinity in the Baltic Sea is another example that put pressure on both marine and limnic organisms in the brackish water. A challenge to any management is to separate the naturally occurring variation in *e.g.* species abundance and habitat coverage as a response to fluctuating environmental conditions from the change in state resulting from pressure factors driven by man.

It is important to recognise that the assessment of management performance should provide information on the effects on both resources as well as uses, *i.e.* biophysical and socio-economical features. Indicators of socio-economical uses and activities in an area can be viewed from different angles, depending on the management objective. Socio-economy is either driver-pressure factors on the environment or a direct socio-economic indicator of the state of society, community and stakeholders. From nature conservation point of view with an objective to maintain ecosystem health, socio-economy is a driver and a pressure factor, which influence the state of the environment. The management effects on the socio-economic uses' state vary depending on the stringency of a zone. A zone with a stringent management, which prohibits and limits several or all uses for nature conservation purposes, would result in high management effects and feed back more pressure and change on a given use state than a general use zone with few or no limitations. Consequently, a significant use which induces high pressure on sensitive biophysical features will be more affected by management effects than an activity, which induces low or no pressure on the environment. The assessment of management performance needs several types of indicators and a range of measures (Table 2).

Table 2 Examples of measures, which can be used in the assessment of management performance

Measure	Example
Amount	Number of habitats, species, individuals or complaints over a decision
Area, size	Coverage of habitat or uses in an area, species distribution
Depth	Depth distribution of macro-algae, photic layer
Distance, location	Distance, location of a sensitive feature to MPA, from source of pressure
Duration	Period of time when a feature is most sensitive, *e.g.* reproduction, spawning period
Frequency	Frequency of vessels per unit time in an area
Length	Length of developed coastline, of erosion sensitive shoreline in an area
Magnitude	How much of a given pressure
Overlap	Assessing the vulnerability of a sensitive feature, proportion of a target features that are inside a specific zone (protection status)
Volume	Volume of water suitable for cod spawning

By analysing the change of the state (compared with a baseline) of a factor over time, the assessment enables a follow up of the effects of management actions against the goals and objectives. Similarly, the management effects can be assessed spatially by comparing the state of factors in different areas or zones (reference areas).

Knowledge of vulnerability is central for the assessment of management performance. By combining spatial information of two factors, the degree of overlap can be analysed. Overlaying spatial information of *e.g.* a biophysical feature (targeted sensitive habitat or species) and a socio-economic use causing pressure on the feature indicates the vulnerability of the feature. The vulnerability can be assessed by combining all feature state-pressure pairs, given that the spatial distribution is available. A pair can 'change side' meaning that a socio-economic pressure then is viewed as a state factor, for example in assessing the management performance expressed as pressure effects on fisheries vulnerability.

Measurements of the state of any component of the ecosystem against a pressure factor include the size of the impact in terms of spatial extent (compared with agreed reference conditions and / or areas, such as core areas, no-take zones) or over time as a temporal change of a component in an area. Alternatively, can the pressure factor be measured directly and used as a proxy of the potential risk of a likely state change in a targeted ecosystem component. Measuring direct pressures may be a more efficient way to safeguard ecosystem health given the variability of nature (Rogers & Greenaway 2005).

Pomeroy et al. (2004) provide four central elements to consider when conducting assessment of management performance. Selecting appropriate indicators that match the goals and objectives set in the plan is crucial. Our intention is to adapt the existing guidelines for indicators described in Pomeroy *et al*. (2004) to the prevailing conditions of the Baltic Sea, focusing on the Pilot Areas of the project (Lindeberg *et al.* 2006). The main target groups that can use this type of indicators in their work are regional and local officials and organizations that use indicators to help report on progress towards sustainable development.

Central criteria and steps for selecting indicators and implementing assessment of management performance according to Pomeroy et al. (2004) are:

- Select indicators that are flexible to the conditions in the area, match the goals and targets of the plan. The relationship between indicators need to be known and they should cover the essential parts of the process, and features (*e.g.* by DPSIR).

- Plan the evaluation in a written report to assure that the plan can be followed. The plan should include calculated costs and a budget for resources, time and costs for the area that the plan is made for. It should be clearly stated who is responsible and conduct the evaluation and to who get access to the result.

- Conduct the plan. How is the practical part of the plan achieved, especially concerning the collection, management and analysing of data and the quality check? It must be assured that this step is conducted so that the result can be used for the adaptive plan. How is the result communicated on the right audience reached?

2   RECIPES – HOW TO USE THE GIS TOOLS

The report comprises of descriptions on how to use GIS tools, hereafter denoted as recipes, for delineation of marine and coastal biophysical properties and for identifying specific ecosystem component such as target species and habitats. The socio-economical aspects are viewed both as state as well as pressure factors of a marine area.

The recipes cover main principles and steps on how to use the tools. The purpose of the recipes is to provide a tutorial for a successive and easy use of the tool. The tools should be viewed as the first generation, which need testing and further development if adapted to specific purposes. The recipes are based on existing literature, and when new tools are developed, more extensive step-by-step recipes are provided with examples of the principal approaches and the data used. The recipes described here are, when exemplified, influenced by the prevailing conditions of the northern Baltic Sea. The readers and users are encouraged to scrutinise the tools.

The main objective is to describe a methodology and work phases that may be widely applicable using other data sets. The tools are flexible in that they are open for change, and the data used are exchangeable. Many of the parameters (data sets) can be analysed separately or used in various combination of parameters. Thus, the users may develop and modify the idea of the tools after their own taste, according to prevailing conditions.

The used measurement units, *e.g.* distance, depth, density, are not validated during the development of the tools and they are set according to existing literature references or based on expert judgement. The values are flexible and may need re-evaluation according to the occurring conditions of another study area.

The tools are developed using ArcView 3.3 and/or ArcGIS 9.x with freely available extensions and scripts. The majority of tools can be conducted in newer ArcGIS basic versions, but Spatial Analyst may be required.

If not otherwise noted, the computer equipment requirements needed to perform the analysis is a geographical information system (GIS) that can handle and analyze data in raster and vector formats is needed.

A central consideration in the development of the tools has been to base the examples on already existing, widely available and accessible data, which cover a considerable area (*e.g.* nautical charts, digitised features from remote sensing, shoreline).

Alternative uses and different combinations of the developed tools are possible given that the majority of spatial information can be applied for multiple purposes:

- directly, as delineating features in a map for zoning (*e.g.* habitat extracting tools),

- as indicator of the change of state in assessment of management performance, and

- expressing both the state as well as the pressure of a factor in the DPSIR framework.

2.1 Biophysical – Species

2.1.1 Focal species abundance

The abundance of a species is maybe the most common measure related to nature conservation. Species abundance is an estimate of the size (most often as number of individuals) of the population in a certain area. Focal species, which are important for various reasons can be endemic, exotic, flagship, indicator, keystone, habitat forming, target or vulnerable species (Noss 1990). The mapping of invasive species may be of interest.

All these groups are important in spatial planning of marine areas as they are ecologically important and because their existence is supported by the general public, and conservation initiatives based on protecting focal species may be widely accepted among the public. Other parameters related to the abundance are coverage, biomass and density. Coverage is often used to measure plants and sessile benthic organisms. Density is a measure that estimates the number of individuals in a given area or volume.

The various methods used for collecting this parameter are normally relative uncomplicated and can be done in the field by walking, wading, using boats or with remote sensing from the air using aircrafts. The sampling or counting techniques may vary greatly depending on the species of interest and area to be covered, and must be evaluated on a case-by-case basis.

A limited spatial coverage of data might prevent the use of this tool. Distribution of known important habitats for the focal species might then be an alternative (see 2.2.1). A detailed description of the rationale, consideration and suggestion on methods and presentation is given by Pomeroy *et al.* (2004).

Data requirements

Existing data can be compiled from species inventories, monitoring time-series and data-bases, which have information on abundance, density or coverage of species or the biomass. Observe restrictions to pooling data sets from various sources, which may affect the outcome and accuracy. A list of occurring focal species in the area, if available, is a good starting point. Potential attributes that can be considered for the samples include:

- Position of observation (Latitude, Longitude in a defined coordinate system)

- Date and time of observation

- Number, coverage, density of individuals or biomass of the focal species at the position

- Name of the observer

Step-by-step process

1 Create the observation points

For each observation point, define a column for each of the attributes. Define longitude and latitude columns in your dataset in a GIS, which can be done either using existing information or by manually pointing out site descriptions on the map Since errors might occur, especially if positions are written by hand in field, check the positions by putting the observation points on a map. Writing errors are usually very easily visualized by doing this.

2 Make a map

Abundance data can be visualized on a map in many ways. Different numbers of observations can be visualized by *e.g.* differently sized circles, bars, different colours, points with numbers as label and so on. Remember that points with absent data (no individuals detected at position) are as important as points with present data. Classification of abundance data per area might be useful for visualization. A classification with five categories can be motivated referring to the corresponding classification in the Water Framework Directive:

- Class 1: no individuals of species X

- Class 2: few individuals of species X

- Class 3: moderate abundance of species X

- Class 4: high abundance of species X

- Class 5: very high abundance of species X

The class limits must be based on the natural abundance range of the specific species and the prevailing conditions in the area, including any other area that one wishes to make comparisons with.

Abundance data can be interpolated to create continuous surfaces. Note that interpolation should be done carefully. The accuracy of the result is highly dependent on the quality of the source data. In heterogeneous environments, such as archipelagos, or other areas with variable bottom topography, interpolations should be avoided over scales that include these heterogeneities. In these cases models based on statistical predictions is a better option (see Analysis of characteristics for selection of fish nursery areas above).

Abundance data can be presented as a raster by giving abundance values to grid cells. The accuracy of the result is depending of source data.

Indicator use in the Assessment of Management Performance

This parameter is useful and widely understood indicator of ecosystem health. The state of abundance, coverage, biomass or density of a focal species or a group of species is a widely used indicator for describing ecosystem health in an area (Pomeroy *et al.* 2004).

The change in abundance is a significant indicator of the state of a species in an area. Different focal species may have different objectives to be assessed. Species with naturally low abundance and rare species may need additional indicators in order to monitor the status, *e.g.* the distribution of such species may provide additional information.

Spatially, the difference in species abundance, coverage, biomass and diversity can be compared inside and outside an area or a zone and among different zones. Zones with various rigid restrictions for *e.g.* fishing may contain different amounts of targeted species. No-take zones and other agreed areas can be used as reference areas to be assessed against. A no-take zone should improve the abundance of a species. Traditionally, comparisons are illustrated in graphs, but by using the classes suggested in step 2., comparisons can be visualised on a map. The abundance can be compared with the coverage of relevant pressure factors to reveal the spatial vulnerability of the species.

Over time, the change in abundance within an area can be monitored and superimposed with the classes suggested in step 2. The change in abundance of an indicator species for *e.g.* eutrophication may imply a change in water quality over time in an area. Once observed, the trend in abundance of invasive species must be followed up, and by comparing with trends of other species any interactions, such as competition and predation, may be indicated. The abundance can be compared with the coverage of relevant pressure factors to reveal the vulnerability over time.

NB. A general consideration applying in all zones is that the overarching goal of the ecosystem approach to resource management, to sustain ecosystem components, must not be compromised. In the management assessment process (Hockings et al. 2000) this implies that each zone may need re-zoning if the ecosystem health is seen compromised over time.

2.1.2 Seabird abundance

Seabirds are an essential part of marine environment and recognised in the main nature conservation directives of the European Commission. Conservational issues as well as, at a more general level, the construction on marine zoning plans may require to be able to get up-to-date overview of the distribution and status of seabirds. The identification of important seabird areas may be performed using various methods; the instructions given below are mainly based on Garthe (2006).

Seabirds distributions are mainly studied using transect counts from ships and/or aircrafts; a comprehensive summary of methods to be used in the field surveys is provided by Camphuysen *et al.* (2004). Ship-based surveys are quite accurate, enable collecting additional information on the behaviour of the birds, and usually allow for sampling environmental data such as hydrography, which proves very useful for understanding spe-

cies distribution patterns (Garthe 2006). Details and recommendations for appropriate methods on ship-based observations is given by Tasker *et al.* (1984), but there are some problematic issues especially relating to the detection of flying birds (Gaston *et al.* 1987). Aerial surveys are able to cover large areas in short time at lower total cost compared to ship-based surveys; however, they are only feasible at low-wind situations and there may be some restrictions on species identification (Garthe 2006). A more detailed description of recommended methodology is provided by Diedrichs *et al.* (2002).

Data requirements

When performing the identification of seabird concentrations, it is evident that the field work phase takes considerably more resources than later processing of the data. After collecting the necessary data, the analysis performed using the GIS will be quite rapid and straightforward.

Step-by-step process

1 Perform the field data collection

According to Garthe (2006), the best and the most accurate way to collect field data is either to count seabirds from ships using a transect width of 300 m and counting interval of 1–2 min, or, from an aircraft flying at an altitude of 250 ft (78 m) and a speed of 100 knots (185 km/h), with a variable transect band of 100–400 m depending on viewing conditions. Be sure that coordinate information for all observations is as accurate as possible (use a GPS receiver). Along with Garthe (2006), see Camphuysen *et al.* (2004), Diedrichs *et al.* (2002) and Tasker (1984) for more details.

2 Pre-process the data sets
After collecting the field data, separate the bird species (or groups defined on some other way relevant to the study) to unique data sets.

3 Make species distribution maps
The "species distribution maps" as referred here are based on densities, that is, the number of individuals per unit area. Because some species may be distributed over large areas while others are heavily concentrated and reliably predictable, two different approaches are suggested to be utilised.

- For widely distributed species, distributions may be visualised easily by using a grid map. For each grid cell, the overall density can be calculated obtaining the sum of all birds recorded in transects, and dividing it by the total area mapped. This way, the data will be corrected for effort.

- For spatially aggregated species, a spatial interpolation method based on *ordinary kriging* (or some other interpolation method) is the best alternative. With this procedure, distributional data is interpolated and smoothed between survey lines on the basis of the species-specific spatial abundance structure.

4 Determine the borders for seabird concentrations

Boundaries of concentrations may be determined by investigating the gradient of density change over space. In order to do that, the modelled distributional data should be projected to a two-dimensional map, and the isoline of bird density (the line drawn through the same level of bird density) locates just outside the strongest gradient in spatial density that is chosen as a border of a concentration; in this way, the major part of the concentration is included in the selected area. The density value of the borderline should then be noted and used as the species- and season-specific minimum density defining a seabird concentration. This value may be then taken for plotting the contour line showing the spatial extent of the respective concentration.

Indicator use in the Assessment of Management Performance
Spatially, patchiness and aggregation patterns of sea bird species can be assessed in different zones to compare *e.g.* habitat quality in terms of importance and function among zones. Occurrence of a threatened species may indicate a direct need for protection. The presence / absence pattern and frequency of occurrence in zones can be visualised and compared as a measure of management performance. The distribution can be compared with the distribution of relevant pressure factors by an overlay operation of the two layers to reveal the vulnerability on a spatial level.

Over time, the presence / absence patterns can be observed to indicate change in the species distribution and occurrence. Similarly, a distribution line can be assessed manually or by an interpolation process and compared over time. Changes in patchiness and aggregation patterns may indicate a change in habitat quality. The distribution can be compared with the coverage of relevant pressure factors to reveal the vulnerability.

2.1.3   *Focal species distribution*
The distribution of species is important to consider in marine area planning since it visualises the species diversity in a direct spatial dimension. The distribution of focal and rare species may directly influence the nature conservation value of an area. In a marine environment, distribution may include both a horizontal and a vertical dimension. Patchiness and aggregation of species are ecologically important aspects of distribution, and may indicate important areas in terms of habitat quality, structure and function (*e.g.* spawning and feeding habitats).

When building a species distribution dataset it is important to include both presence and absence data whenever available as absence of a species does not necessarily mean that it is actually missing from an area. Only with enough and equal research efforts, the real situation can be reflected. Thus, absence data must be handled with caution.

Data requirements
The spatial information needed for this tool can be extrapolated using the same approach as in the tool previous 'Focal species abundance'. The spatial scale of the information should preferable exceed the scale of the area of interest. Nonetheless, the pat-

terns of important species aggregation and patchiness ideally should be identified in the information. The data need to be spatially referenced (geo-referenced) to be useful.

Step-by-Step process

1   Create a layer with observation points

This step is identical to the corresponding step in the tool 'Focal species abundance' with presence / absence data as the parameter.

2   Make a map

Distribution data can be visualized on a map as point data. Remember that points with absent data (no individuals detected at position) are as important information as points with present data. If both present and absent data is available, it is useful to include both on the map with different symbols.

Distribution of focal species can be presented with lines for distribution limits. Distribution data can be presented as a raster by giving presence or absence values to grid cells. It is important to notice that the accuracy of the result is depending on the quality of the source data.

Various species aggregation and patchiness patterns can be highlighted using *e.g.* symbols, colours and number.

Indicator use in the Assessment of Management Performance
The parameter is a useful indicator for showing the spatial distribution of species.

Spatially, patchiness and aggregation patterns can be assessed in different zones to compare *e.g.* habitat quality, function and structure among zones. Occurrence of a threatened species indicates a direct need for protection. The presence / absence pattern and frequency of occurrence in zones can be visualised and compared as a measure of management performance. The distribution can be compared with the distribution of relevant pressure factors by an overlay operation of the two layers to reveal the vulnerability on a spatial level.

Over time, the presence / absence pattern can be observed to indicate change in the species distribution and occurrence. Similarly, a distribution line can be assessed manually or by an interpolation process and compared over time. Changes in patchiness and aggregation patterns may indicate a change in habitat quality. The distribution can be compared with the coverage of relevant pressure factors to reveal the vulnerability over time.

2.1.4   *Population structure*
Population structure is defined as the proportion of different ages and sizes of a species occurring within a certain area as well as the female:male ratio. A stable structure is es-

sential for population persistence, and a healthy population comprises of all sizes and ages where recruitment to the population is equal or larger than the loss through mortality and migration. This parameter can be used as a proxy for ecosystem vigour. Population structure has implication for the function of the ecosystem, *e.g.* predator-prey interactions, particularly since larger individuals often are important predators on smaller individuals as well as other species. Severe divergence from a normal female:male ratio or imposex, *i.e.* sex organ abnormalities, may indicate a serious species health conflict. It is important to notice that accurate estimates on population structure may be achieved only after long enough time-series.

In order to capture all sizes of a species, several methods and approaches may be needed. Different life-stages of the same species may use different habitats. A first and easily understood measure of population structure is the mean size.

Harvested species may often show a skewed population structure towards smaller individuals if larger individuals of a population suffer from mortality due to *e.g.* targeted fishing. Population structure, defined as proportion of large fish in survey catches, is recognised in fisheries management as a potential indicator for targeted fishes (Anon 2002b; ICES 2006). The ecological rationale of this measure is that large reproducing individuals must be kept on a certain level in order to sustain a population. A detailed description of the rationale, consideration and suggestion on methods and presentation is given by Pomeroy et al. (2004). The use of population structure as a tool requires knowledge and analytical skills to be interpreted.

Data requirements
The data requirements are essentially the same as in the tool 'Focal species abundance' (see above). The data need additional information on one or more of the following parameters: gender, length, weight and age. If the relationship among these parameters is known *e.g.* length:weight and length:age regressions, lacking information can be extrapolated.

Step-by-Step process
1 Create a layer

   The process is essentially the same as in the tool 'Focal species abundance' with information of age, gender, length, weight as additional parameters of interest.

2 Make a map

   Population structure can be presented in many ways depending on the data source and objectives. As population structure is a fairly complex component, the result may not easily be presented directly on a map. Pomeroy *et al*. (2004) discuss several questions that can be addressed.

   • Length, weight and age can be visualised in intervals with *e.g.* five categories where the first (1) category indicates very few intervals present in the population, *i.e.* the population structure is very homogenous comprising of individuals

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of same length, weight and age, and the fifth (5) category indicating a very heterogeneous, more viable structure. The actual intervals must be adjusted according to the species concerned.

- The dominance of different age, size and weight classes can be visualised with different symbols or colours with preferable five classes ranging from no to very high dominance of a certain class.

- Proportion of large individuals of commercially fished fishes (Anon 2002b; ICES 2006) *e.g.* individuals above a certain threshold length or weight may be visualised by number in different areas of appropriate scale.

- The female:male ratio may be indicated by number or the dominance can be indicated with symbols and colours.

- The proportion of adult *i.e.* individuals capable of reproducing can be visualised with numbers or colours.

- The ability of a population to regenerate and be viable (Pomeroy 2004) assessed by experts can be expressed on a map with different symbols or colours, preferably in five classes ranging from poor to very good ability to regenerate.

Indicator use in the Assessment of Management Performance
The parameter can be used as an indicator for various purposes. Compared with the two previous parameters, this parameter may need more knowledge of biology and ecology in order to be used as an indicator of management performance.

Spatially, a comparison of length, weight and age of populations can be made between inside and outside a zone using the same five classes. The same comparison can be made among zones. Dominance can help in visualising if the population is skewed towards large or small individuals, and thus highlight homogeneous structures due to *e.g.* unsustainable high mortality from fishing. Hypothetically, a no-take zone should contain species with more heterogeneous structure. Proportion of large fish is used in fisheries management indicating the sustainability of the fishing. Zones with various rigid restrictions for *e.g.* fishing may contain different sizes of targeted species. No-take zones and other agreed areas can be used as reference areas to be assessed against. A no-take zone should improve the size of a species. A five category classification may be used to indicate very low to very high proportion of large individuals in a zone or compared among zones. The sex ratio, proportion adults and regeneration capability are measures applicable for various species and organisms and can be visualised in the same way as the above measures. The structure measures can be compared with the coverage of relevant pressure factors using an overlay operation of the two layers to reveal the vulnerability on a spatial level. The population structure may be a useful parameter to monitor the degree of connectivity between marine areas (Per Nilsson, pers. comm.) assuming that a good connection is reflected in the similarity in the structure among areas.

Over time are the dominance and length-weight-age structure parameters that indicate changes in overall population structure within a zone. A change toward a more homogeneous structure may indicate a deterioration of population health. The proportions of adults and large fish are directly associated to the development of fisheries management over time. Any change over time of sex ratio, regeneration capability and proportion adults should be considered as a sign, which must be addressed in order to sustain populations of concerned species. The structure measures can be compared with the coverage of relevant pressure factors to reveal the change of the vulnerability over time.

2.1.5 Community composition

The community composition is essential for the structure and function of the ecosystem. It is related to the overall diversity of the ecosystem and shows the abundance, coverage, biomass and density relationship among species present in an area, and is commonly described in terms of relative abundance, species richness, dominance, and diversity indexes. Information of presence and absence of a species can be seen as a first level of community composition (see tool for 'Focal species distribution' above).

Areas with high diversity are normally seen as 'hot spot areas' with a high nature conservation value. There is a great variability in community composition in different habitats in the Baltic Sea. Capturing all community components in an area may be laborious, and the surveys of sub-areas may be needed. A detailed description of the rationale, consideration and suggestion on methods and presentation is given by Pomeroy *et al.* (2004). The use of community composition as a tool requires knowledge and analytical skills to be interpreted.

Data requirements
Data requirements are the same in the tool 'Focal species abundance', see above. A list of occurring species, species richness, dominance and diversity indexes may be derived separately for each such survey type. Data sets from different surveys may be pooled only if this is appropriate based on the sampling methods and sample size applied.

Step-by-step process
1   Create a layer

Principle steps are the same as in the tool 'Focal species abundance', see above, the data need to contain information on species richness, dominance and diversity indexes.

2   Make a map

The community composition can be presented in many ways depending on the data source and objectives.

- Patterns in species richness and diversity can be visualised with five categories ranging from low to very high level.

- Species dominance relationships can be pictured on a map *e.g.* by using pictures and symbols resembling dominating species.

- The likelihood of persistence of the a community based on agreed composition parameters can be assessed by an expert panel an showed on a map preferably in five classes ranging from very low to very high likelihood of persistence.

Indicator use in the Assessment of Management Performance
The same general considerations as the previous indicator apply.

Spatially, a comparison of patterns of composition can be made between inside and out-side a zone using the same five classes. The same comparison can be made among zones. Similarly, the likelihood of persistence of any given community can be used in a comparative way. The dominance of species can help in highlighting *e.g.* variously abundant indicator species. The composition measures can be compared with the coverage of relevant pressure factors using an overlay operation of the two layers to reveal the vulnerability on a spatial level.

Over time, changes in species richness, diversity indices and dominance in a zone can be visualised and compared using several maps. Temporal change to the worse such as the likelihood of a community to persist in different zones implies inefficient management. The composition measures can be compared with the coverage of relevant pressure factors to reveal the vulnerability over time.

2.1.6 *Genetic diversity*

Genetic diversity has a fundamental position in the ecosystem organisation (UNEP, 1992), where genes as a component contribute to the overall diversity. A high genetic diversity is an indication of good health and may secure persistence of a species. Highly endangered species with low abundance often show low genetic diversity, which may compromise the long-term persistence of the species. Changes at the gene level are ultimately translated to populations, communities and to the whole ecosystem.

Genetic diversity can be measured as *e.g.* differences in heterozygosity and allelic richness (Li & Leberg, 2002). In a review Costello *et al.* (2004) points out that differences associated to both morphological and physiological phenotypic attributes can be used for approximating within marine species genetic diversity, because polymorphism can be early signs of adaptive radiation (Svanbäck & Eklöv 2002). Considerable few genetic diversity indicators have been developed for monitoring marine biodiversity (Costello *et al.* 2004).

Data requirements
Georeferenced data point set for *e.g.* populations of focal species or other species of interest (see Focal species distribution recipe) with information of differences in poly-

morphism or differentiation in allele frequencies or other genetic information compiled from *e.g.* monitoring programs, literature reviews and databases.

Step-by-Step process
Li and Leberg (2002) give an example how discrete populations can be geo-referenced and how GIS can be used for showing the genetic diversity in a landscape.

By applying the software CONTRIP (Petit *et al*. 1998) that measures populations' contribution to the overall genetic differentiation in alleles, the relative genetic diversity can be indexed and extrapolated to maps.

Indicator use in the Assessment of Management Performance
Spatially, a comparison of genetic diversity can be made between inside and outside a zone using the same five classes as described in the previous tool. The same comparison can be made among zones. Populations may be ranked according to their relative contribution to the genetic diversity as an indicator of the population's vigour. Similarly, the likelihood of persistence of any given community can be used in a comparative way. The genetic diversity measures can be compared with the coverage of relevant pressure factors using an overlay operation of the two layers to reveal the vulnerability. Genetic diversity and the structure may be useful parameters to monitor the degree of connectivity between marine areas (Per Nilsson, pers. comm.) assuming that a good connection is reflected in a low level of diversity and similarity in the structure.

Over time, changes in genetic diversity indices a in a zone is an important indicator of population health and can be visualised and compared *e.g.* by percentage change over time. Temporal change to the worse of the likelihood of a community to persist in different zones implies inefficient management. The genetic diversity measures can be compared with the coverage of relevant pressure factors to reveal the vulnerability over time.

2.2   Biophysical – habitats

2.2.1   Fish nursery areas
Habitats that are defined as nursery area for fish are important features in Marine Spatial Planning as they serve both the functioning of the ecosystem and provide socio-economical benefits in terms of reproduction to the fish stock that is utilised by fishers. Delineation of habitats can be done in several ways. In this example, it is done with predictive modelling, where individual species and life stages are studied separately. The empirical relationship between species abundance and a set of environmental variables at discrete sample sites is estimated statistically, and the achieved explanatory model is used to predict the probable occurrence of the species over the whole target area. As a final step in the process, maps for each species/life stage may be combined in order to produce one map where all identified nursery areas are ranked by priority for the concerned fish assemblage, given that a sustainable fish assemblage need a sufficient amount and coverage of suitable nursery areas.

> Here, the general considerations of the tool are provided. The full description of the analysis of characteristics for selection of fish nursery and recruitment areas of some commercially important coastal fish species is presented in Bergström et al. (2007).

Data requirements
- Georeferenced abundance data of the fish species and life stages to be modelled. Data can be collated from a variety of sources, here from earlier studies and in part from new inventories within the project.

- A set of relevant environmental variable maps. The choice of variables will depend on the specific ecology of the fish species and life stages to be modelled. For example, for freshwater species spawning in shallow coastal waters in early summer, the variables depth, wave exposure, vegetation cover, temperature and turbidity are considered as relevant. A critical point for the analysis is to achieve environmental variable maps with adequate extent (full coverage in the target area), resolution and precision.

- A separate validation data set on the abundance/occurrence of the target species, which is not used in the model building. This data is ideally sampled using the same method as the data used for model building, but datasets sampled using other methods may be used.

Step by step process
The statistical relationship between the focal species / life stage and the environmental variables at the sampled sites is estimated by multivariate regression modelling (Fig. 1), *e.g. Generalised additive models* (GAM) or *Generalised linear models* (GLM). Artificial neural networks have proven to be efficient in constructing explanation models.

The acquired model is used to make spatial predictions of the distribution of the focal species in new areas, based on the values of the concerned environmental variables in all points of the target area. For GAMs, this can be done using the software GRASP (*Generalized Regression Analysis and Spatial Prediction*) that is implemented as an interface and a collection of functions in the statistical software packages *S-plus* and *R*, and is compatible with the GIS-software *ArcView 3.x*.

The output is validated by estimating the precision of the model in relation to actual observations of focal species abundance/occurrence using a separate validation dataset.
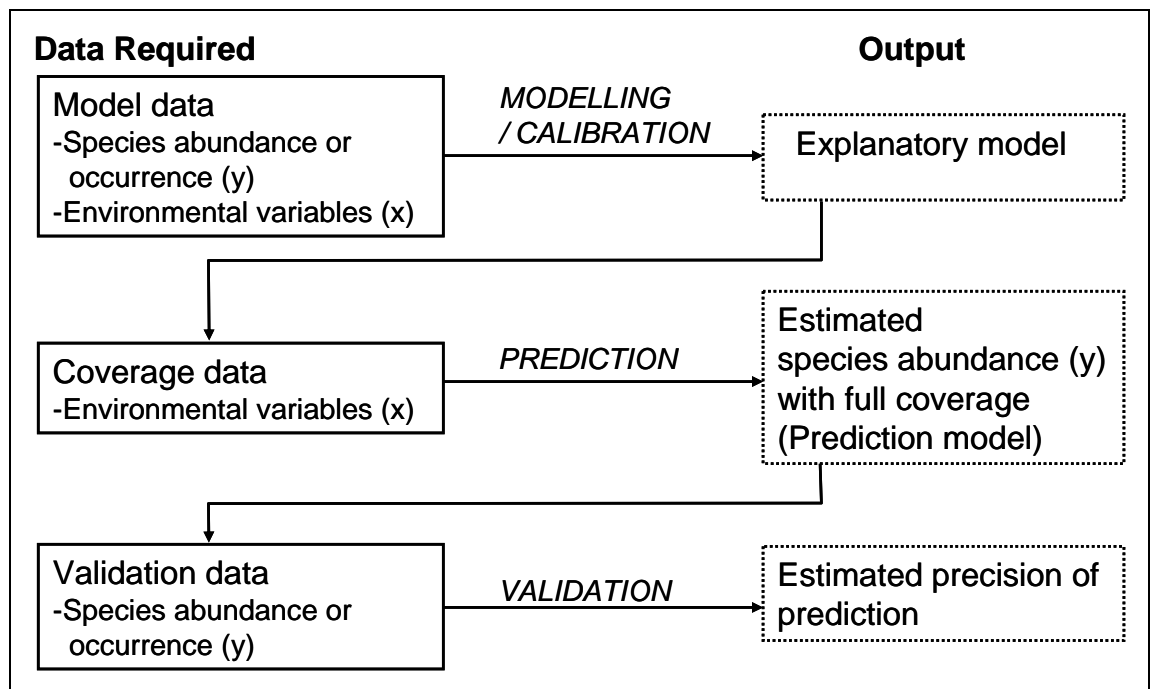

Fig 1   Steps of the modelling concept of Analysis of characteristics for selection of fish nursery areas.

Indicator use in the Assessment of Management Performance
This tool is a useful indicator for showing the spatial distribution of a feature. As this tool produces the potential nursery areas based on specified environmental conditions, the change in a habitat status cannot be assessed given that the conditions stay unaltered over time, *i.e.* if the input data used in the model is not updated or changed (compare with the monitoring of *e.g.* species abundance).

The tool can be applied as an indicator for other purposes. A first step in the assessment of management performance could be to validate the quality and suitability of the potential habitats trough model validation, remote sensing or field surveys in small represen-

tative areas. This is a normal part of the model process, but in addition it may serve as an indicator of the management performance in terms of how well the 'right' habitats are delineated. Additionally, areas with low abundance of nursery areas for a specific species may need stricter management by zoning to secure recruitment to the adult population of the species.

This step needs to be conducted prior to the implementation of the zoning scheme in order to be efficient. In this respect, the indicator may be used as a Governance indicator of the MSP process.

Once the potential habitats are located, the vulnerability can be assessed by combining and overlaying the distribution of the nursery habitats with the spatial distribution of potential pressure factors, *e.g.* distribution of recreational boats and fishers in the area (see tool 2.4.4). Over time, the vulnerability may be assessed again if the development of pressure factors changes in the area or the distribution of nursery areas is reassessed. Spatially, comparisons among zones may reveal if the zoning is adequate or not, as well as the assessment over time within and among zones.

2.2.2   *Suitable environmental conditions (habitats) for species*
Important habitat (or suitable environmental conditions for species) and potential species occurrence are measures that can be used if sufficient field data is lacking on abundance and distribution for a certain species (compare with Tools 2.1.1 and 2.1.2 above, which uses real species data). The habitat preference for a specific species varies depending on life-cycle and season, which must be taken to account in the process.

Habitats and the probability of species occurrence can be predicted by different methods. Many methods require both presence and absence data of species occurrence (Guisan & Zimmermann 2000). Ecological-niche factor analysis, generalised linear models (GLM) with simulated pseudo-absence data (Engler *et al*. 2004; Santos *et al*. 2006) and presence-only methods (Zaniewski *et al.* 2002) can be used when absence data is lacking (Engler *et al*. 2004; Santos et al. 2006). Lack of absence field data is a problem especially when predicting distribution of endangered or rare species.

Data requirements
- Data on environmental factors that limit the distribution of the focal species (*e.g.* environmental and/or human-related)

- Georeferenced presence data of focal species.

- An ecological-niche factor analysis based on environmental and presence data (ENFA, Hirzel et al. 2002)

Step-by-step process
Habitat Suitability Layer; The ecological-niche factor analysis is explained in Hirzel *et al.* 2002 and used by *e.g.* Engler *et al*. 2004, Chefaoui *et al.* 2005 and Santos *et al*. 2006). Reclassification of the obtained 'Habitat Suitability Maps' from the ENFA (*e.g.*

very low habitat suitability, low moderate high, very high habitat suitability, Chefaoui 2005).

Indicator use in the Assessment of Management Performance
The same general considerations apply as in previous tool, 2.2.1. It is crucial to find the relevant pressure factors in the overly comparisons for habitat vulnerability analysis.

2.2.3 *Distribution of three key phytobenthic species*
Species I: The brown alga *Fucus vesiculosus* is the dominant macroalgal species in the Baltic Sea comprising up to 43% of the benthic plant biomass. In recent years the biomass of the species has notably diminished at many localities. This decline was attributed to their lower competitiveness at higher nutrient concentrations and the shading effect by the filamentous alga *Pylaiella littoralis* (L.) Kjellman combined with increased herbivory by *Idotea baltica* (Pallas). Offering habitat and food for many macroalgal and invertebrate species the species is recognized as one of the keystone species in the Baltic Sea area.

Species II: The eelgrass *Zostera marina* is the most common marine angiosperm in the Northern Hemisphere. It is well represented in the brackish Baltic Sea where the species grows at its lower salinity tolerance limit. Yet eelgrass is one of the most abundant macrophyte on exposed sandy bottoms in the Baltic Sea and is regarded as a keyspecies of this habitat. In the north-eastern part of Baltic Sea, the coastal waters of Estonia, the distribution of eelgrass has never been directly studied why the information on eelgrass communities is scarce and occasional.

Species (group) III: Charophytes are a highly developed and diverse group of algae. They are widely distributed in freshwater, brackish and marine habitats from tropical to polar regions. In recent decades, species number, distribution area and biomass of charophytes have significantly declined virtually in the whole Baltic Sea. This decline has been attributed to increased nutrient loads resulting in higher productivity of phytoplankton, epiphytic algae and angiosperms and indirectly resulting in elevated grazing of mesoherbivores on Charophytes.

Computer equipment requirements
To perform the analysis, a geographical information system (GIS) that can handle and analyze data in raster and vector formats is needed (ESRI ArcGIS package ArcView or higher). Statistical software S-Plus, -GRASP module for S-Plus, and database software (*e.g.* MS Access)

Data requirements

- Point data on the occurrence or biomass of a phytobenthic species from field sampling stations. The point data should be preferably collected from the same area where the predictions are made.

- Raster data sets on environmental variables which can be used to predict the occurrence or biomass of phytobenthic species. Particularly useful variables are *e.g.* depth, seabed sediment type, seabed slope calculated at different spatial scales. In this analysis, depth raster of sea area (50 m resolution), raster of seabed slope (50, 100, 500, 1000, 5000 m resolutions), raster of seabed sediment type (50 m resolution).

- Coastline vector data. Inclusion of environmental variables of multitude spatial scales results in better predictions as in such models the processes operating at different spatial scales and their relative contribution are simultaneously taken to account.

Step-by-Step process

- The field data of the species occurrence is imported to MS Access database table including the following columns: station ID, X-coordinate, Y-coordinate, presence/absence (values 1 and 0, respectively). The data set is given a representative name, *e.g.* 'YYY'. One file is produced for each species.

- The species occurrence data is linked to environmental data (cell values from all raster layers at each sampling station) using *Sample* tool in ArcInfo. The output file is saved in MS Access file format including the following columns: station ID, X-coordinate, Y-coordinate, environmental variable 1, environmental variable 2, etc. The file is given a representative name, *e.g.* 'XXX'. The order of sampling stations is same as in 'YYY'.

- Extract the environmental information of the study area. Point grid at 50 m interval is created in ArcInfo covering the whole pilot area. Environmental data from all raster layers is collected for each grid points using *Sample* tool in ArcInfo. The output file is saved in MS Access file format and it included the following columns: sample ID, X-coordinate, Y-coordinate, environmental variable 1, environmental variable 2, etc. The file is given a representative name, *e.g.* 'XXXpred'.

- Calculate the predicted distribution and create the model for each species. GRASP module is installed to the statistical software S-Plus. GRASP (generalized regression analysis and spatial prediction) is a general method for making spatial predictions of several response variables (RV) using point surveys of the RV and spatial information of predictor variables (PV). The created data sets YYY, XXX and XXXpred are opened in S-Plus. In GRASP GUI the following options are selected prior to starting the calculation:

  - Binomial distribution for presence/absence data or gaussian distribution for biomass data.

  - Stepwise model.

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- Selection test type: AIC.

- Model validation.

Calculate and save the predictions.

The model is regarded acceptable if its validation showed more than 85 % coincidence between observed and predicted values. However, different limits may be set depending on species considered and aims of the modelling.

The GRASP model predicted the probability of occurrence of a species in each 50 m grid point. The predictions were saved in MS Access database table file and it included the following columns: ID, X-coordinate, Y-coordinate, prediction (probability of species occurrence in a location ranging between 0 and 1). Predictions were calculated separately for each species.

The modelled predictions were opened in ArcInfo as point data and then converted to raster data set using *Point to Raster* tool.

Indicator use in the Assessment of Management Performance
The same general considerations apply as in previous tool, 2.2.1. It is crucial to find the relevant pressure factors in the overly comparisons for habitat vulnerability analysis.

> Three marine habitats sensu the Habitats Directive are described in detail here, *Sandbanks (1110)* Coastal lagoons and Large Shallow Inlets and Bays (1150) (1160). An elaborated description of how to delineate seven HD marine habitats is provided by Wennberg et al. (2007). Readers are encouraged to read this report in connection to this section.

2.2.4 *Sandbanks (1110)*
Sandbanks, which are slightly covered by seawater all the time (1110), are sub-littoral, permanently submerged sandy ridges, which clearly rise above their surroundings, and are found throughout the North and the Baltic Sea. They occur in near-shore coastal waters as well as in offshore waters and may be without or with vegetation, primarily consisting of *Zostera marina*, *Coralinaceae*, *Potamogeton pectinatus*, *Ruppia cirrhosa* and *Tolypella nidifica*. The sediments of the sandbanks are in general not well described, which makes it difficult to give an exact biological description of the habitat. The degree of exposure to currents and waves will influence the biological composition of sandbanks (European Commission 2003; Dahl *et al.* 2004; Boedeker *et al.* 2006).

Sandbanks have several significant ecological functions, such as being an important habitat and recruitment area for rare, threatened or declining benthic organisms. They

have a great importance as feeding, resting and nursery grounds for demersal fish species and marine mammals, as well as feeding habitat for resting and wintering seabirds (Boedeker *et al.* 2006). The most important anthropogenic pressures for the sandbanks are eutrophication, bottom dragging fisheries, extraction of sand, and hazardous substances like antifouling paints. Introduces invasive non-endemic species may impact on the quality of nature (Dahl *et al.* 2004).

The recipe below is a straightforward procedure for distinguishing potential sandbanks based on depth data, and is discussed in more details by Klein (2006). However, given the complexity of the natural conditions, the result gained by performing the analysis will only give the potential distribution of sandbanks and must be further developed to match geological and biological requirements (see Rachor 2006; Zettler & Gosselck 2006).

Data requirements
At the preliminary stage of sandbank detection discussed in this recipe, only depth data as points (or alternatively as a ready-made raster data set) is needed. In order to fully identify sandbanks as defined in the Habitats Directive, additional data sets of seabed substrate and biological features are needed.

Step-by-step process
1   Make a clear definition for a sandbank

Referring Klein (2006) a *sandbank* should fulfil the conditions:

- it is permanently submerged

- it can be distinguished as independent elevations of the seabed

- its boundaries are generally marked by slopes of more than 0.5°, if the density of source point data is low, slopes of up to 0.1° can be included

- its boundaries are generally drawn at the transition from slopes of the bank to the surrounding plains

- in more level areas, boundaries are marked by the straight line between the ends of the slopes as defined above

- the line marking the slope should be at least 3 times longer than the straight line

- the banks that the model accounts for must be bigger than 1 km²

2   Produce a TIN model

   Produce a TIN (triangulated irregular network) with aid of a GIS program that represents connections between all individual x, y and z coordinates. If it is not possible to perform TIN modelling, an interpolated raster data set (if not already present as preliminary data) may alternatively be constructed.

3 Calculate attributes required to detect sandbanks

Calculate the inclination and average depth of the (triangular) areas produced by the TIN. If you are using an interpolated raster data set, the depth of a single map unit (a raster cell) is already known.

4 Produce the layer indicating Sandbanks

Based on the defined conditions to detect sandbanks, make a layer indicating the location of the banks. Notice that final classification whether a formation is a sandbank or not, has to be checked manually (for example, inclined areas above the defined limit which represent the slopes of the bank to the surrounding plains have to be distinguished from areas with a structured relief surface on top). After producing the layer, additional attributes such as the area or minimum and maximum depths may be updated.

Indicator use in the Assessment of Management Performance
The same general considerations apply as in previous tool, 2.2.1. It is crucial to find the relevant pressure factors in the overly comparisons for habitat vulnerability analysis.

2.2.5 *Coastal lagoons and large shallow inlets & bays (1150 & 1160)*
Coastal lagoons (1150) are defined as expanses of shallow coastal salt water of varying salinity and water volume, and wholly or partially separated from the sea by sandbanks or shingle, or, less frequently, by rocks. Salinity may vary from brackish water to hypersalinity depending on rainfall, evaporation and through the addition of fresh seawater from storms, temporary flooding of the sea in winter or tidal exchange.

Large shallow inlets and bays (1160) are morphologically quite similar habitats to coastal lagoons, but the influence of freshwater is more limited and salinity therefore less variable. They have in common that they are normally sheltered from significant wave action and they contain a great diversity of sediments and substrates with a well-developed zonation of benthic communities. Coastal lagoons are listed as a European natural habitat type in danger of disappearance and therefore special attention is needed (European Commission 2003).

This method of recognizing coastal lagoons is produced at the Baltic Sea coast of Sweden (Axelsson 2003) further developed by Lindblad et al. (2007) and developed mainly for identifying flads and gloes (small, usually shallow, more or less delimited water bodies still connected to the sea or have been cut off from the sea very recently by land upheaval). The recipe may be applied to other conditions as well but some methodological changes may be needed and the suitability of the procedure should carefully be evaluated.

Using the method, two types of coastal lagoons are recognized: fully (having an occasional connection to the sea depending on the sea level) and partially closed (having a constant connection to the sea but restricted by a narrow and shallow mouth). Fully

closed lagoons are here considered as being separated from the sea by not more than 30 m, their depth is less than 6 m and the elevation above sea level less than 5 m. Partially closed lagoons are connected to the sea by inlet(s) having a width less than 30 m, their depth is less than 6 m and they are situated more than 50 m away from a significant (>1 km2) freshwater area. Depending on the geographical area and characteristics of the marine environment, some other values or definitions may be used.

NB. Since all stages of land uplift lagoons can not be identified with the present tool, additional methods may be utilised, such as field investigations and remote sensing.

Data requirements
- Data set separating land and water areas, in vector or raster format

- Elevation and depth data sets of the research area, in vector or raster format

Step-by-step process
1 Pre-process the elevation / depth data sets

If the data is in vector format (elevation / depth contours), it is needed to be interpolated to raster format

- Classify the raster to four classes:

    o land area, elevation < 5 m

    o land area, elevation > 5 m

    o water area, depth < 6 m

    o water area, depth > 6 m

2 Pre-process the data set separating land and water areas

If your land / water data is on raster format, you need to vectorize it (to polygons) first. Separate three classes from the data: land, sea and lake areas. Depending on the data, the class "sea" may include freshwater areas via rivers. Save the three classes as separate polygon layers.

3 Separate fully closed lagoons

- Alternative 1:

    o If the GIS program you are using is capable of making spatial selections and the amount of data is not too large, select features from class "lake" that are less than 30 m from the shoreline (from the polygons of the class "sea").

- For selected features, create a centre point data set (in *ArcView*, for example, can be done by using *Xtools*).

- If the centre point of a selected feature is located on a land area with elevation of 5 m or less, or on a water area with depth of 6 m or less, the feature (the original polygon corresponding to the centre point) will finally be selected as a fully closed lagoon.

- Alternative 2:

  - If not already available in raster format, rasterize the polygon layer for "sea" and choose 15 m for the pixel size. Expand the rasterized result by one pixel.

  - Save the result as a separate polygon layer – the layer "sea" has now been expanded to cover land areas within a distance of 15-30 m from the shoreline.

  - Select features from layer "lake" that overlap (intersect) with the expanded sea layer. For selected features, create a centre point data set (in *ArcView*, for example, can be preformed by using *Xtools*).

  - If the centre point is located on a land area with elevation of 5 m or less, or on a water area with depth of 6 m or less, the feature (the original polygon corresponding to the centre point) will finally be selected as a fully closed lagoon.

- Select lagoons < 30 hectares in size.

4 Separate partially closed lagoons

- Rasterize the polygon layer for "land" (if not already available), choose 15 m for the pixel size and expand the rasterized result by one pixel (see Fig. 2).

- Make the result again to a polygon layer – the layer "land" has now been expanded to cover sea areas within a distance of 15-30 m from the original shoreline.

- Identify the "holes" that are surrounded by land areas – whether they are lakes, or partially closed lagoons now completely separated from sea areas. Make a new polygon data set containing these holes, and create a centre point data set for them.

- From the hole-polygons, select those not overlapping with "lake" polygons and that have their center point locating on a land area with elevation of 5 m or less or on a water area with depth of 6 m or less. Moreover, discard polygons locating less than 50 m away from a significant ($> 1\ km^2$) freshwater area (this can be done by using automatic methods described above, but in many cases it may be faster to be done by manual visual check).
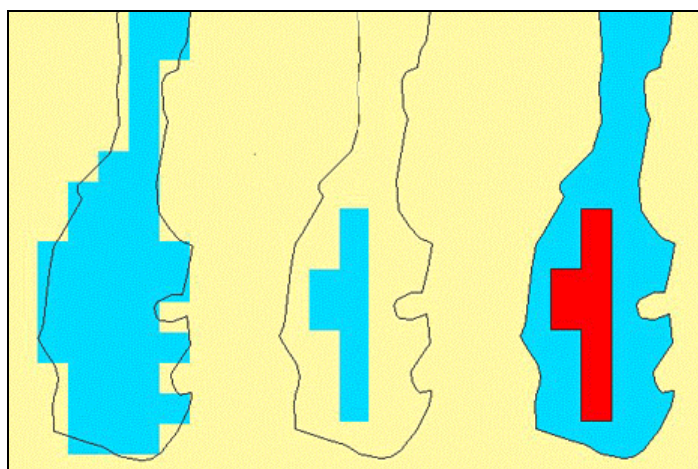
- Select lagoons < 30 hectares in size.

Fig 2   The process steps for separating partially closed lagoons (Axelsson 2003).

5   Present the result

Combine the results of fully and partially closed lagoons, visualize it or continue processing if needed.

Indicator use in the Assessment of Management Performance
The same general considerations apply as in tool, 2.2.1. It is crucial to find the relevant pressure factors in and do overlay comparisons for habitat vulnerability analysis.

Since, this type of habitat is highly affected by the process of land-uplift, and undergoes and successional development, it is recommended to link this tool with Archipelago Zonation tool (Section 2.3.2), in order to evaluate the distribution and status of habitats in different archipelago areas.

The tool 'Predicting anthropogenic influence on coastal lagoons (Habitats Directive habitat 1150) and large shallow inlets and bays (1160)' presented in 2.4.2., is a detailed description of how to combine the habitats with relevant pressure factors to assess vulnerability.

2.2.6 *Habitat heterogeneity indicator*
Biological diversity (biodiversity) is an important measure of the many components of the ecosystem. Knowledge of biodiversity is a key parameter in and a desirable target of nature conservation. It is widely understood that heterogeneous environments normally support more species than homogeneous ones.

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Description / full name	Predicting habitat heterogeneity with depth, wind exposure and shoreline data.
Zoning purpose	To provide a measure of the variation of conditions, acknowledging the paradigm of diverse conditions supporting more habitats and species, thus being an indicator of biodiversity. May be used for focusing further field studies of 'hot spot' areas.
Target use / feature	Marine nature conservation / areas with diverse habitats and species.
DPSIR indicator	Environmental state.
Assessment indicator	Biophysical assessment of the coverage of areas regarding heterogeneity.
Data used	Water mask (Polygon data of sea areas), shoreline (in vector format), depth model in raster format and wave exposure model in raster format.
Principal steps	Create a polygon grid, calculate and classify the water/land ratio, the ratio of depths < 3m, shoreline length, depth variation and wave exposure variation in each grid cell. Combine the results.
Related tools	Biophysical tools such the habitat extracting tools presented above (2.2.1-2.2.5).
Accuracy	Highly dependent on the accuracy of depth and wave exposure data and on the scale of the grid. Most suitable for near shore coastal areas.
Difficulty, 1-5	3
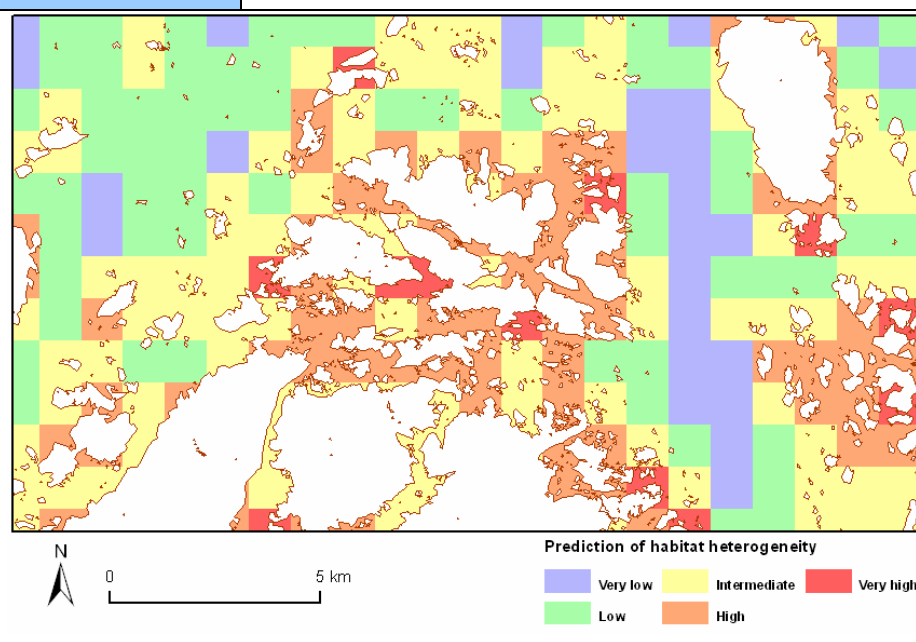
Fig 3

The final result derived from the tool indicating habitat heterogeneity at a 1x1 km grid scale and with a five-level classification. Shown is a part of Pilot Area 3, the Archipelago Sea.

In complex habitats, more niches can be realized due to *e.g.* the positive relationship among complexity, available area and space, and non-extirpative biotic interactions are enabled due to the mitigation of predation and competition. Basically, heterogeneity normally increases the amount of three significant resources for the organisms – food and shelter and space.

The need of marine nature conservation is widely agreed, but problem arises when trying to choose appropriate management targets without having spatially extensive bio-

physical data from field inventories to meet the targets with (*e.g.* Ardron 2002). Other tasks involving biodiversity issues are regional and coastal development planning. However, management decisions have to be made regardless of whether or not comprehensive data are available to be incorporated to the decision making process (Stanbury & Starr 1999). Fortunately, it is possible, to a certain extent, to predict the biodiversity based on environmental conditions. A powerful tool for the purpose is GIS technology that enables analyzing and combining of a variety of data sets to produce estimates of *e.g.* benthic biodiversity (Ardron 2002; Burne & Parvey 2002).

As Longhurst (2001) points out, a natural expectation is that the strongest boundaries between biogeographic regions are associated with the most significant discontinuities of the physical environment. Generally speaking, the most fundamental characteristics of marine benthic habitats relate to the topography of the seafloor (Burne & Parvey 2002), but problems with revealing small-scale changes influencing the biological communities often arise from insufficient spatial resolution of the available information sources (Ardron 2002; Bates & James 2002). However, the ability to map geophysical variation – at least locally – is improving as sensors become more sophisticated (Roff *et al.* 2003). The absolute depth is clearly a key factor affecting the benthic species composition (*e.g.* the amount of filtered light), other elements include the heterogeneity of bottom topography, wave (wind exposure) action, currents and tides, aspect, ice coverage, temperature, salinity, water column stratification, site distance from the headwaters, substrate type (sediment grain size, surface roughness and organic content), bottom slope, biotic interactions and human actions (Breneman *et al.* 2000; Koch 2001; Murray *et al.* 2002; Roff *et al.* 2003; Martin & Torn 2004; Salas *et al.* 2004). Still, there are some highly unpredictable phenomena affecting to biodiversity on the marine environment, such as the deep sea vents in areas of seafloor spreading (Roff *et al.* 2003).

If listing factors affecting benthic habitats is a rather easy task, defining their significance, in terms of ecological relevance, for predicting spatial heterogeneity may prove to be troublesome. Depth, for example, definitely forms quite linear habitat zones at least for submersed vegetation, but the absolute shifting values may vary depending on *e.g.* type of ecosystem and turbidity of water – in the Great Lakes, North America, two different habitat classes are defined to be changing at a depth of 5.5 meters (Brenemann *et al.* 2000), but in the Scotian Shelf area, Canada, the first significant habitat alteration is determined to happen at a depth of 50 meters (Roff *et al.* 2003).

Not just environmental conditions but point of view/scale are apparent when analyzing habitat parameters such as the wind fetch; a fetch distance of a few kilometres may be even at a fairly similar conditions defined as "protected" (Murray *et al.* 2002) or "extremely sheltered" (Jones *et al.* 2001), giving slightly different ideas of possible community structures. It is not insignificant what the primary target of the investigation is – in a quite general habitat classification study conducted by Roff *et al.* (2003), a habitat shift value for bottom slope was defined to 2 %, but in the Baltic Sea, Bladder wrack (*Fucus vesiculosus*), was reported to occur at slope banks 38 % or less (Isæus 2004). Thus, depending on the relationship between the environmental factors and the involved species or communities, any given value may be interpreted differently. Nonetheless, as a 'general rule', if comparing high and low 'values' of heterogeneity, the latter would presumably indicate high biodiversity.

We used four sets of widely available data on abiotic measures to create a single marine biodiversity indicator of near shore archipelagos. The basic principle behind the design was to account for the spatial variation of the measures. Using the variation of environmental conditions in an area, potential habitats inhabiting different organism can be quantified assuming that heterogeneous conditions indicates more and different kind of habitats. The tool can be viewed as a modified version of the benthic complexity tool developed by Ardron (2002), who in his study used the variation of depth as a proxy of benthic complexity. In addition to depth information we included land/sea and shoreline vector data sets as well as wave exposure / wind fetch data.

In an archipelago landscape with a varying land/sea ratio these additional parameters most probably add heterogeneity to marine habitats. The measure of land/sea ratio is related to wave exposure as both describe aspects of openness and shelter. One distinction between the two can be made; wave exposure merely describes the physical conditions of an area, whereas the land/sea ratio describes a variety of conditions, such as the potential run-off, physico-chemical properties of the water, material transport, and the degree to which processes on land potentially influence the marine environment. Archipelago landscapes are very shoreline intense, and information describing *e.g.* length and form of shoreline are important factors. The complexity of shoreline may not be an adequate single indicator for habitat heterogeneity, but when combined with depth and wave exposure variation, it helps to point out the most heterogeneous areas. The presence of shallow areas should be included in the analysis as they are productive and important nursery areas for a variety of organism thus indicating high variety of possible habitats.

The approach described in this recipe may not be fully comprehensive and the result must be seen as a coarse estimate of heterogeneity, and, hence, a proxy indicating areas with probable high biodiversity. The tool does not especially concentrate on a single species or a group of species, acknowledging the paradigm of complex habitats supporting more species without any references to particular habitat conditions. Thus, the tools requires adjustment if adapted to more species-specific research purposes. The main target is to describe the methodology and work phases that may be applied to different data sets – for example, if data of benthic substrate is available, it can be similarly processed and taken to account when compiling the overall results. The parameters can be analysed separately or used in any combination of parameters. The idea behind the development of the tool is to classify different factors affecting marine biodiversity based on the variability, and finally combine them to class values representing areas of varying heterogeneity. The tool can be used for delineating areas for further biological studies on biodiversity in the field.

All the factors presented here are calculated based on a fixed polygon cell grid, thus being totally dependent on the geographical location of cell borders. More reliable and smoother results would be gained by using moving windows (by recalculating the classification values with several, displaced grids) and averaging the results, but it would require considerably greater computational effort.

Data requirements

- Water mask (Polygon data of sea areas or some other data separating sea from land, converted to polygon format)

- Shoreline (in vector format, as accurate as available)

- Depth model in raster format (vectors, *e.g.* depth contours, have to be interpolated)

- Wave exposure model in raster format (defining the maximum fetch distance for each raster cell; this can be extracted from land/sea data with a suitable script available *e.g.* at http://arcscripts.esri.com). In this tool the wave exposure model described by Isæus (2004) was used.

Step-by-step process

1 Construct a square-cell polygon grid theme for your analysis

- Decide a suitable cell size for your end result to satisfy the research purpose. In a heterogeneous environment, smaller cell size may be better than in areas where depth and fetch face only minor changes among nearby locations. The size should exceed the resolution of depth and wave exposure models substantially in order to gain enough variation of values within each square. The development of this recipe was performed using data from the Archipelago Sea, SW Finland – an area where small islands surrounded with shallow water and deep basins result in a very complex environment. A cell size of 1 x 1 km was found suitable (the resolution of depth and wave exposure models was 25 m).

- Create a *polygon grid*. Using *ArcView*, an easy way to perform the task is to use an *Avenue* script *Square your polygon* (available on http://arcscripts.esri.com/ at least at the time this recipe was written) that squares your research area (a single polygon) to distinct square polygons of a defined size. Place the script on your *ArcView* project, compile it and execute.

- Furthermore, you need a unique id-number for all polygons (hereafter referred as *Polygon ID*) for joining distinct data sources on later steps. You may use, for example, an *Avenue* script *Autonumber a field* available on http://arcscripts.esri.com/ (visited July 2006).

2 Update water ratios in each polygon cell

When calculating habitat heterogeneity, the water / land area ratio has to be taken to account. In these instructions, water ratio is used both as a multiplication factor to correct the classification values for cells situating partly on land surfaces, and as a separate value to estimate the increase of underwater diversity due to land / sea interactions. The water mask should preferably be a single water polygon, or else there may be a need for dissolving several water polygons inside a single polygon grid cell.

- If your data set is not especially extensive, and/or the computer you are using is powerful enough, you may run the process of calculating the *water ratios* without additional intermediate phases.

  o Perform an intersecting function between polygon grid cells and water mask (in *ArcView*, use *GeoProcessing Wizard* or *XTools*); select a polygon grid file as input theme and water mask as overlay / intersect theme. As a result, water mask will be split to smaller parts separated by the border lines of the polygon grid theme. Make sure that *Polygon ID*s are present in the resulting file; if there are several features having the same *Polygon ID*, they have to be dissolved.

  o Calculate the area of each feature (water polygon that has been cut to the grid cell extents); the easiest way to perform the task in *ArcView* is to use the *XTools* extension (*Calculate Area…*), or by adding a new column in the attribute table and using the *field calculator* (in *ArcView*, area may be calculated by typing *[Shape].returnArea*).

  o Calculate the water ratio for each feature. Make a new column and update values using a formula *<calculated water area> / <total square cell area>*; the maximum value should be "1" and cells situating partly on island / mainland areas will gain a ratio between 0…1.

  o Join the resulting water ratios to the original polygon grid file using the *Polygon ID* column – you have now updated the correction factors for each polygon cell. You may copy the numbers to a new column and remove the join to keep the data as simple as possible.

  o Delete polygons that possess no ratio information after the joining operation – they should be cells that are completely on the land surface and are not needed for later analyses.

- If you have computational problems when trying to follow the steps above, another approach may help you to complete the task.

  o From the polygon grid file, select all the polygons that are completely on the land surface (no water) and delete them. You may try to spatially select them, or just manually – the purpose is just to reduce the amount of data, so it is not absolutely necessary to pick every single polygon that fulfils the terms.

  o From the polygon grid file, select all polygon cells that are completely on the sea surface (no land). Extract the selected polygons and store them as a separate file (make sure that *Polygon ID* column is present). Delete the extracted polygons from the original polygon grid.

  o The remaining polygons should be cells situating partly on sea and partly on land surface. Follow the steps described above to calculate their water ratios; perform the analysis in smaller parts if needed.

   o   When completed, include the extracted polygon grid cells (situating on
       the sea surface) to the result and update a water ratio of "1" for them.

- Classify the water ratio to estimate the land/sea interactions in each polygon cell

  Besides of being a corrective multiplication factor, water ratios may be interpreted as
  a diversity factor to reveal the level of interconnections between land and sea areas.
  The optimal high value may be assumed to lie around 0.5 (half land, half water) and
  declining in both directions. The classification result will partly correlate with shore-
  line complexity (step 7), but both of these two measures will reveal new, uncorre-
  lated components affecting the underwater heterogeneity.

- Make a new column to the polygon grid attribute table, and store the classified values
  presented in Table 2 (perform an attribute query of land / water ratios for each class,
  and save the corresponding class value for selected polygons).

Table 3   Classified values of the land / water ratio.

Water ratio	Classified value
0…0,199	1
0,2…0,399	2
0,4…0,599	5
0,6…0,799	2
0,8…1,0	1

3 Classify the depth variation in each polygon cell

  The depth model first has to be classified in order to find out what is the significance
  of depth variation in each polygon grid cell. The class limits given below are sugges-
  tions and seem suitable for shallow, topographically heterogeneous coastal areas,
  such as the archipelagos of SW Finland, Åland and Stockholm and Uppsala counties,
  Sweden.

Table 4   Original depths and classified values used in this tool.

Depth value (m)	Classified value
0…2,99	0
3…5,99	1

6…9,99	2
10…14,99	3
15…29,99	4
30…	5

- Reclassify (in *ArcView*, choose *Analysis* → *Reclassify*) the depth raster model to class values presented in Table 3 or by using ones of your own classification system.

- Calculate how many different classes there are present in each polygon cell; if needed for computational reasons, you may have to split the depth raster to several subparts and perform the summarizing task for each of them separately.

   o Make the polygon grid cell theme active

   o In *ArcView*, choose *Analysis* → *Summarize Zones*. The field that defines the zones is *Polygon ID*, and the variable to summarize is the reclassified depth raster file.

   o In the resulting table, you may remove all other fields except the *Polygon ID* and *Range*.

   o Join the results to the original polygon grid cell theme using the *Polygon ID*.

   o Open the attribute table of the polygon grid cell theme. Create a new column representing the number of different depth classes on each cell and calculate values for the field using a formula *<Range> + 1* (if there is only one depth class present on the polygon cell, the resulting value would without the formula be "0"). Remove the join.

- The number of depth classes must be proportional to the coverage of water areas in each polygon cell. Corrected values may be calculated by using a formula

   ((<Depth classes> - 1) / <Water ratio>) + 1

   The purpose of the subtraction and addition of "1" in the formula is to make sure that cells having a water ratio substantially less than 1 and containing only one depth class will not be altered at all.

   Polygon cells locating almost thoroughly on land areas may gain unreasonably high values after the corrective calculation. The maximum number of classes for the depth variation is considered here to be no more than "6", and all the exceeding values must be updated manually.

NB. A key factor affecting to the final results, is the accuracy of the depth model. Very often there are considerable deficiencies or inaccuracies relating to the depth data of public use. In most cases, this is just a fact to be recognized and accepted.

4   Classify the wave exposure variation in each polygon cell

The wave exposure model has to be classified in order to find out what is the significance of wave exposure variation in each polygon grid cell. The class limits given in Table 4 are only suggestions and may require revising at least in more open coastal and offshore areas. Check that all land areas have been masked away from the exposure model.

- The procedure is identical to Step 3. Repeat the steps.

Table 5   Original wave exposure and classified values used in this tool.

Exposure value	Classified value
1…999	0
1000…1999	1
2000…4999	2
5000…9999	3
10000…19999	4
20000…	5

5   Classify the ratio of areas shallower than 3 m in each polygon cell

- First, reclassify (in *ArcView,* choose *Analysis → Reclassify*) the depth raster model so that depth values between 0…3 will be given *e.g.* value "1" while other cells will be classified as *NoData*.

- Select the polygon cell theme and choose *Analysis → Summarize Zones*. Field to define the zones is *Polygon ID* and theme containing the variable to summarize is the reclassified depth raster. The resulting table indicates polygon-specific calculations of raster zones that were summarized, including the *Area* (the coverage of areas shallower than 3 meters in each polygon cell). Make sure that the *Polygon ID* is present in the table.

- In the resulting table, make a new column and name it *area_shal3*, for example, and copy the *Area*-values there. Delete all attribute columns except *area_shal*3 and the id-column.

- Join the first table to the polygon grid cell theme by using the *Polygon ID*.

- Then, reclassify the depth raster again so that depth values deeper than 3 m will be given *e.g.* value "1" while other raster cells will be classified as *NoData*. Summarize zones similarly as above.

- In the resulting table, create a new column and name it *area_deep3*, for example, and copy the *Area*-values there. Delete all attribute columns except *area_deep*3 and the id-column.

- Join the second table to the polygon grid cell theme by using the *Polygon ID*.

- Open the polygon grid cell attribute table and create a new column to store the shallower/deeper than 3 m ratio. First, select all rows that contain no *area_deep3* value (cells of which water areas are completely shallower than 3 m). Update manually "1" for the 3 m ratio. Similarly, select rows that contain no *area_shal3* value (cells completely deeper than 3 m) and update manually "0" for the 3 m ratio. Calculate the remaining values by using the formula

$$<area\_shal3> / (<area\_shal3> + <area\_deep3>)$$

- Classify the resulting ratio column; suggestions are given in Table 5. You may remove all the joins.

Table 6   Original ratios for areas shallower than 3 m and classified values used in this tool.

3 m ratio	Classified value
0 (cells deeper than 3 m)	0
0,001…0,199	1
0,2…0,399	2
0,4…0,599	3
0,6…0,799	4
0,8…1	5

6 Classify the shoreline complexity in each polygon cell

Shoreline complexity may be calculated in several ways, but when the target is a polygon cell matrix, an easy and properly trendsetting way to accomplish the task is to calculate the summed length of all shoreline segments falling inside each polygon cell. The total length of the shoreline is highly susceptible to the nominal scale of the data to be used; the shoreline data set used for the development of this recipe was constructed at a nominal scale of 1 : 20 000.

The shoreline length classes are only intuitive suggestions and based on visual interpretation, and most likely suitable only for relatively complex shoreline structures.

- Perform an intersecting function between the polygon grid cells and the shoreline data (in *ArcView*, use *GeoProcessing Wizard* or *XTools*); select the shoreline data as the input theme and the polygon grid data as the overlay/intersect theme. As a result, the shoreline will be split to smaller parts that are cut by the border lines of the polygon cells. Make sure that the *Polygon ID*s are present in the resulting shoreline file.

- Dissolve the separate shoreline segments situating on the same polygon grid cell for a single, multipart feature. Use the *GeoProcessing Wizard* and select *Polygon ID* field for the attribute to dissolve.

- Update the length of shoreline segments on the dissolved data set. You may use *XTools* or add a new column in the attribute table and calculate polyline lengths by typing *[Shape].returnLength* on the *ArcView* field calculator.

- Join the results to the original polygon grid file using the *Polygon ID*.

- Add a new column in the polygon grid cell attribute table to store the shoreline complexity class values given in Table 6 (or ones of your own). When completed, the join may be removed.

Table 7   Original shoreline lengths and reclassified values used in this tool.

Shoreline length (m)	Classified value
0 (cells having a water ratio of "1")	0
1…499	1
500…1999	2
2000…3999	3
4000…6999	4
7000…	5

7   Combine all the preceding results

- Open the polygon grid cell attribute table where the calculations of preceding phases have been stored.

- Create a new column in the attribute table to store the sum of sub-calculations. Perform the addition of classified water ratio (for land/sea interactions), classified and corrected depth variation, classified shallow area (<3 m) ratio, classified and corrected wave exposure variation, and classified shoreline complexity. The maximum value should be <27.

- Classify the final result to five classes described in Table 7.

Table 8   Five classes of the combination used in the tool.

Summed value	Classification
1 – 6	Class 1 – Very low habitat heterogeneity
7 – 12	Class 2 – Low habitat heterogeneity
13 – 18	Class 3 – Intermediate habitat heterogeneity
19 – 23	Class 4 – High habitat heterogeneity
24 – 27	Class 5 – Very high habitat heterogeneity

Indicator use in the Assessment of Management Performance
The same general considerations apply as in previous tool, 2.2.1. It is crucial to find the relevant pressure factors in the overly comparisons for habitat vulnerability analysis.

The usage in a screening phase is one of the major advantages with this tool, *e.g.* to locate areas for further studies on biodiversity. Additionally, the tool may be useful in delineating areas based on their probable importance for several habitats. The linkage between general and habitat-specific biophysical features is described in Section 3.

The heterogeneity of different areas can be ranked in order to assess the relative importance of the heterogeneity in different archipelago types, *e.g.* by combining with the tool Archipelago Zonation (2.3.2).
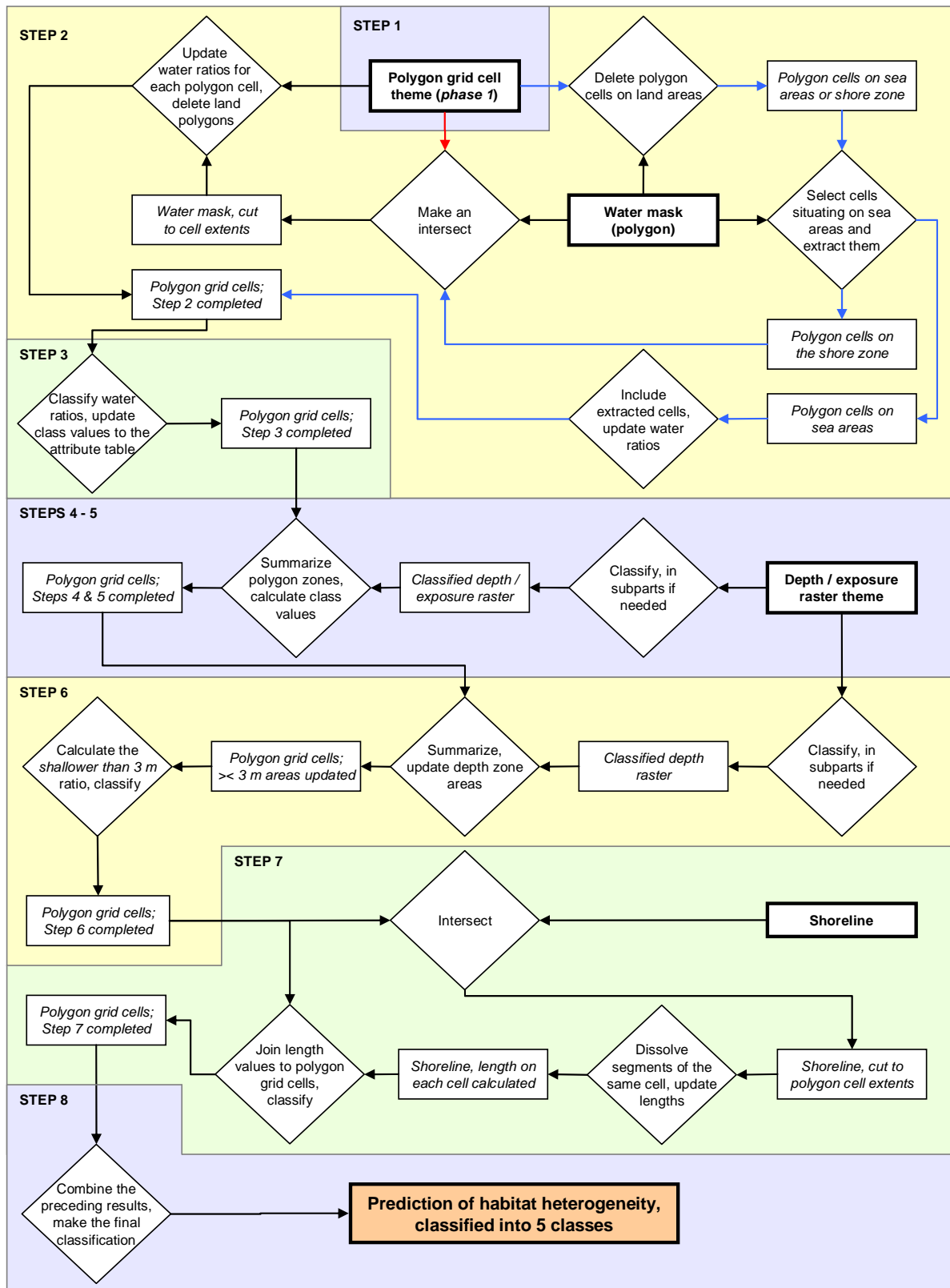
Fig 4   Principle steps of performing the analysis Predicting habitat heterogeneity with depth, wave exposure and shoreline data. *Different background colours indicate distinctly numbered steps; coloured (other than black) arrows at Step 2 define optional routes for fast computers / small data sets (red arrows) and slow computers / large data sets (blue arrows).*

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Fig 5 Sample images of performing the analysis Predicting habitat heterogeneity with depth, wind exposure and shoreline data.

2.3   Geophysical

2.3.1   Interpolation of depth and elevation

In this context, interpolation can be defined as a set of methods for transforming geographical data consisted of separate points or lines and having some assigned value to a constant raster surface. The purpose of interpolation is to fill the gaps between known values and make sure that every (*x,y*) location is given a defined value (Heywood *et al.* 2002: 125). Interpolation is based on the presence of spatial autocorrelation – a common phenomenon that locations near to each other tend to have more similar values than locations far away (Longley *et al.* 2001: 295).

When interpolating depth or elevation models, the source data often consists of contours. Using contour data may still lead to inaccurate results suffering from crude, systematic and random errors (Oksanen 2003). Random errors are in most cases unavoidable and systematic errors, if detected, may be easily fixable, but the best way to reduce crude errors is to choose a proper interpolation method. Unsatisfactory results are frequently obtained when a contour line is converted to point values and interpolation is committed using local methods such as IDW or Kriging. The problem is mainly caused by the geometric structure of the searching algorithm – it only recognizes depth/elevation points at short distances but does not identify the contour line as a whole (Burrough & McDonnell 2000). As a result, terrace-like structures and unnatural slopes may be produced (Fig. 1) especially if interpolation parameters are unsuitable (*e.g.* the searching window around a single point is set too small). Interpolation methods capable of contour line detection (*e.g. Topo to raster* in *ArcGIS*) are highly recommended whenever possible.
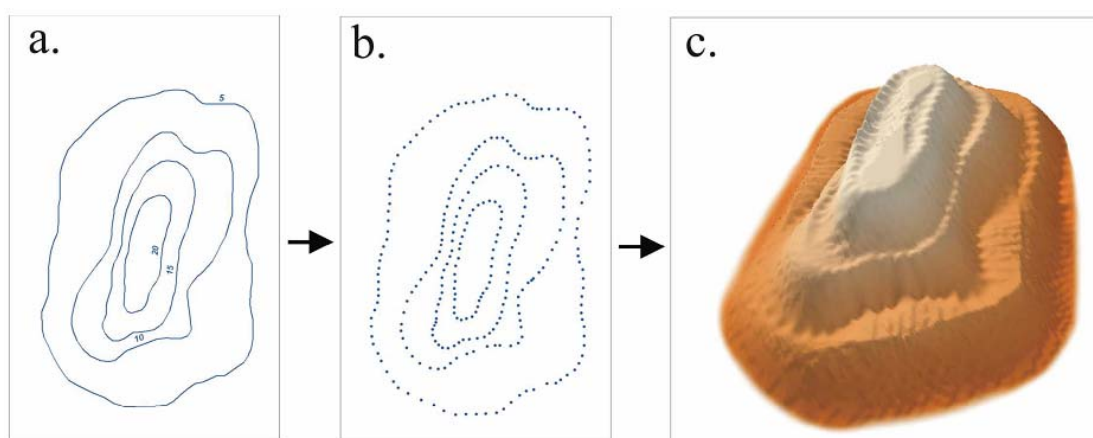

Fig 6   An example of problems, which may arise when using point-oriented interpolation methods. Contour lines (a) converted to point values (b) and the result of interpolation using IDW (c). (Redrawn from Pitkänen 2006)

One should remember that there might be errors related to the original point/contour data. Especially large data sets that have at least partly been collected before the use of computer-based devices may possess a considerable amount of inaccuracies that originate from human errors or the lack of processing time (Heywood *et al.* 2002). For that

reason, it is advisable to make at least a quick check for depth/elevation attribute values before running the interpolation.

Data requirements
The source data may be consisted of elevation/depth contours and/or points. The best result is normally gained by using contour line data (possibly adjusted with separate point values) and an interpolation method capable of dealing with contours.

Step-by-step process
1   Check and, if needed, pre-process the original data

The first step at the interpolation process is to make sure there are no major errors in the source data. Even when using official and data of good quality, it is likely that all attribute values are not correct, especially when dealing with large data sets. One easy way to make a quick-check is to sort elevation/depth attributes of contours or points to descending (or ascending) order and take a look at extreme values. Along with extremes, one should pay attention to zero values – numerical attributes that somehow have missed their original value, tend to be converted to zeros.

It is highly recommended to use an interpolation method that is able to process contour data without any modifications (*e.g. Topo to raster* in *ArcGIS*), another possibility is to convert contours to node points. Converting may be done in *ArcGIS* by using *Feature Vertices to Points* (requires *ArcInfo*), or by downloading a suitable script from http://arcscripts.esri.com. If only point data is used, a suggested interpolation method is Kriging.

2   Perform the interpolation

- If using contour data and ArcGIS, choose Topo to raster and set correct parameters. Selecting CONTOUR as the input feature type gives the best result in most cases, and the use of drainage enforcement may be a good idea. Other parameters may be fine-tuned if necessary and if the user has a clear idea how different alterations really work (see desktop help for more instructions). Remember to set a correct feature type for all inputs.

  Topo to raster is likely to give error messages if too large data sets are given as inputs; in that case data may have to be split in smaller parts and combined to a resulting grid after the interpolation process is completed. At some cases, *ArcInfo Workstation* may be capable of handling larger data sets without splitting. If using the *Workstation*, one should be aware that the same interpolation method is called *TOPOGRID* and at least in Windows environment, it may require a resetting of an environment parameter *GRIDALLOCSIZE*.

- If using only point data, there is a wide variety of different interpolation methods of which the use of Kriging is advisable. One should still remember that it is not possible to define the best method for all circumstances, and therefore users are encouraged to test different approaches and parameters to find the most suitable method.

3 Check the result

When the interpolation process is completed, the result should be investigated carefully. If some values seem highly incorrect, it may be due to errors in original data that need to be checked and corrected before attempting the interpolation again. If possible, the use of 3D-views may offer an easier way to assess the quality of the produced data.

Indicator use in the Assessment of Management Performance
The tool has no direct indicator use, but indirectly it is a crucial part of several other tools.

2.3.2 *Archipelago zonation*

NB. Not to be confused with the term zoning in the Marine Spatial Planning process.

Archipelago areas are very diverse when it comes to environmental conditions and landscape morphology, with a range of gradients working in various directions and with scattered islands and islets adding diversity to the mosaic landscape. The diversity within an archipelago, in terms of the variability of environmental conditions, is particularly obvious when comparing the innermost areas with numerous sheltered bays close to main land with the transitional area where the archipelago turns to open sea. Consequently, the archipelago gradients are important and need to be considered in the management as the conditions and properties of an area likely vary depending on the geographical position within the archipelago.

Archipelago type can be determined based on several environmental parameters, *e.g.* salinity, depth, wave exposure, openness, land/sea ratio and floristic aspects. One common way of delineating archipelagos is to inner, mid and outer archipelago zones. The data sets used in this recipe, mean values of wave exposure, depth, and sea/land areas, all possess clear gradients within an archipelago.

Data requirements
- Wind exposure model (land areas assigned to NoData)

- Water mask (in raster format; land areas assigned to NoData. May be constructed by reclassifying the exposure raster.)

- Depth model (land areas assigned to NoData)

Step-by-step process
1 Construct a polygon grid

- Create a *polygon grid*. Using *ArcView*, an easy way to perform the task is to use an *Avenue* script *Square your polygon* (available on http://arcscripts.esri.com/; visited

July 2007) that squares your research area (a single polygon) to distinct square polygons of a defined size. Place the script on your *ArcView* project, compile it and execute.

- Furthermore, you need a unique id-number for all polygons (hereafter referred as *Polygon ID*) for joining the distinct data sets on the following steps. In *ArcView* you may use, for example, an *Avenue* script *Autonumber a field* available on http://arcscripts.esri.com/ (visited July 2007).

2 Update mean wave exposure values to polygon grid cells

- Select the polygon grid cell theme and click *Theme → Summarize Zones*. The field to define zones is the *Polygon ID*, and the variable to summarize is the wave exposure model. Remember that areas that are not included to the analysis (land areas) must not have zero values because that will affect the calculations; excluded areas have to be assigned to *NoData*.

- Join the resulting table to the original polygon grid cell theme by using the *ID* column. Copy *Mean* values to a new column and remove the join.

3 Update mean depth values to polygon grid cells

   The procedure is similar to Step 2.

4 Update water percentage values to polygon grid cells

- Select the polygon grid cell theme and click *Theme → Summarize Zones*. The field to define zones is the *Polygon ID*, and the variable to summarize is the water mask. Remember that areas that are not included to the analysis (land areas) must not have zero values because that will affect the calculations; excluded areas have to be assigned to *NoData*.

- Join the resulting table to the original polygon grid cell theme by using the *ID* column. Be sure that *Area*-column will be joined.

- Make a new column to store water area percentage values on each polygon grid cell. Calculate values using the *MapCalculator* :

  *(<Area> / <total cell area>) * 100 %*

- Remove the join.

5 Calculate the zonation scores and classify

- Make a new column to the attribute table to store the zonation scores.

- First, check the mean wave exposure values on each polygon grid cell and update score values presented below to the column.

        o Mean exposure 0…10000 m   → score value 1

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- o Mean exposure 10000…25000 m   → score value 2

- o Mean exposure over 25000 m   → score value 3

- Check the mean depth values on each polygon grid cell and add (sum) score values presented below to the score column.

  - o Mean depth 0…10 m   → score value 1

  - o Mean depth 10…20 m   → score value 2

  - o Mean depth over 20 m   → score value 3

- Check the water percentage values on each polygon grid cell and add (sum) score values presented below to the score column.

  - o Water percentage value 0…40 %   → score value 1

  - o Water percentage value 40…75 %   → score value 2

  - o Water percentage value 75…100 %   → score value 3

- Make the final classification (Table 8) based on the zonation score column.

Table 9   The archipelago zonation produced by the tool.

Final zonation score	Archipelago zone
3 – 4	Inner archipelago
5 – 7	Middle archipelago
8 – 9	Outer archipelago

Indicator in the Assessment of Management Performance
As this tool produces a delineation of the archipelago based on predetermined conditions it may be linked with several types of tools in order to define the location of features or pressures according to the zones. This is especially helpful in land-uplift areas where management needs to consider the ongoing change of the landscape. The tool may be useful in *e.g.* the evaluation of the distribution of habitats in order to ascertain a sustainable development in the successional and changing landscape.

In the natural succession of land-uplift archipelagos, many habitats and associated species follow the dynamics of the changing environmental conditions. In areas where the land-uplift is significant, the zonation of archipelagos has implications for the management. For example, a certain type of habitat may show the highest quality / importance for species when occurring in the inner archipelago as a consequence of species-specific demands on the conditions. In order to secure a sustainable succession of that habitat, management needs to account for the fact that the archipelago undergoes a change, and

that the present outer archipelago in the future will turn in to an inner archipelago. If not properly managed, present unsustainable use in the outer and mid archipelago may compromise the future occurrence of habitats. Thus, habitats in all zones may need management in order to secure the long-term persistence of habitats.

2.4   Socio-economical – Pressure

2.4.1   Shoreline exploitation
The coastal areas and archipelagos of the northern Baltic Sea are under constant and increasing human pressure, such as coastal development and physical exploitation. Since these areas are biologically important and sensitive as well as valuable for leisure activities a monitoring method was produced to measure the human impact on the coastal areas (Tullback *et al*. 2001; Mattisson 2003, 2004).

In this recipe, exploitation is defined as anthropogenic physical modification of the natural environment. Since it is impossible to analyse all aspects of human impact, a set of indicators are used to represent exploitation. These are the *jetty* and *building* indicators and the exploitation types they are based on in Sweden are shown in Table 9. For more information on the methodology used, see Mattisson (2003, 2004). The method may need adjustment to be suitable for local environmental conditions and problems – the description below should therefore be seen as a basic recipe that can be altered to suit any situation and objective.

Table 10   Definitions of the Jetty Indicator and the Building Indicator, respectively.

The Jetty Indicator	The Building Indicator
Jetty/pier frequency divided in five degrees of exploitation outside population centres	Jetty/pier frequency divided in five degrees of exploitation outside population centres
Presence of population centres	Presence of population centres
Presence of harbours/marinas	
Dredging/filling	

Data requirements: the jetty indicator
- Shoreline data; in vector format

- Location of jetties, piers or similar constructions; in vector format

- Location of population centres; in vector or raster format

- Location of harbours/marinas; in vector or raster format

- Locations of dredging/filling; in vector (point) or raster format, depending on the extent of the environmental interference

Step-by-step process: the jetty indicator
1   Create the analysis zone

The analysis zone is the part of the shoreline that you want to present as statistics or maps showing the extent and degree of exploitation. To create the analysis zone, buffer the shoreline with the wished-for extent. A suggestion, that at least is applicable for Swedish and Finnish conditions, is to use a 100 m zone around the shoreline, 50 m on the land and 50 m in the water.

2 Analyse the jetty frequency

- If your jetties are polylines or polygons, transform them to centroid points. In *ArcView*, the task may easily be done with the help of the *XTools* extension.

- Perform a neighbourhood analysis in which the number of jetties are summarised within a moving window (radius 100 m) to give a frequency map. In *ArcView*, the analysis can be performed on a point vector layer which simultaneously is transformed to a raster (cell size *e.g.* 20 m) using the *Neighborhood statistics*. Remember that you can only get a correct frequency calculation where you have an all-covering data set within 100 m of the cell being analysed.

- Divide the jetty frequency by reclassification to four classes of degree of exploitation (see table 10 below) – the lowest exploitation class cannot be recognized here as zero values have been turned to *NoData* due to the neighbourhood analysis.

    o 1–2 jetties: weak indication of exploitation

    o 3–4 jetties: clear indication of exploitation

    o 5–7 jetties: strong indication of exploitation

    o 8– jetties: very strong indication of exploitation

  - The class limits must be based on the conditions in the area analysed, including any other area that one wishes to make comparisons with. If your population centres are in vector format, then vectorise your frequency map.

3 Add population centres and harbours/marinas to frequency map

Population centres as well as harbours/marinas are classified as areas with very strong indication of exploitation (Class 5). They are often defined for the land areas and not for the water. Therefore, in case it is motivated, buffer the population centres in order to catch the exploitation in the water as well. This will enlarge the land area which will have to be accepted or removed.

- Superimpose the population centre map on the classified frequency map. The process of doing so depends on whether the format is raster or vector and what software you are using. Just make sure that the population centres are classified as Class 5 while all the other classes on the classified frequency map remain as they are in Step 2.

- Superimpose the harbour/marina areas on the map produced in the previous step and classify them as belonging to Class 5.

- If you have worked with raster, you may transform your dataset to vector format.

4 Extract data from the analysis zone

Use the analysis zone layer from Step 1 to extract the result within the shoreline zone.

5 Classify areas with *No indication of exploitation*

All areas, inside the analysis zone, that lack classification are considered and classified as areas with *No indication of exploitation*, *i.e.* Class 1.

6 Present the result

The result may of course be further processed, dividing and calculating statistics for *e.g.* different regions or municipalities. It is strongly recommended to create detailed metadata, either in the map layer itself of in a separate document of your preference.

Table 11   The class limits that the County Administrative Board of Stockholm used to classify their shoreline exploitation (Mattisson 2004). The class limits were produced using four study areas around the coast of Sweden (Mattisson 2003).

Indication of exploitation	Jetty frequency	Building frequency
No indication	0	0
Weak indication	1-2	1-2
Clear indication	3-4	3-5
Strong indication	5-7	6-13
Very strong indication	8-	14-

Data requirements: the building indicator

- Location of shoreline separating sea from land – line or surface vector format

- Location of buildings/houses – point or surface vector format

- Location of population centres – surface format, vector or raster

Step-by-step process: the building indicator

1   Create the analysis zone

The analysis zone is the part of the shoreline that you want to present as statistics or maps showing the extent and degree of exploitation. To get the analysis zone buffer the shoreline with the wished-for extent. Depending on whether you work with line or surface vector data you may need to do this in more than one step. A suggestion, that at least is applicable for Swedish and Finnish conditions, is to use a 100 m zone from shoreline extending up on land.

2 Analyse the building frequency

- If your buildings are in vector format, transform them to a centroid points. In *Arc-View*, the task may easily be completed with the help of the *XTools* extension.

- Perform a neighbourhood analysis in which the number of buildings are summarised within a moving window (radius 100 m) to give a frequency map. In *ArcView*, the analysis can be performed on a point vector layer which simultaneously is transformed to a raster (cell size *e.g.* 20 m) using the *Neighborhood statistics*. Remember that you can only get a correct frequency calculation where you have an all-covering data set within 100 metres of the cell being analysed.

- Divide the building frequency to four classes of degree of exploitation (see table 10 above) – the lowest exploitation class cannot be recognized here as zero values have been turned to *NoData* due to the neighbourhood analysis:

    o   1–2 buildings: weak indication of exploitation

    o   3–5 buildings: clear indication of exploitation

    o   6–13 buildings: strong indication of exploitation

    o   14– buildings: very strong indication of exploitation

- The class limits must be based on the conditions in the area analysed, including any other area that one wishes to make comparisons with. If your population centres are in vector format, then vectorise your frequency map.

3 Add population centres to frequency map

Population centres are classified as areas with very strong indication of exploitation (Class 5).

- Superimpose the population centre map on the classified frequency map. The process of doing so depends on whether the format is raster or vector and what software you are using. Just make sure that the population centres are classified as Class 5 while all the other classes on the classified frequency map remain as they were.

- If you have worked with raster, you may transform your dataset to vector.

4 Extract data from the analysis zone

Use the analysis zone layer from Step 1 to extract the result within the shoreline zone.

5 Classify areas with *No indication of exploitation*

All areas, inside the analysis zone, which lack indication of exploitation are considered and classified as areas with *No indication of exploitation*, *i.e.* Class 1.

6 Present the result

The result may of course be further processed, dividing and calculating statistics for *e.g.* different regions or municipalities. It is strongly recommended to create detailed metadata, either in the map layer itself of in a separate document of your preference.

Indicator in the Assessment of Management Performance
The tool visualises pressure factors in a coastal environment. The tool can be combined with specific features for assessing the state and change of state of the vulnerability of these features in relation to the level of exploitation.

Spatially, the shoreline exploitation can be compared within and among zones. Special attention should be given to the state and the change of state of Class 1 *No exploitation*, which indicates natural conditions. The comparison may be done by measuring the relative coverage of different classes, the frequency of occurrence, length and the proportion of classes.

Over time, the change of above mentioned measures can be conducted.

Fig 7   Creating the Jetty, Building and Road Indicators – Principle steps (Tullback et al. *2001; Mattisson 2003, 2004).*

2.4.2 Human influence on coastal lagoons and large shallow inlets and bays

Description / full name	Predicting anthropogenic influence on coastal lagoons (Habitats Directive habitat 1150) and large shallow inlets and bays (1160).
Zoning purpose	To identify pressure on these sensitive habitats highlighting that a '0-level' indicates low vulnerability and a favourable conservation status (fcs) of Habitats Directive habitats
Target use / feature	Marine nature conservation, recreational use, boating / naturalness, flora and fauna
DPSIR Indicator	Environmental state and socio-economic pressure
Assessment indicator	Biophysical in assessing the fcs and Socio-economic in assessing the level of pressure. Preferable assessment of change: 5-10 years interval
Data used	Polygon data of sea and of lagoons and or shallow inlets and bays, location of buildings in vector format (points or polygons), road network in vector (polyline) format, divided in different road classes if available, shipping / boating lanes in vector (polyline) format, including channel depths if available.
Principal steps	Calculate the area of each site, buffer roads, buildings and shipping lanes for overlap with the sites, classify end-result according to degree of total pressure
Related tools	Archipelago Zonation (2.3.2), Habitat extracting tools (2.2.1-2.2.5), socio-economical pressure tools (2.4.1-2.4.7)
Accuracy	Dependent on the attributes available for the input data
Difficulty, 1-5	3 – 4
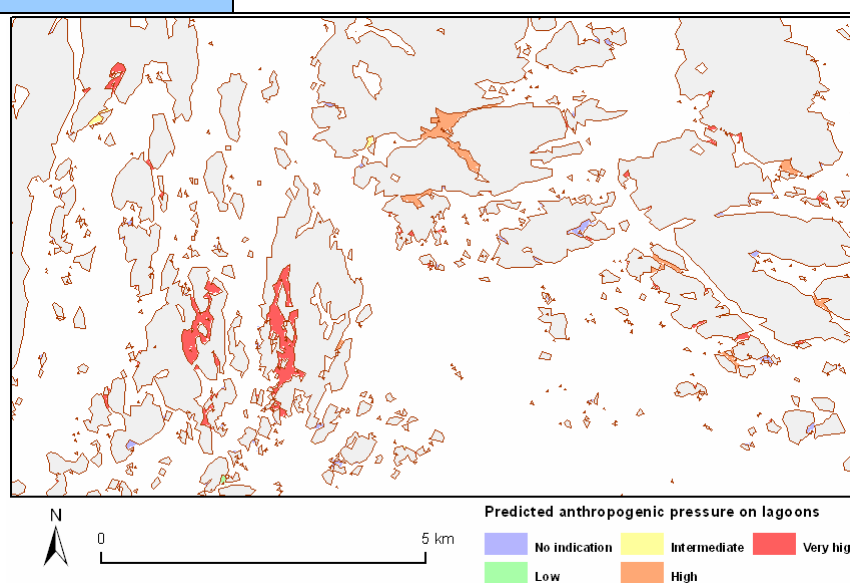
Fig 8

The final result of the tool indicating level of vulnerability (site-specific pressure of sensitive habitats) of coastal lagoons from very low level (no indication of pressure, suggesting natural conditions) to very high level.

Predicted anthropogenic pressure on lagoons

No indication   Intermediate   Very high
Low   High

Coastal development, exploitation of the shoreline and other human activities are increasing issues along the coasts of the Baltic Sea and induce multiple pressures on the coastal environment. Many marine habitats near to or associated to land are highly vulnerable to pressures originating from land. Managing activities on land is motivated as the land/sea ratio is significant in a coastal environment and the impact of pressures from activities on land is often first recognized near the coast.

The properties of coastal lagoons and flads and large shallow inlets and bays gloes (HD habitat 1150 & 1160) are described above (section 2.2.5). Coastal lagoons normally have a long shoreline and restricted water exchange and are typical examples of sensitive habitats, which are highly impacted by activities on land. They are subject to natural change as they gradually become cut off from the sea in land-uplift areas. Assessing the extent of pressure provides an opportunity to model their ecological state (conservation status) as well as the vulnerability of the habitats. Coastal lagoons are listed priority habitats and one important aspect of their natural conditions is the magnitude of anthropogenic influence.

In this recipe, the attention and instructions are focused on coastal lagoons and large shallow inlets and bays, but they are applicable for other habitats with similar geomorphology as well. Three significant sources of anthropogenic disturbance are recognized – buildings at the shore zone, the construction of roads, and boating activities (navigable routes). They all have certain areas of influence, which in the GIS environment may be modelled by buffering. The analysis performed by using figures and limits presented here is suited best for quite small features, say, when a single lagoon / inlet / bay cover < 10 km^2. Thus note that the figures and limits may vary in another situation.

Buildings on shores have often indirect consequences on the aquatic environment as associated activities, such as dredging and boating, may harm and deteriorate habitats and prevent the natural succession (in case of coastal lagoons in land-uplift areas). For this reason even one or a minor number of buildings may have a significant influence on the faunal and floral characteristics of a flad / glo (Appelgren and Mattila 2005) as facilitator of the harmful activity. More directly, inhabitants relating to the presence of buildings may, for example, alter the rates of nutrient recycling and sedimentation thus causing stress to natural ecosystem (Ellis *et al.* 2000); so the greater is the number of buildings, the more extensive is the level of human disturbance. The shore zone where buildings are considered to have a notable effect on nearby coastal areas has been denoted to 100 meters, which in the coastal areas of Finland and Sweden is a widely accepted estimate (Tullback *et al.* 2001; Finland's Ministry of the Environment 2005).

Boating activities and maintenance dredging of navigational lanes are examples of activities that result in increased wave action, elevated turbidity levels, substrate changes and direct physical disturbances of submersed vegetation. These mechanisms have negative effects on species richness and the natural state of the benthic community (Eriksson *et al.* 2004; Sandström *et al.* 2005). The effective zone of navigable routes depends on the size and the frequency of boats / ships using the route, but at least at deep-water lanes (10–15 m) waves and currents induced by heavy maritime traffic are reported to range significantly more than 500 m off the lane (Kukkonen 2004). Ferry routes induce strong vertical water movements affecting the species composition by

keeping the bottom free of sediments (Roos *et al.* 2005) and contributing to the eutrophication (Lindholm *et al*. 2001).

Roads does not have direct effects on the aquatic environment areas, but they may induce detrimental discharges to water and alter watershed conditions (Tullback *et al.* 2001), and they facilitate access to the shoreline. Highways and motorways may have ecological consequences reaching 500–1000 m off the road whereas secondary/rural roads are estimated to have an influence at a buffer zone of 100 meters, smaller roads or paths even less (Stoms 2000; Reyers *et al.* 2001).

Other land uses that have an impact on aquatic ecosystems is agriculture, particularly due to discharges of phosphorous and nitrogen, and changes in surface water flow (Pakkanen and Jaakkola 2003). Agricultural effects are not observed in these instructions because in a tool development point of view this issue is not important, but may be included to the procedure if found necessary under other circumstances. There are other EU-funded projects that concentrate more on land use management issues and spatial planning, *e.g.* the *Watersketch* project (http://www.watersketch.net/; visited July 2007).

The analysis of anthropogenic influence along the shorelines can be a useful tool in eco-regional planning and, in addition, involves identifying conservation targets as described by Ferdaña (2002). It enables the modelling of the ecological state and pressure factors of marine environment. As a preliminary suggestion, should the analysis indicate that over 40 % of all investigated areas belong to one of the two highest classes (class 4 or 5), there may be a demand for actions to guarantee a satisfactory ecological state. These actions may involve intensified monitoring, restrictions, conservation or other appropriate means. One should remember that the influence of human activity on the marine environment may be significant without navigable routes (Oulasvirta & Leinikki 2003), housing (Christensen 2002), or roads. Nevertheless, this recipe describes a tool for estimating the likelihood of human impact on important coastal habitats.

The recipe can be seen as a further development and application of the tool by Tullback *et al.* (2001) and Mattison (2003), see previous tool, section 2.4.1. The work phases and instructions presented below are suggestions how to perform the analysis - users are encouraged to alter buffer distances, numerical values or other elements, if needed. The recipe is written to be carried out using lagoon data, but is applicable for inlets and bays and any type of considered habitat, as well.

Data requirements
- Water mask (data separating sea areas from land, converted to polygon format)

- Polygon data of coastal lagoons and and / or shallow inlets and bays

- Location of buildings, in vector format (points or polygons)

- Road network, in vector format (polylines), in different road classes if available

- Shipping / boating lanes, in vector format (polylines), including channel depths if available

Step-by-step process

1 Pre-process the lagoon and building data sets and the water mask

- Open the attribute table of the lagoon polygon and calculate the areas to a new column. The easiest way to perform the task in *ArcView* is to use the *XTools* extension (*Calculate Area…*).

  NB: Depending on the accuracy and scale of the source data, there may be *e.g.* misclassified land / sea areas in the water mask leading to a biased result. If possible, try to detect and remove or at least reduce errors relating to area calculations.

- Create a new column for storing the unique lagoon identification numbers (later referred to as *Lagoon ID*) and update cell values 1,2,3,…,n beginning on the first row (no sorting should be taking place). Save the changes and close the attribute table. You may use an *Avenue* script *Autonumber a field* (available on http://arcscripts.esri.com/, visited July 2007). Save the changes and close the attribute table.

- If your buildings are in polygon format, you have to convert them to centroid points. In *ArcView*, that can be easily done using the *XTools* extension (*Convert shapes to centroids*).

- If the water mask contains lagoons, they have to be removed (in later analyses, water mask and lagoon areas must not overlap). It is possible, make a union between the polygon themes (*e.g.* by using *GeoProcessing Wizard* or *XTools*) and remove the lagoons in the resulting file.

2 Create a buffer zone for buildings situating close to lagoon polygons

- First, buffer your lagoon polygons to extend 100 m on the land area and store the result in a new file. *XTools* takes the least effort to perform the task (*Buffer selected features* → buffer distance 100 m → buffer option: *Polygon+ / Polygon-* → output structure: *Noncontiguous*), but *e.g. Create Buffers* may be used.

- As a result, you should have lagoons buffered by 100 m (buffered polygons containing the original lagoon area; this is important if the accuracy or scale of building and sea/land data differ). If *XTools* were used, a *Buff_id* field (later referred to as *Buffer ID*) has been created in the attribute table – the values should match the *Lagoon ID* - numbers at the corresponding locations. If buffering was performed in other way, a field like *Buffer ID* has to be created (cell values corresponding to the *Lagoon ID* values may be updated *e.g.* via a spatial join or, if the material is small, manually).

- From building centroid points, separate the ones at the shore zone, *i.e.* that fall inside the buffered lagoon areas. You are able to do that using *XTools* (*Clip With Polygons(s)*) or *GeoProcessing Wizard* (*Clip one theme based on another*).

  NB: If you have an accurate attribute data related to your buildings, you may separate and delete those buildings that have, in your opinion, no anthropogenic influence on the ecological state of a lagoon (*e.g.* a bird-watching tower) – it will help to get

more tenable results. Using a digital elevation model and defining the lagoon shore zone based on topography would be an improvement, but would take considerably more time and effort.

- Make a check whether a building centroid point (from those that have been clipped) is closer to a lagoon or to another water body indicated by the water mask not containing the lagoon areas. The assumption is that a building makes the strongest effect on the nearest shore / water area.

  o An easy way to perform the task in *ArcView* is to download an *Avenue* script *_EC_Nearest Feature ver. 1.10* (available on http://arcscripts.esri.com/, visited July 2007) or similar.

  o Place the script on your *ArcView* project, compile it and make two runs – first to check what is the minimum distance between centroids and lagoon areas, then between centroids and sea bodies (Base theme: building centroid points; Target theme: lagoon polygons or water mask).

  o Select building centroid points that have a longer distance to lagoon than to the water mask and remove them.

  NB: if you have access to aerial photo, you can manually check the buildings that are closer to sea than lagoons before removing them – if there is a visible pier/dock or some other signs of anthropogenic pressure on lagoon area, the building centroid point should not be removed.

- After tuning the building centroid points as described above, you are ready to create a polygon data set representing the surrounding effect zone. Make a buffer of 100 m (or another relevant distance) around the points (*XTools* or *Create Buffers*) and choose the distinct buffers to be dissolved.

- Update the information about the absolute number of buildings related to each lagoon – you will need this information later on.

  o Make a spatial join (in *ArcView*, using the *Shape* column in attribute table) between buffered lagoon polygons and building centroid points (those at the shore zone affecting the lagoon). As a result, the attribute table of centroid points is updated so that every point has information of *Buffer ID* – the id-number of a polygon in which the centroid point is locating.

  o Summarize the *Buffer ID* field on the centroid points' attribute table (summarize by sum); as a result you will get a table where there are *Buffer ID*s and *Count*, the latter meaning the amount of buildings on the shore zone of a certain buffered lagoon.

  o Make a tabular join between the table just created and original, non-buffered lagoon polygons; join *Buffer ID* to *Lagoon ID* (if instructions

are followed, the id-numbers should be corresponding at the same locations).

- o Make a new column in the lagoon polygon attribute table, copy the number of buildings there and remove the join.

3 Create a buffer zone for road network

- Open the attribute table of road network polylines and make a new numerical column for calculating the buffer zones.

- For the column just created, set buffer zone values representing the disturbance area around the roads. You may use class values given in Table 9, or create ones of your own. If the road network data you are working with is not classified at all, you may have to decide a constant value (*e.g.* 50–100 m).

Table 12   Road buffer zones according to road class (Stoms 2000; Reyers et al. 2001).

Road class	Buffer zone (m)
Motorway, highway or other very significant road	500
Other two-track road, main road	250
Significant one-track road, secondary road	100
Less significant one-track road, rural road	50
One-track road, less than a few meters wide	25
Smaller tracks	5–15

- After updating the buffer values you can create the road buffer polygon file. In *ArcView*, use either *Xtools* or *Create Buffers* and define the buffer distance to be decided based on the attribute table (buffer zone field). Choose the distinct buffers to be dissolved.

  NB: This approach does not take the traffic densities to account, however, if you possess such data, you may perform the buffering based on that information

4 Create a buffer zone for shipping / boating lanes

- Open the attribute table of shipping / boating lane polylines and create a new numerical column for storing the appropriate buffer zones.

- In the column just created, calculate the buffer zone values by multiplying the lane depth by 50 – at least in the conditions of Finland and Sweden this may be an adequate estimate, but the real disturbance to floral and faunal conditions induced by ship/boat traffic is still not so well-known.

  NB: The channel depth does not tell the actual dimensions or traffic density of vessels, but is a good substitute for more detailed data (if your data include information on traffic density, you may define buffer values using them). Differences on the disturbance zones between diverse benthic substrates are not considered on this recipe.

- After updating the values you can create the buffer polygon file representing the lane disturbance. In *ArcView*, use either *XTools* or *Create Buffers* and define the buffer distance to be decided based on the attribute table (buffer zone column). Choose the distinct buffers to be dissolved.

5 Create a merged polygon theme combining different anthropogenic pressures

- Merge all three buffer data sets created above to one single data set (*GeoProcessing Wizard* or *XTools*).

- After merging the data sets, dissolve distinct polygons together because of overlaps and irrelevant feature borders. You can do this, for example, using *GeoProcessing Wizard*. An *attribute to dissolve* should be any same value for all polygons – if you do not have such a column on the attribute table, create it.

- Clip the dissolved polygons with original, non-buffered lagoon polygons (*GeoProcessing Wizard* or *XTools*).

- You should now have one multipart polygon including all buffered areas on lagoons. Because areal extents have to be calculated separately for each lagoon, the polygon has to be separated to singlepart polygons. In *ArcView*, an easy way to complete the task is to use the *XTools* function *Convert Multipart Shapes to Single Part*.

6 Calculate the proportional areas of anthropogenic pressure zones of each lagoon

- Make a spatial join (in *ArcView* a join using the *Shape* column) between original, non-buffered lagoon polygons and merged, single-part buffer polygons created at Step 5 – you get the information at which lagoon a buffer polygon is situated (*Lagoon ID*).

- On a single lagoon area there may be several buffer polygons and they have to be dissolved before area calculations take place. Use *GeoProcessing Wizard* or *XTools* (the *Attribute to dissolve* is *Lagoon ID*).

- Open the resulting, dissolved file and calculate areas for polygons (the easiest way in *ArcView* is to use *XTools*).

- Join the dissolved file to the original lagoon table using the *Lagoon ID* –column (a tabular join; the column should be present in both tables). In the original lagoon file attribute table you now have the information of how large area of each lagoon is affected by anthropogenic activities (a summed area of building, road and shipping / boating lane activity buffers, respectively).

- Create a new numerical column on the table and calculate the proportion of buffer areas on each lagoon (divide the total area by buffer area using the *Calculate* function). You can multiply the result by 100 to transfer the result to percentages.

7 Classify the result

- Make a preliminary classification of anthropogenic pressure using class limits described in Table 12 or ones of your own.

Table 13 Classification of anthropogenic pressure on lagoons according to the proportion of buffer area that covers the lagoons.

Proportion of the buffer area	Classification
0 %	Class 1 – No indication of exploitation
0,1 – 10 %	Class 2 – Low indication of exploitation
10 – 25 %	Class 3 – Intermediate indication of exploitation
25 – 50 %	Class 4 – High indication of exploitation
50 – 100 %	Class 5 – Very high indication of exploitation

- Check and make some corrections to the classified results:

  o If there is a shipping / boating lane intersecting the lagoon area, the pressure class should be set to Class 5 regardless of the buffer proportion, as presence of a lane inside a lagoon is a very strong indication of exploitation. The lagoons of this category may be found by spatial selection or, at least in relatively small data volumes, manually.

  o There may be some misleading classifications for semi-large lagoons. If a diameter of a lagoon is, say, several hundred meters, the buffered areas of buildings or smaller roads only constitute a minor part of the whole area, and if there are no navigable routes, the classification may indicate only moderate level of exploitation no matter how many buildings there are at the shore zone. A suggestion for correction based on the absolute number of buildings relating to each lagoon (should have been calculated in the lagoon attribute table) is described in Table 13.

  NB: The correction methods and the values presented here are intended to be used only with small-sized lagoons (diameter preferably 0,1 – 3 km) and are best suited for conditions in Finland and Sweden; other locations may require revision.

Table 14 Recommendation of re-classification of anthropogenic pressure on lagoons based on absolute number of building present at the shore zone of the lagoons.

Absolute number of buildings at the lagoon shore zone	Recommended update for classification
Less than 5	No update needed
5 – 9	Change the class value to Class 3 if not already 3 or more

| 10 – 14 | Change the class value to Class 4 if not already 4 or more |
| 15 or more | Change the class value to Class 5 if not already 5 or more |

Indicator in the Assessment of Management Performance

The tool visualises pressure factors in a coastal environment. In areas with post-glacial land-upheaval, the location as well as the succession stage of lagoons must be seen in the light of the ongoing land uplift process, which continuously changes the archipelago landscape. Therefore, a link to the Archipelago Zonation tool (Section 2.3.2) is justified. Management of these habitats then needs to incorporate all lagoon stages and see to that the chain of succession in a given area is not cut due to anthropogenic influence. Thus, an area needs to possess all types of lagoons in an unaltered pristine state. Only then can the occurrence of these threatened priority habitats be secured. The linkage between a general pressure and a habitat-specific pressure is described in Section 3 (Fig. 29).

Spatially, the human influence can be compared within and among zones. Special attention should be given to Class 1, which together with Class 2 is suggested to indicate a favourable conservation, referring to the Habitats Directive. The comparison may be done by measuring the relative coverage of different classes, absolute number and the frequency of occurrence and the proportion of different classes. The spatial extent of the input parameters can be analysed separately.

Over time, the change of above mentioned measurements can be conducted. As mentioned above, the land uplift, especially in the northern part of the Baltic Sea, gives an extra temporal dimension to this indicator.

Fig 9   Principle steps of performing the analysis Predicting anthropogenic influence on coastal lagoons and large shallow inlets and bays*.*

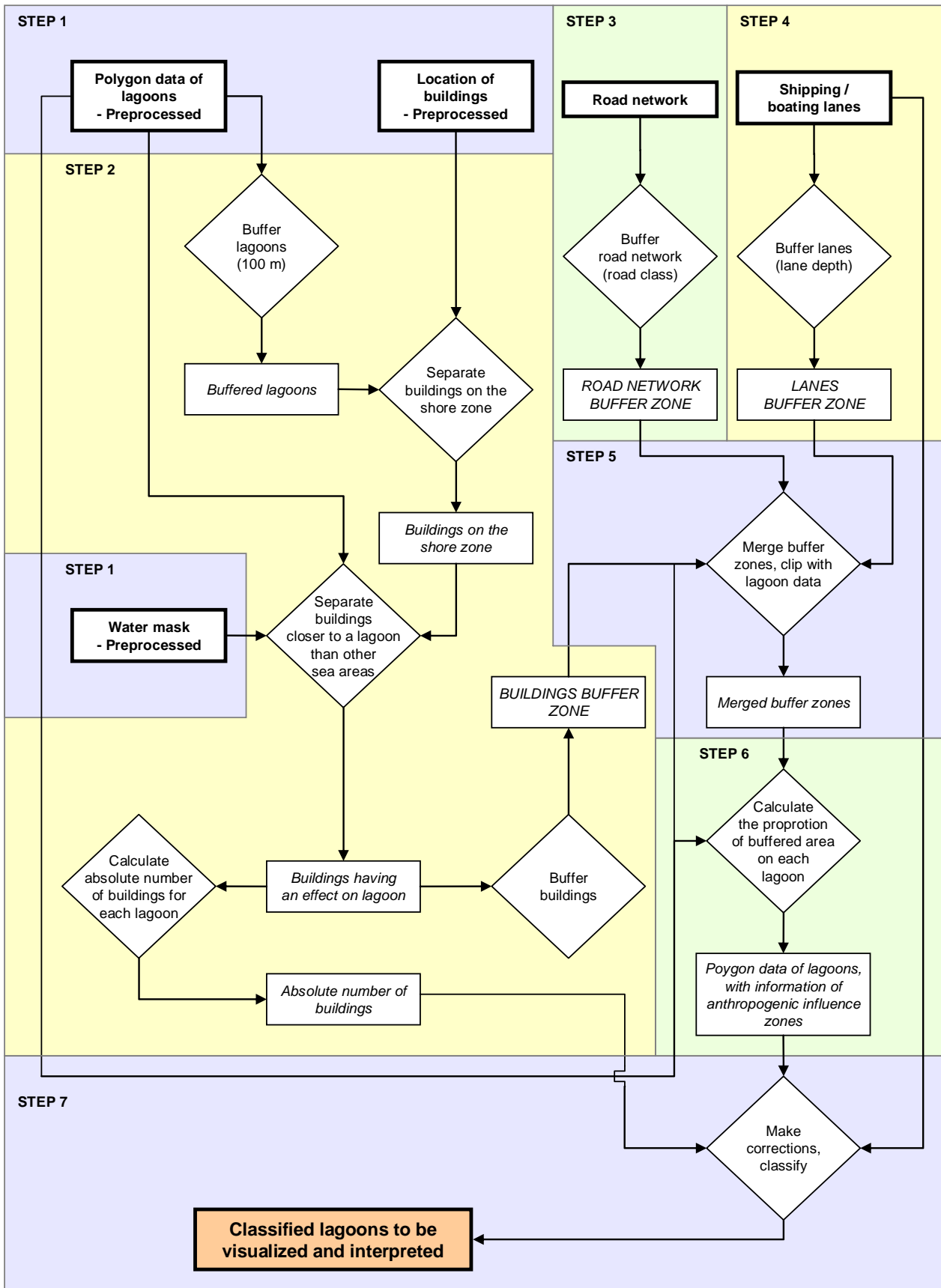*Fig 10   Sample images of performing the analysis* Predicting anthropogenic influence on coastal lagoons and large shallow inlets and bays.

2.4.3 Communication infrastructure

Description / full name	Predicting pressure induced by anthropogenic influence on marine nature with a communication indicator of islands
Zoning purpose	To provide an indicator of pressure expressed as the direct habitat displacement caused by the demand of space and the indirect influence on nearby habitat quality
Target use / feature	Coastal development, recreation / non-specific coastal and marine habitats
DPSIR indicator	Urban sprawl Driver; assumption: the easier an area is accessed, the greater is the pressure on the environment due to coastal development and requirement of space
Assessment indicator	Socio-economic pressure: Multiple uses causing *e.g.* deterioration of sensitive habitats. Preferable assessment of change of pressure: 5-10 years interval
Data used	Polygon data of islands, public transport status in vector or tabular format, electrification status in vector or tabular format, mobile network coverage in raster or vector format, regional population centres and the number of inhabitants
Principal steps	Update the attributes of public transport, electrification and the mobile network coverage data sets to the island polygon. Calculate the influence of population centres, and classify the final communication level
Related tools	Archipelago Zonation (2.3.2), biophysical tools (2.1.1-2.2.5), socio-economic pressure tools, *i.e.* lagoon pressure indicator
Accuracy	Dependent on the quality and format of the input data
Difficulty, 1-5	2 – 3
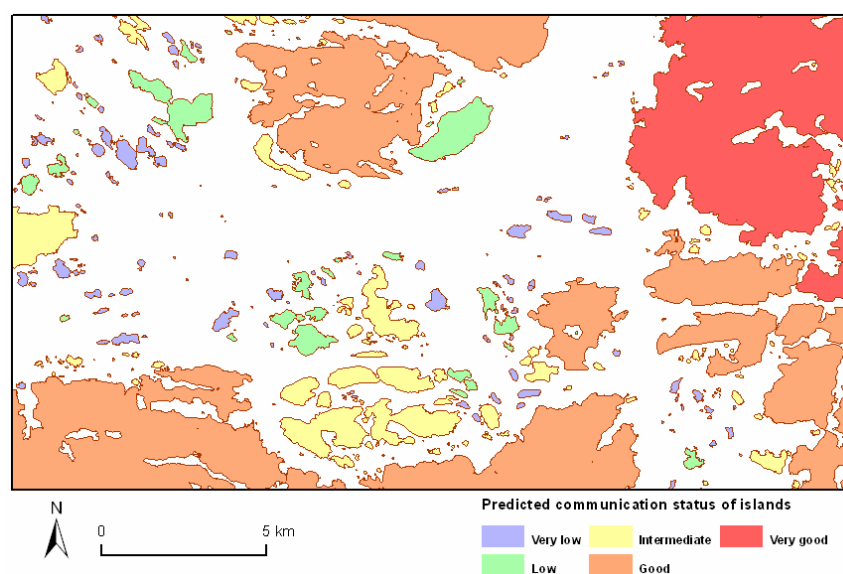
Fig 11

The final result of the tool indicating communication infrastructure on an island level with a five-level classification. Shown is a part of Pilot Area 3, the Archipelago Sea.

Predicted communication status of islands

Very low   Intermediate   Very good
Low   Good

In coastal and marine environment, single uses often can be considered as relative sustainable. However, when summing up all different type of uses in an area, the cumulative impact can increase the pressure on the environment to an unsustainable level (*e.g.* Dee Boersma & Parrish 1999; Francour *et al.* 2001). The diffuse and cumulative effects of multiple uses, such as coastal development and recreation, on ecosystem structure and processes can be challenging to assess. Multiple uses put greater demand on the management, as they are less easily controlled than discrete single uses, and the common separation between terrestrial and marine management can induce negative impacts (Francour *et al.* 2001). A tool facilitating management of coastal and marine ecosystems would indeed need to consider the above.

There are only few investigations that concentrate on modelling communication or accessibility aspects using GIS methods. Most of them are related to the road network and the results are calculated by using either direct distances along linear features (*e.g.* Department of Health and Aged Care 2001), or by constructing a constant cost/time surface based on varying travel efforts (*e.g.* Julaio 1999). The location of roads is an essential matter in archipelagos as well, but there must be made a clear distinction between the different types of transport connections as they potentially facilitate varying amount of human influence. A constant cost surface is not either the best method to be used – an island may be situated very close to an area of good connections, but in lack of public transport (accessible only by boat) it must be classified to have a fairly low communication level. There are some studies that concentrate on the accessibility of island areas (*e.g.* Cross & Nutley 1999), but they often tend to be descriptive rather than specific and quantitative.

In the DPSIR framework, human presence and communication infrastructure can be viewed both as driver and pressure factors, respectively: As driver, the better the connections to a specific place are the more people are arriving there, which increase pressure. On the other hand, as drivers, the more people there are that are willing to travel to an area, the better communication facilities are being built, which increase pressure. Normally most uses are facilitated by presence and number of humans and so are the accessibility and the development of communication infrastructure important factors in assessing human influence (*e.g.* Stoms 2000). The easier an area is accessed, the greater is the likelihood that pressure impacts the nature, including the coastal and marine environment. In archipelagos with deviating land/sea ratios, islands normally only are accessed with bridges, ferry and boat connections, which are easily measured. Hence, communication infrastructure can be used as a proxy indicator pointing out areas under varying level of potential anthropogenic pressure on the terrestrial as well as the marine environment.

Four data sets related to communication infrastructure are used: public transport, mobile phone network, electrification status and geographical distance from regional population centers. The factors can optionally be used as separate indices, or as a single combined indicator. We decided not to include the distribution of houses as this information may be used separately to show human influence. Optimally, the indicator can be used parallel to the distribution of houses as the indicator has a wider information basis that indicates pressure originating from more than presence of houses.

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Public transport is probably the most powerful single indicator for the presence of human influence. The data set used in the development of the recipe is consists of four classes: bridge-connected islands, islands having a permanent ferry bridge connection (frequent runs, quite short distances), islands having an occasional ferry connection (scheduled but infrequent runs) and islands without any public transportation and accessible only by boat. Mobile phone network is as well divided in four classes (UMTS / GSM functional indoors / GSM functional outdoors / no network coverage), and electrification status in three classes (an own distribution station / cable connection / no electricity). Geographical distance from population centres alone is not adequate indicator of communication status because of the non-continuous structure of archipelago connections, but may be used to complement other indices. A place near a large population concentration may be assumed to have easier access and a larger pool of potential visitors compared with location far off.

Geographical distance was decided to be weighted so that the highest communication status would prevail only very close to population centres while the following levels extend to a considerably larger area, especially around large cities. This approach was thought to be the most suitable to represent human activities and was carried out using *gravity index* – an index initially developed to describe the degree for which cities attract retail trade from surrounding locations (Kline *et al.* 2003). The gravity index is calculated by using a formula *population / (distance in kilometres)^2*. The population limit for including a centre to analysis was decided to be 5000 inhabitants (*cf.* Department of Health and Aged Care 2001); smaller population centres were regarded as insignificant for communication status.

The recipe is consisted of aforementioned parts and has been constructed using a quite straightforward approach: a *communication level* of an island is calculated as a sum of different components. Therefore, it is always possible to add or delete data sets to the analysis. The end result is classified to five classes representing the communication level on a more general scale. The data sets and numerical limits set in the recipe are estimated to be somewhat suitable for the archipelago of SW Finland, but may not be the best ones for other areas. There may be differences in the availability of data sets, so one should consider the recipe primarily as an example and feel free to modify it whenever needed. The example maps should be viewed just as examples, with the notion that errors in in-data may occur and are not controlled for.

Data requirements
- Polygon layer of islands on the research area (from a digital map database, sea chart etc.)

- Public transport status data (land bridge / ferry bridge / occasional ferry / no public transport; in vector or tabular format)

- Electrification data (island having an own distribution station / having a cable connection / not having electricity supply; in vector or tabular format)

- Mobile network coverage data (in raster or vector format, usually containing both islands and surrounding sea areas; may be available from a local telecommunications service provider)

- Regional population centres (points) and the number of inhabitants (from a digital map database, or often may be quite easily self-digitized).

Step-by-step process

1 Update the attributes of vector/tabular data sets (public transport & electrification) to the island polygon layer

Depending on the scale and the similarity of the available data, attributes may be updated easily or it may require a vast amount of work. In a simple case, transport status and electrification data are available as polygon data sets that have exactly congruent borders or share some unequivocal attribute (a unique name or ID number) with the island polygons – the task to be done is only a simple join by using common attributes or location (a spatial join by using shape-column), possibly after that copying attributes of interest to a new column and removing the join to keep the data as simple as possible. If public transport and electrification are available as tabular data, they must share some common attribute with island polygons. Tables may as well be added to ArcView in dbf-format and joined to the island theme.

Unfortunately, updating polygon attributes to another data set may sometimes be a tricky task. Quite often there are no common attributes, and a direct spatial join may give an unsatisfactory result if polygon borders are slightly different. If polygons are at least approximately similar, the solution for the problem may be first to convert the island polygons to centroid points and only after that create a spatial join (see instructions below).

- Open the attribute table of island polygons and if not already present, add a new field to store a unique polygon ID number (or similar) for each polygon. You may use, for example, an Avenue script *Autonumber a field* available at http://arcscripts.esri.com/ (visited July 2007).

- Convert the island polygons to centroid points using the *XTools* extension (*Convert Shapes To Centroids*), available at http://arcscripts.esri.com/ (visited July 2007). Make sure that the ID column (or similar) is transferred to the centroid points.

- The purpose is to spatially join the necessary polygon attributes with the centroid points. Open the attribute table of the input polygon data set (public transport or electrification) and make a spatial join with island centroid points (in *ArcView*, a join by using shape-column). As a result, polygon attributes should now be updated to the centroid point layer. Necessary attributes may now be copied to new columns in the centroid points' attribute table and the join can be removed.

Now, the centroid points should fall inside the polygons, and one polygon should contain only one point feature in order to create a one-to-one relationship. That is not

always the case, so this step may require some fine-tuning of data sets before it can be completed successfully.

- When the necessary attributes have been updated to the centroid point data set, they have to be transferred back to the island polygon layer. The task can be completed by making a simple tabular join – centroid points and island polygons can be joined using the identical ID column of respective layers. After joining, necessary attributes may be copied to a new column in the polygon data set attribute table and the join can be removed.

2 Update the mobile network coverage to the island polygons

- If not created during step 1, a new attribute field for storing a unique ID number (or similar) for each island polygon is needed. A centroid point data set is required as well (see Step 1 for more instructions).

- If the mobile network data is in polygon format, you can first join it spatially with island centroid points, and the points again with island polygons using a tabular join (see Step 1). In this case, one mobile network polygon may contain many centroid points as polygons do not represent single islands.

  Using the procedure described above, the mobile network attribute value that is present at the centroid point of an island will be given for the whole island – it may not be the most suitable way to process large islands, but still gives a good approximation for the mobile phone network and is easy to do.

- If the mobile network data is in raster format, it may first require some level of generalization (should not be too detailed for this purpose). The raster data can either be converted to polygons (in *ArcView*, using the function *Convert to Shapefile*) and the process carried on as described in Step 2, or raster values may directly be extracted to centroid point attribute table to be finally joined to island polygons. One way in *ArcView* to extract raster values is to use function *Summarize zones* (*zone-defining field* is the point data set's ID field and *theme to summarize* is the raster data set). The resulting table can then be joined to island polygons by using the ID number, and raster values (column *Min*, *Max*, *Mean* or *Sum* – all having the same value due to the point location) can be copied to a new column.

3 Calculate the influence of population centres and update the information to the island polygon data set

- Check the population centre data and remove all features indicating less than 5000 inhabitants. Make sure that population data extends to a somewhat larger area than the primary research area – the effective zone especially around major city centres is considerably large.

- Calculate gravity matrixes for population points.

    o Make the population point data set active and select a single point at a time.

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o Select *Find Distance*; define grid extent and cell size. A cell size of 500 m was found appropriate when testing the recipe.

o Add a small distance number to the calculated distance matrix, say 1 m, using the *Map Calculator*; otherwise a grid cell situating precisely on the centre location will gain a zero value that complicates later calculations.

o If the map units are other than kilometres, the matrix needs to be tuned by using the map calculator (*e.g.* if the units are in meters, you have to run a calculation *<matrix> / 1000*).

o Calculate the value for gravity matrix by using the *Map Calculator* (*<population> / <matrix>²*) – if you encounter problems when performing the calculation, try first to calculate *<matrix>x<matrix>* and after that *<population> / <the preceding result>*.

o Select *Theme → Save Data Set* to save a single gravity matrix, and repeat the procedure for every population centre.

- After calculating gravity matrixes for every population point, they need to be summed for a single grid surface. Use the *Map Calculator* and apply a formula:

  < matrix of point 1> + < matrix of point 2> + ... + < matrix of point n>

- Perform a classification (*Reclassify*) for the summed gravity matrix. It may be difficult at first to perceive and understand the actual values produced by the index, and Table 14 is intended to clarify the method. The values are gravity index scores for a single population centre with regard to the number of inhabitants and distance from the centre point; one should still remember that the data used in the recipe is a summed value of several points.

Table 15 Gravity values around a single population centre.

	Distance 1 km	Distance 5 km	Distance 10 km	Distance 25 km	Distance 100 km
Population 100 000	100000	4000	1000	160	10
Population 25 000	25000	1000	250	40	2,5
Population 10 000	10000	400	100	16	1
Population 5 000	5000	200	50	8	0,5

- A classification to four classes was used (class limits defined below, should be applicable at least in the conditions of Finland and Sweden).

- o Summed gravity matrix score 10000 or more: a location very near to a densely populated area

- o Summed gravity matrix score 1000 – 9999: a location quite near to a densely populated area

- o Summed gravity matrix score 100 – 999: a location quite far away from a densely populated area

- o Summed gravity matrix score below 100: a location very far away from a densely populated area

- Add the summed, reclassified gravity matrix scores to the island polygon data. The task may be performed again by checking which raster value is present at the centroid point of an island. See Step 2 for more instructions.

4   Calculate the final communication level and classify the result

- The island polygon data now contains public transport, electrification and mobile network information, and gravity index values as attributes. Make a new numerical column in the attribute table and name it as *communication level*, for example.

- Sum the different communication scores to the overall communication level so that the result will vary between 0…100, for example. You may use the proposed values given in Table 15, or choose ones of your own to better correspond the reality of your research area.

Table 16 Proposed communication points for different communication factors.

Communication category	Category class	Communication scores
Public transport	Land bridge	35
Public transport	Ferry bridge	20
Public transport	Occasional ferry	10
Public transport	No public transport	0
Electricity	An own distribution station	25
Electricity	Cable connection	10
Electricity	No electricity	0
Mobile network	UMTS	20
Mobile network	GSM, indoors	15
Mobile network	GSM, outdoors	10
Mobile network	No coverage	0
Regional pop. centres	Very near	20
Regional pop. centres	Quite near	10
Regional pop. centres	Quite far away	5
Regional pop. centres	Very far away	0

- Classify the summed result to five classes as described in Table 17.

Table 17 The five classes indicating the communication level in the archipelago area.

Communication level	Classification
0 – 20	Class 1 – Very low communication status
21 – 40	Class 2 – Low communication status
41 – 60	Class 3 – Intermediate communication status
61 – 80	Class 4 – Good communication status
81 – 100	Class 5 – Very good communication status

Indicator in the Assessment of Management Performance
The tool visualises pressure factors in a coastal environment as a proxy for the direct habitat displacement caused by the demand of space of human activities and the indirect influence on nearby habitat quality. It can be combined with several biophysical features in assessing the state and change of the vulnerability. It visualises the difference in potential pressure on island and can be used to direct monitoring efforts to areas of concern. The linkage between a general pressure and a habitat-specific pressure is described in Section 3 (Fig. 29). The tool shows where human presence may be found, *i.e.* houses and cottages, but it also has a broader information basis, thus providing a potentially wider perception of the human presence that likely is not attributed only by physical attributes such as houses at the shoreline.

Spatially, the communication infrastructure of islands can be compared within and among zones. Special attention should be given to Class 1, which indicates no human influence and unaltered conditions. The comparison may be done by measuring the frequency of occurrence and the proportion of classes. Over time, it is not highly relevant as a management performance indicator regarding the follow up of pressure change since the input data is not likely updated or changed on a regular basis.
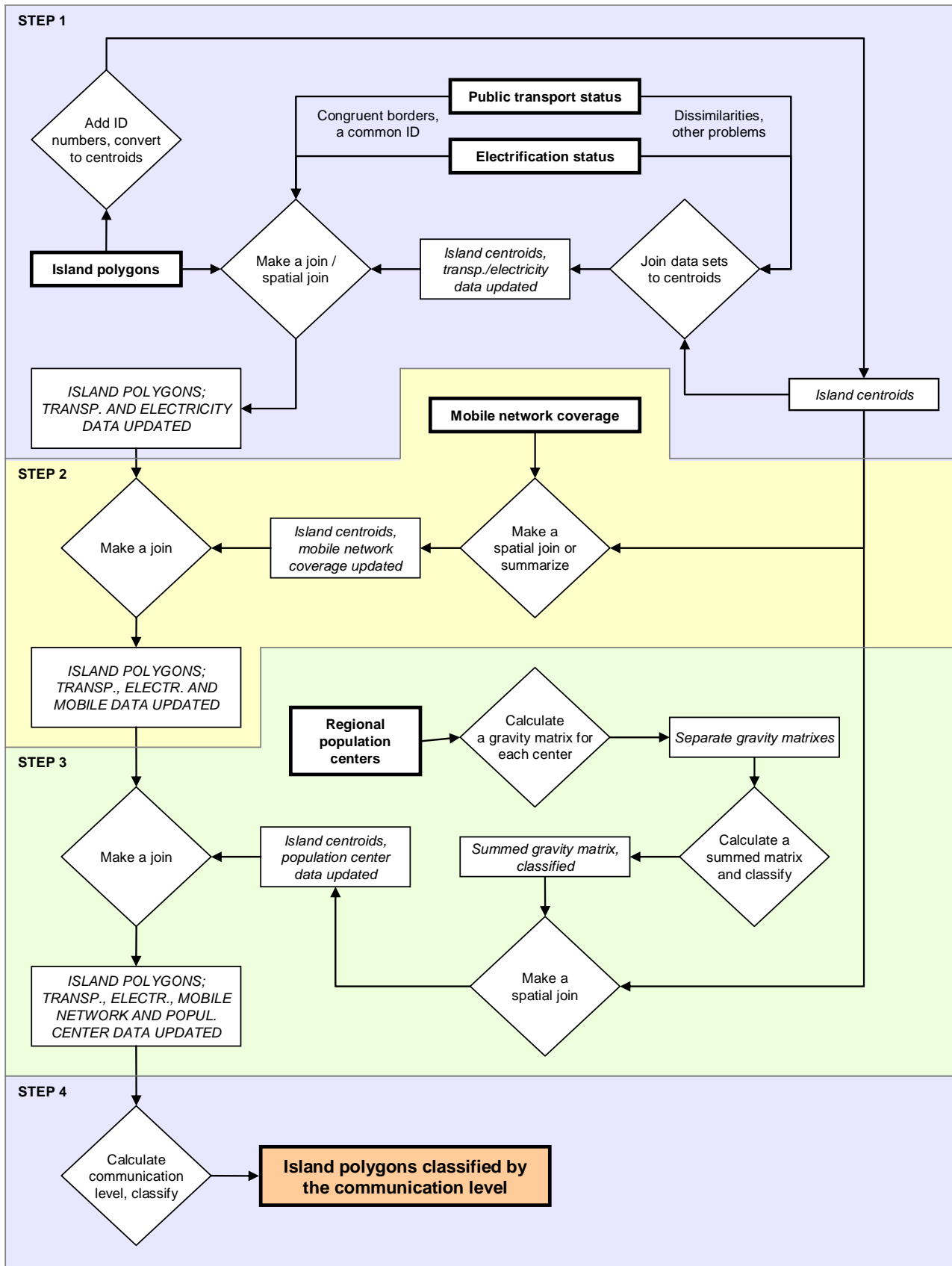
Fig 12   *Principe steps of performing the analysis* Predicting pressure induced by anthropogenic influence on marine nature with a communication indicator

Fig 13   *Sample images of performing the analysis* Predicting pressure induced by anthropogenic influence on marine nature with a communication indicator.

2.4.4 *Effects of recreational boating and fishing on sensitive habitats*

Description / full name	Predicting the effects of recreational boating and fishing on sensitive habitats
Zoning purpose	To indicate the vulnerability of habitats based on the predicted distribution of pressure from angling and gill-netting recreational fishing from small boats
Target use / feature	Recreational boating and fishing / shallow sheltered fish nursery habitats (*e.g.* pike, perch)
DPSIR indicator	Environmental state and socio-economic pressure
Assessment indicator	Biophysical in assessing the vulnerability of the habitats, Socio-economic in assessing the level of pressure. Preferable assessment of change: 5-10 years interval
Data used	Polygon or raster layer of land/sea areas, location of harbours (points), built-up areas or other population density data in polygon or raster format, depth raster model and wind exposure raster model, location of houses and cottages (points)
Principal steps	Calculate the distance matrix of single harbours weighted with population density of the harbour influence area, summarise to a cumulative raster, classify as a pressure layer. Separate sensitive areas and overlay with pressure to indicate vulnerability
Related tools	Indicator of vulnerability of coastal lagoons to human influence (2.4.2), Effects of marine management activities on fishing (2.5.1)
Accuracy	Depends on the accuracy of harbour and population data, and the success in separating sensitive areas
Difficulty	4

Fig 14

The final result derived from the tool indicating level of vulnerability of fish nursery habitats from very low level (low or no indication of recreational fishing) to very high vulnerability. Shown is a small part of Pilot Area 3, the Archipelago Sea.

The main purpose of this tool is to exemplify how to combine spatial information of marine features and pressure factors in order to express the distribution of sensitive aquatic habitats and pressure from sea uses, respectively, and thus indicate the vulnerability of habitats. The princip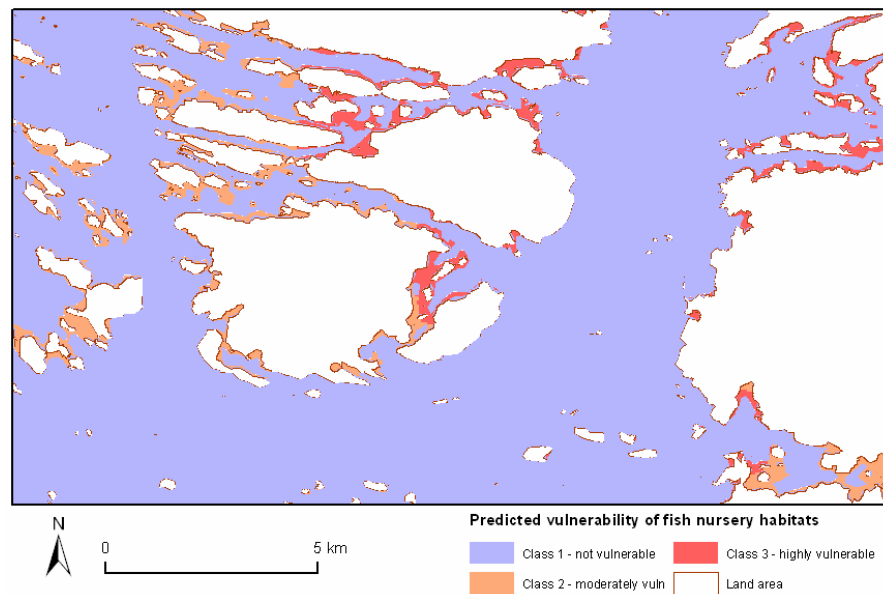al approach for assessing vulnerability can be used for other marine feature-pressure pairs as well. Hence, the present recipe is an example of one such pair, and the possibility to combine any set of relevant feature-pressure pairs should be underlined.

The majority of studies concerning the impacts of fishing on the aquatic environment deal with commercial fishing. During the last decades, the importance of non-commercial, recreational fishing has been rising and the effects on the aquatic environment therefore likely are underestimated (Lewin *et al.* 2006). Accurate statistics concerning the extents of recreational fishing are not available, but it has been estimated that approximately 12 % of the global fish harvest is contributed by recreational fishermen (Cooke & Cowx 2004). The importance of recreational fishing and number of fishers varies greatly among regions. In the Central European countries, approximately 5 % of the population consider themselves as recreational fishermen whereas in Norway the proportion is about 50 % (Mikkola & Yrjölä 2003). In the European Union, recreational fishing is most common in Finland (Mikkola & Yrjölä 2003). Year 2004 there were 1,858,000 non-commercial fishermen in Finland (35 % of the total population) and the total fish harvest was 38 208 tons (Nylander 2006); the proportion of the total harvest was approximately one third, but the economical value twice as high (Anon 2001).

Recreational fishing often is a small-scale activity performed on a sustainable basis without any harsh detrimental effects on the aquatic environment and the general perception is that recreational fishing only has minor effect compared to commercial fishing (Winn 2006). However, the cumulative effect of several small activities can be significant, especially in sensitive areas, and evidence of the negative consequences of recreational fishing activities is mounting rapidly. Factors such as lack of monitoring programs, spatial and temporal variability of fish populations, diffuse and small structure of the recreational fisheries, complexity of the behaviour of anglers, poor intergenerational memory of angler communities, and management actions masking the decline of fish stocks make difficult to obtain an accurate picture of the impacts of angling (Post *et al.* 2002; Almodóvar *et al.* 2004; Asoh *et al.* 2004; Cooke & Cowx 2004; Arlinghaus & Cooke 2005; Lewin *et al.* 2006). The underestimation of the effects is further supported by the fact that studies tend to concentrate on marine, offshore areas whereas recreational fishing normally occur in near shore areas and in freshwater (Arlinghaus & Cooke 2005) including sensitive areas.

One of the main characteristics of recreational fishing is the high selectivity with respect to species and habitat, size class, age, sex, and behavioural traits thus inducing alterations in trophic structure and fish population dynamics (Westera 2003; Cooke & Cowx 2004; Lewin *et al*. 2006; Winn 2006). Lewin *et al.* (2006) provide a comprehensive list of possible negative effects induced by recreational fishery. Firstly, there are direct effects on the target species, such as the alteration of the natural age and size structure, delay of stock rebuilding through depensatory mechanisms, loss of genetic variability and evolutionary changes. Secondly, there are indirect impacts that occur via the exploitation of a target species on other components of the aquatic food webs (changes in trophic cascades, trait mediated effects). Thirdly, there are impacts that are associated with

the fishing activity (side-effects), *e.g.* habitat, bird and wildlife disturbance, boat traffic, noise, nutrient inputs and loss of fishing gear. When assessing the pressure from recreational fishing in a wider context, it is important to recognise that the side effects may have considerably more widespread effects than the actual fishing.

One key issue in estimating the effects of any pressure in an area is to spatially predict the level of pressure. Regarding recreational fishing, this can be achieved by estimating the location, frequency and abundance of the activities as accurately as possible. Fishermen often choose a fishing site, which provides the maximum yield (Hunt 2005) and abandon areas that do not satisfy their expectation of quality (Lewin *et al.* 2006). There has been attempts to create advanced models to predict the behaviour of fishermen, including factors like travel costs, fishing quality in general, environmental quality, infrastructure, level of encounter with other fishermen, regulations, expected catch, weather conditions, time elapsed since the last trip and aesthetic values (*e.g.* Provencher & Bishop 1997; Train 1998; Hunt 2005). In general, a good fishing site is a location near the origin of the fishermen, and the expected catch at a fishing site should attract the fishermen. One quantifiable factor is the distance from the place of origin, *e.g.* home of fisher. Most fishermen try to minimize the travel costs and most fishing trips are committed over a single day. Provencher & Bishop (1997) concluded that most anglers (driving a car of their own and having an own boat on a trailer) do not travel further than 15 miles (*c*. 24 km) to reach a boat launch site, and Zacharias & Gregr (2005) estimated that small-boat traffic (*e.g.* fishing boats) extend seawards no more than 25 km away from the launch site.

The recipe consists of two easily estimated data sets: a layer indicating the likelihood of recreational fishermen to be present (the *general pressure* layer), and a fish nursery habitat (Bergström *et al.* 2007) layer (here, shallow and sheltered areas used as spawning and nursery areas for coastal freshwater species). The two layers overlaid together result in a vulnerability estimate showing areas where sensitive habitats spatially overlap with the general pressure from recreational fishing. Since fishermen normally fish near the place of origin (harbour, shoreline-locating home or cottage), distance to that location is considered to express the likelihood of recreational fishing pressure to occur. The significance of harbours should additionally be weighted with the number of boats (if accurate data is not available, alternative information like local population density may be used), where a large harbour or population pool increase the pressure on the area. Harbours used in this recipe are typical for SW Finland – they are generally quite small and mainly used by the local people and owners of inland summer cottages. Shallow and sheltered areas are ranked as important marine areas as they are important spawning and nursery areas for fish and overall contain habitats susceptible to deterioration and may therefore be sensitive to the pressure from recreational fishing mainly from boats (Eriksson *et al.* 2004). As being recognized as quality fishing sites for *e.g* .pike and perch, the habitats are favoured by fishermen, especially during spring when fish aggregate to spawn – a period when other bird and wildlife is sensitive to disturbance. The instructions must be seen as estimates and, if committing the analysis for true management purposes, the potential need for additional information has to be recognized, *e.g* .the use of alternative models or real data of the distribution of nursery areas. The assumptions and estimations presented in these instructions are considered to be fairly suitable for the conditions of the Archipelago Sea, SW Finland, and may be modified whenever needed.

Data requirements

- Polygon or raster layer of land/sea areas.

- The location of harbours in the research area (points); in the development of this recipe, the data provided by the project Better Water Quality (Löfgren 2006, Lönnroth 2006) was used.

- Built-up areas or corresponding data to investigate the population characteristics, in polygon or raster format (if accurate data of the usage of harbours is not available).

- Location of houses and cottages (points) on the research area

- Depth raster model (or other applicable data set, for estimating the coverage of vulnerable areas to recreational fishing).

- Wind exposure raster model (or other applicable data set, for estimating the coverage of vulnerable areas to recreational fishing)

Step-by-step process

1 Calculate the population pool in the vicinity of the harbours

One of the most important factors affecting the magnitude of recreational fishing activity originating from a single harbour is the number of people living in the nearby area. In this recipe, it is assumed that people travel at maximum 25 km to a harbour, and the estimate of fishing activity is based on the population density of this radius. If accurate data of the importance or usage of harbours in the research area is available, a classification similar to Table 17 should be done by using that data; otherwise the procedure below is recommended.

Population figures are supplied in a number of ways, one of the most suitable being the number of individual buildings, or better, the number of dwelling houses. However, because such data sets are quite massive to handle, the location of continuous built-up areas are presented here as a good surrogate of population density. The users are encouraged to consider different options to find the best solution for the any given research area, and carefully consider the suitability of the class limits presented below.

- Add the harbour point data set to the view and open the attribute table. Make sure that every point has a unique ID number (1,2,3,…,n). If not, add a new field to the attribute table to store such numbers. You may use, for example, an *Avenue* script *Autonumber a field* available at http://arcscripts.esri.com/ (visited July 2007).

- Make the harbour point data set active and select *Theme → Create Buffers*. Create buffers at a specified distance of 25000 (assuming that your map unit is in meter) and select the buffer barriers not to be dissolved. Save the buffer data set and add it to the view.

- At least in *ArcView 3.x*, buffers are created without joining the point features' attributes and in the reverse order compared to the point data set, *i.e.* the first buffer polygon in the buffer attribute table correspond the last point feature on the harbour points' attribute table. However, every buffer should be given the very same ID number as the corresponding harbour-point to make the analysis possible.

  o Open the buffer polygons' attribute table and add there a new numerical field. Use, for example, an *Avenue* script *Autonumber a field* to create the ID-numbers for every polygon (beginning from "1").

  o Calculate new ID numbers to match the harbour point IDs using the formula.

  [maximum ID number] + 1 – [ID number]

  e.g. if there are 50 buffer polygons and you are recalculating the ID number for polygon number 14, the result will be 50 + 1 – 14 = 37.

  o Check the correspondence of the ID numbers between buffer polygons and harbour points.

- If your population data (built-up areas) is in vector format, you need to convert it to a raster. The pixel size should be sufficiently small but there is no matter what value do the raster cells gain.

- For the buffer polygon theme, select *Analysis → Summarize Zones*. Field to define the zones will be the ID number, and the variable to summarize will be the rasterized population data.

- Join the resulting table to the harbour point data using the ID columns. Add a new column for harbour points to store the *Area* (if using built-up area data) or the *Count* (if using single building data) of raster cells. Copy the required values there and remove the join.

- If using built-up area (or corresponding) data, you may further process the areas to percentage values by using the formula.

  *([area value] / Π * (25 000 m)²) * 100 %*

- Classify the result to a new column using the class values presented in Table 17, or ones of your own – these are later used as a weighting factor to assess the probable importance of harbour points.

  NB! The class values presented here are based on the percentage coverage of built-up areas and may not be applicable for other type of data sets. In addition, the values represent the conditions in the SW Finland archipelago with a quite low population density but proportionally a great number of recreational fishermen.

Table 18 Population density classification based on the percentage coverage of built-up areas in a 25 km radius.

Built-up area coverage	Class value
0 – 0.1 %	1
0.101 – 0.5 %	2
0.501 – 1 %	3
1.001 – 5 %	4
More than 5 %	5

2 Calculate the distance matrixes on water areas around harbour points and weight the results based on the population pool

In order to reveal the potential magnitude of recreational fishing in the marine environment, a distance over water to harbour points must be included to the analysis. In this recipe it is presumed that recreational fishermen at maximum travel 25 km from the harbour with a boat.

However, because matrixes around the harbour points are first weighted based on the distinct population density and finally summed, every distance matrix has to be done as a separate raster layer – this may take some time. In addition, the analysis must be carried out in such way that matrix layers do take the location of islands to account.

- Every harbour point should have a unique ID number from Step 1. If not, add a new field to the attribute table to store such numbers. You may use, for example, an *Avenue* script *AddAutonumbers* available at http://arcscripts.esri.com/ (visited July 2007).

- In order to mask land areas off for constructing realistic distance matrixes, you need first to create a *cost grid*.

  o If your land/sea data is in polygon format, you should first create a new numerical column in the attribute table. Update all the sea areas to possess a value 1 and all the land areas a considerably larger value, say, 100000. After that, convert the polygon layer to a raster theme (*Theme → Convert to Grid*). Do not choose too small cell size or your analyses will get too heavy but if too large cell size is chosen, small inlets or waterways are likely to disappear causing misleading results; when compiling this recipe, a cell size of 50 m was chosen and there was a need to manually make a couple of important channels open.

  o If your land/sea data is in raster format, reclassify it (*Analysis → Reclassify*) so that all the sea areas gain a new value of 1 and all the land areas a considerably larger value, say, 100000.

- For every harbour point you take to account in the analysis of distance matrix, repeat the procedure below. Notice that harbour points on top of land areas will give wrong

results; they must be moved slightly to the sea side of the shoreline. The procedure below takes the location of land areas to account; however, if there is a need to simplify the analysis, one can calculate the straight distances instead (in *ArcView*, selecting *Analysis* → *Find distance*) but the result will less accurate.

- o Open the harbour point data set and select a single harbour point at time.

- o Convert it to a raster layer (resulting in a single raster cell) by using the function *Theme* → *Convert to Grid*; as a field for cell value you can use the ID number, for example (it does no matter in later analyses). Select a quite small cell size but not smaller than it is in your cost grid (otherwise, analyses may not work). Add the new theme to the view.

- o Now, the idea is to gain a distance matrix layer representing the effective area of a single harbour, extending 25 km seawards off the harbour, taking land areas to account and having linearly decreasing values (1…0), which finally will be multiplied with the population density class of each harbour (Step 1). In *ArcView* this may be calculated using the *Map calculator* and entering the formula given below (presumption: map units are meters). For additional information on *e.g. CostDistance*-function, check the *ArcView Help*.

  *(25000.AsGrid – [harbour point raster layer].CostDistance([land/sea cost grid], nil, nil, 25000)) / 25000 * [population density class]*

- o Later calculations need *NoData*-values to be changed to zero values. You can do the task by using the *Map calculator* and using a conditional formula that checks whether a cell value is assigned to *NoData*, and if the condition is found to be true, the value will be transferred to "0".

  ([distance matrix].isNull).con(0.AsGrid, [distance matrix])

- o Check the result and save it using an informative name, *e.g.* matrix_[ID].

3 Calculate a cumulative (summed) raster data set from single distance matrixes (created at Step 2) indicating recreational fishing pressure originating from harbours

After calculating distance matrixes for water areas surrounding each harbour and weighting them according to population density, they have to be summed for a single, cumulative raster data set. You may use the *Map calculator* to sum all the grids (must be opened at the current view) as follows: *[matrix 1] + [matrix 2] + ... + [matrix n]*

4 Calculate a raster data set indicating the recreational fishing pressure from houses and cottages located along the shores the harbours

After calculating the amount of recreational fishing pressure originating from harbours, a second data set indicating the significance of home- or cottage-departing fishermen is needed. In this recipe it is assumed, that only houses/cottages on the

shore zone (<100 m from the shoreline) should be included to the analysis, and the distance travelled for fishing is five kilometres, at maximum. As houses/cottages probably outnumber the harbours greatly, the similar methods relying on distance-weighted rasters are not to be used; however, the total number of houses/cottages that are present in the predefined distance from a certain location offer a reasonable surrogate for estimating the pressure.

- First, houses/cottages locating further away than 100 meters from the shoreline, should be excluded as it is assumed that they are not regarded as places of origin for recreational fishing, or their pressure is channelled through the nearby locating harbours.

  o To be able to separate the houses/cottages not relevant for the analysis, sea areas (in polygon format) should first be buffered by 100 meters to cover the shore zone. In *ArcView*, that may be done by *Theme → Create buffers*, or by *XTools*.

  o After buffering the sea areas, use the buffered polygons to select the houses/cottages locating on the shore zone: make the house/cottage point data set active, click *Theme → Select by theme* and choose to select features that intersect the buffered sea polygon data set.

  o To delete the irrelevant houses / cottages, be sure that the theme is active, open the attribute table and start editing. The features locating on the shoreline should still be selected – those are the points to be spared. To delete the irrelevant points, click the *Switch selection* button, and press *delete*. Save the edits and stop editing.

- Then, calculate a raster surface indicating the house / cottage density (number of houses / cottages on a 5 km radius)

  o Pre-process the shoreline house/cottage data set: create a new column on the attribute table, and calculate every polygon to possess the attribute value "1". Save the edits and close the table.

  o For the house/cottage data set, select *Analysis → Neighbourhood statistics*. Select the output grid extent and cell size to correspond the harbour raster created at Step 3.

  o As the neighbourhood statistics window opens, select the newly created column to be summed (*Statistic*: *Sum*) thus giving the number of single houses / cottages. Neighbourhood is recommended to be circle and the radius that was used when developing the recipe was chosen to be five kilometres (Actually, this step was completed by *Point statistics* function using ArcGIS 9.2 when creating the layer based on the recipe, but *ArcView 3* should be capable of the analysis as well, as instructed above).

  o Check the validity of the result.

- Change the *NoData* values to zero values – this is necessary for the further calculations. Open the *Map calculator* and use the conditional formula below:

  ([house/cottage density raster].isNull).con(0.AsGrid, [house/cottage density raster])

5 Combine the harbour (Step 3) and house / cottage data sets (Step 4) to a single raster surface indicating the general recreational fishing pressure

The two data sets from Steps 3 and 4 indicate recreational fishing pressure originating from harbours and shoreline-locating houses/cottages, and they must be combined to a single data set for estimating the total effects of recreational fishing. The resulting raster may be calculated by using the Map calculator, but as the ranges of the two data sets may considerably vary, a proper coefficient may be needed. The formula presented below was found a suitable one when compiling and testing this recipe for SW Finland.

  *[harbour raster from step 3] + (0,01 * [house/cottage density from step 4])*

6 Classify the resulting raster to evaluate the general pressure of recreational fishing

Use the raster data set created at Step 5 to evaluate the general pressure of recreational fishing. You may try the class values presented in Table 18, but probably there is a need to fine tune them to better correspond with the local conditions.

Table 19 Ranges for classifying the resulting raster data set.

Cumulative raster value	Classification
0	Class 1 – No recreational fishing pressure
0.01 – 5	Class 2 – Low recreational fishing pressure
5.01 – 10	Class 3 – Moderate recreational fishing pressure
10.01 – 25	Class 4 – Significant recreational fishing pressure
25 or more	Class 5 – Strong recreational fishing pressure

7 Estimate the area sensitivity to recreational fishing activity

Recreational fishing is often concentrated to areas that are vulnerable to human influence, for example, important spawning areas or nursery habitats for fish that are easily disturbed by the fishing activity or its side effects. The pressure may be strong on the surrounding near shore environment as well, as on bird and wildlife.

In this recipe, the estimation of sensitivity is exemplified with the use of depth and wind exposure conditions expressing shallow and shelter areas. Other sources of information with sensitive areas (known and modelled spawning and nursery areas, important bird areas, other habitats needed to protect *etc*.) may be used in parallel analysis.

- In addition to the classified general pressure raster, open the depth and wind exposure data sets (or other data to be used) to the same view.

- Separate the sensitive areas that meet the defined conditions – here water areas not deeper than 5 m and not having a wind exposure value >10 000 m are defined as sensitive in respect to spawning and nursery areas for fish. You may run the analysis using a single conditional function as below assigning a value "1" for areas to be separated, and value "0" for other areas, or complete the task by reclassifying the both grids and combining the results. For additional information on *Con*-function, refer to *ArcView Help*.

  *(((([wind exposure raster] > 0) and ([wind exposure raster] < 10000)).Con (1.AsGrid, 0.AsGrid)) * (((([depth raster] < 0) and ([depth raster] > -5)).Con (1.AsGrid, 0.AsGrid))*

- Compile the sensitivity classification based on the resulting raster and the estimated general pressure of recreational fishing (Step 6). The classification suggested below may be performed by using conditional functions, by reclassifying the rasters and summing them, for example, to reveal the different combinations, or by polygonizing the grid layers and overlaying (union) them.

  Class 1 / not vulnerable areas: the area is whether classified as being under a low or negligible recreational fishing pressure, or it is not separated as being a sensitive area.

  Class 2 / moderately vulnerable areas: the area is both classified as being under a moderate or significant recreational fishing pressure, and it is separated as being a sensitive area

  Class 3 / highly vulnerable areas: the area is both classified as being under a strong recreational fishing pressure, and it is separated as being a sensitive area.

Indicator in the Assessment of Management Performance
The tool visualises pressure factors in a coastal environment. The tool serves as an example on how a specific socio-economic sea use can be combined with a biophysical feature in order to express the spatial distribution of vulnerability.

The pressure layer can be visualised as such describing the predicted intensity of pressure in areas, the boating in this case, or in combination with specific sensitive habitats, such as models of fish nursery areas and / or extracted shallow shelter areas and coastal lagoons.

Spatially, the human influence expressed as pressure on sensitive habitats can be compared within and among zones. Special attention should be given to Class 1, which is suggested to indicate low vulnerability of the habitat. The comparison may be done by measuring the relative coverage of different classes, absolute number and the frequency of occurrence and the proportion of different classes.

Over time, the change of above mentioned measurements can be conducted.

The frequency of boating may also be viewed as the state of the activity in the marine area, and this is information that may be used when assessing the management effects on sea uses. Areas in frequent use of boats (and recreational fishers are more likely to show conflict with stakeholders due to low compliance with management decisions.

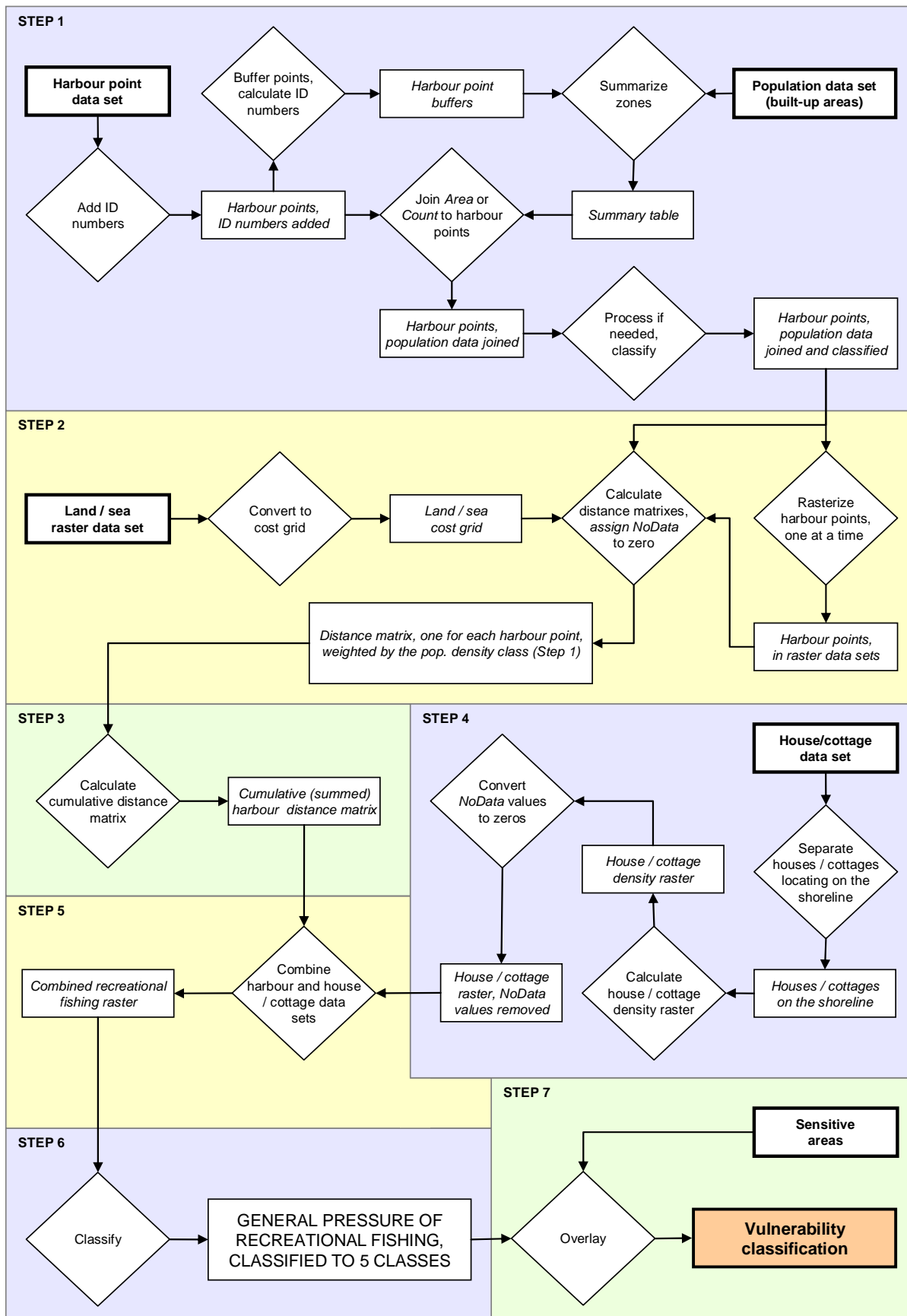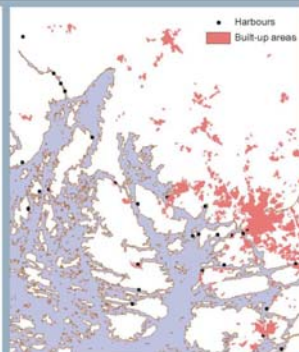*Fig 15   Principle steps of performing the analysis* Predicting the effects of recreational boating and fishing on sensitive habitats.

Fig 16   *Sample images of the performing the analysis* predicting the effects of recreational boating and fishing on sensitive habitats

2.4.5 Marine noise disturbance from vessels

Description	Predicting the impacts of anthropogenic noise in the marine environment
Zoning purpose	To indicate the potential spatial noise distribution from large and small vessels
Target use / feature	Navigational activities / unspecified biological features
DPSIR indicator	Socio-economic pressure
Assessment indicator	Biophysical in assessing the vulnerability of habitats, Socio-economic in assessing the level of pressure. Preferable assessment of change: 5-10 years interval
Data used	Polygon or raster layer of land/sea areas, harbours in the research area (points), and shipping lanes in vector (polyline) format, including depth information if available
Principal steps	Classify navigational lanes based on size. Calculate class-specific noise rasters for large (based on lanes)and small vessel (harbours), respectively, combine to single noise raster
Related tools	Shoreline erosion induced by navigational activities (2.4.7), Communication indicator (2.4.3), Effects of recreational boating and fishing on sensitive habitats (2.4.4), Economic value of marine areas (2.5.2)
Accuracy	Depends on the accuracy of the harbour, navigational lane data and on the distance estimate
Difficulty,1-5	4
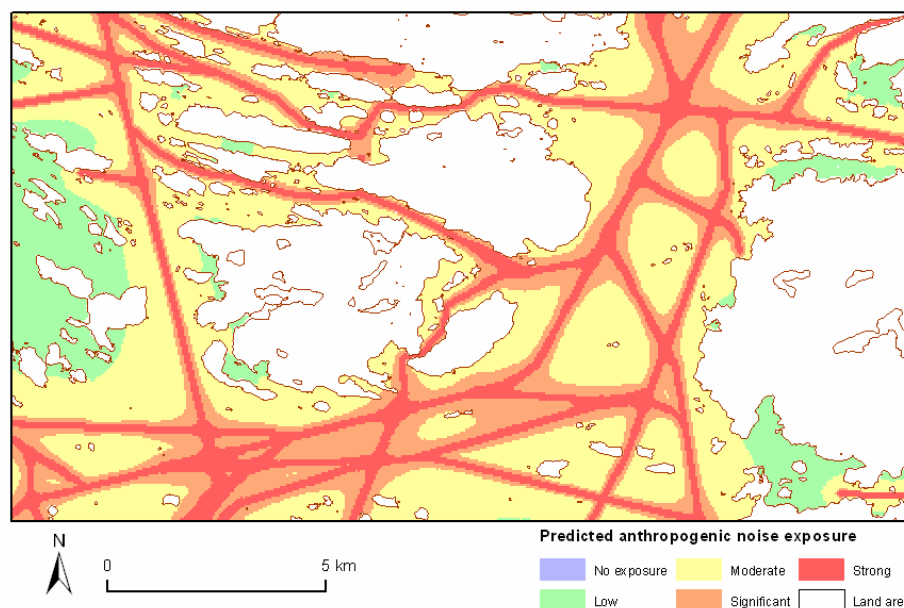
Fig 17

The final result showing the predicted noise distribution based on large vessel following lanes and small vessels associated to harbours. Noise classes range from no noise *to* very high indication of noise disturbance. *Shown is a small part of Pilot Area 3, Stockholm archipelago.*

Predicted anthropogenic noise exposure

No exposure   Moderate   Strong
Low   Significant   Land area

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The occurrence of anthropogenic noise in the marine environment is widely agreed on but the effects on organisms are poorly understood. It is often assumed that noise levels are similar both below and above the water surface, but the reality is quite different – many researchers point out that the air-sea interface actually creates a substantial sound barrier, which means that sound generated in the water will not easily pass over to the air, and vice versa (*e.g.* Gausland 1998; Hildebrand 2004). Though, Nedwell *et al.* (2003) remind that the interpretation of the significance of noise lies in the great difference in sensitivity to sound of marine and terrestrial animals. Many marine animals and fish are adapted for living in the noisy underwater environment – their hearing is much less sensitive than most of the terrestrial animals, and for this reason they are able to tolerate much higher levels of noise.

Underwater noise induces several types of effects in the immediate vicinity of significant sources and diminishes as the distance from the source increases. Nedwell *et al.* (2003) classify the consequences of noise exposure to primary effects, such as immediate or delayed fatal injury, which mainly occur near powerful sources, *e.g.* explosive blasts. Secondary effects are injuries such as deafness, which may have long-term implications for survival, and tertiary (behavioural) effects, such as avoidance of the area. The first two categories imply mostly on single individuals, but behavioural effects may be detrimental to whole populations in case individuals are displaced from areas important for feeding or breeding (Perry 1999; Roussel 2002; Nedwell *et al.* 2003). Besides influencing animals' physical condition and behavioural patterns, noise may mask important acoustic signals thus inhibiting the communication or orientation of animals such as many whale species (Perry 1999; Erbe 2002; Roussel 2002; Wahlberg & Westerberg 2005).

Sources of anthropogenic noise in the marine environment include vessel traffic, seismic explorations, sonars, offshore oil production, wind-farms, including their installation, and dredging (*e.g.* Hildebrand 2004; Nedwell & Howell 2004; Hildebrand 2004, Zacharias & Gregr 2005). Ship-generated noise is probably the most widespread and constant source and is generated primarily by propeller action, propulsion action and hydraulic flow over the hull (Hildebrand 2004). It may not be directly lethal to organisms, but it can induce several reactions including behavioural responses, such as escape reaction and stress, or cause hearing loss (Erbe 2002; Smith *et al.* 2004), which may have critical consequences for the organisms. Birkun (2002) reminds that since traffic is more concentrated to coastal waters, the influence of shipping noise is more pronounced on inshore species than on offshore species. Another quite common and more powerful source of noise is pile driving activity when constructing *e.g.* wind-farms. There are observations of mortality and some injury to fishes that are close to the pile driving location, but the actual degree of damage is more related to the received sound level and duration of exposure (Hastings & Popper 2005). However, the disturbance level of noise is highly dependent both on the species and the individual. Table 19 presents a summary of scientific research and findings related to noise and the distance of influence on the marine environment.

Indicating the potential distance of influence of noise is neither easy nor straightforward because of the species– and individual–specific differences in the response, the varying strength of noise sources, and the variation of physical factors of the area, including seabed geomorphology, water depth and water density (Zacharias & Gregr 2005).

Table 20   Summary of scientific research related to noise in the marine environment.

Source	Range / description	Reference
Wind turbine piling	Calculations indicated strong underwater avoidance by a range of animals at ranges of up to several km.	Nedwell *et al.* 2003.
Rock socket drilling	Tonal components of the drilling could be identified in the water at ranges of up to 7 km.	Nedwell *et al.* 2003.
Pile driving a major road	The kill range for young Pacific salmon was estimated to 700 m.	Nedwell *et al.* 2003.
Underwater explosions	Blast injuries for marine mammals occur within ranges of 77 m at 5 m water depth, and 60 m at 10 m water depth.	Nedwell *et al.* 2003
Plane (vertical range)	Harbour porpoises reacted to a plane at 500 m, did not show other signs of anxiety at 200 m, but disappeared when the plane came down to 50 m.	Birkun 2002.
Shipping	Reaction range of fish on noise caused by a research vessel was measured to be 790 m, at maximum.	Mitson & Knudsen 2003.
Pile driving for bridge	Dead fish of several different species found to at least 50 meters from the pile being driven.	Hastings & Popper 2005.
Shipping (fast boats)	Audible to killer whales > 16 km, to mask killer whale calls over 14 km, to elicit a behavioural response over 200 m, to cause a temporary threshold shift (TTS) in hearing of 5 dB after 30-50 min within 450 m.	Erbe 2002.
Shipping (slow boats)	The noise was modelled to be audible and masking calls of killer whales at 1 km, to induce behavioural responses at 50 m and to cause TTS at 20 m.	Erbe 2002.
Ice-breaking ships	Belugas avoided the approaching ships at ranges of 45-60km, and seemed aware of an approaching ship at a distance of 85 km	Perry 1999.
Seismic vessel	Bowhead whales swam away from a vessel at 24km.	Perry 1999.
Military sonar	Sperm whales reacted at distances of 20 km.	Perry 1999.
Powerboats	Boats detectable by otophysine fish at 400 m, by hearing generalists of 200 m (perch) and 30 (whitefish).	Amoser *et al.* 2004.
Shipping	Reactions of herring significant at distances of 220–270 m to a 3 t vessel cruising at 10.9 knots	Amoser *et al.* 2004.
Seismic survey	Behavioural changes by marine mammals up to 10 km for blue whales and 8 km for humpback whales.	Zacharias & Gregr 2005.
Super tankers	Detected by marine mammals up to 500 km.	-"-
Oil platforms	Affecting the distribution of bowhead whales at 50 km.	-"-
Jet ski	Heard by bottlenose dolphin up to 450 m.	Roussel 2002.
Inflatable boat	Heard by bottlenose dolphin up to 1 km.	Roussel 2002.
Speed boat	Heard by bottlenose dolphin up to 1800 m.	Roussel 2002.
Fishing boat	Heard b bottlenose dolphin up to 3.1 km.	Roussel 2002.
Drilling dredging	Bowhead whales avoid the noise up to 3 – 11 km	Roussel 2002.
Wind turbine	Dab and salmon are able to detect some noise at a distance of 100 m, cod may sense noise at 200 m.	Jonasson 2002.
Wind farm	The distance for fish is 0.4-25 km at wind speed of 8-13 ms^{-1}; it is estimated that fish are consistently scared away at ranges of 4 m at high wind speeds.	Wahlberg & Westerberg 2005.
Pile driving	Pile driving sounds are audible to many marine mammals at very long ranges of more than 100 km	Madsen *et al.* 2006.
Wind farm	Little evidence that benthic invertebrates perceive.	Anon 2002a.

This recipe describes one way of predicting the spatial influence of noise without emphasizing too much on any single species. The methodology is mainly based on techniques introduced by Zacharias & Gregr (2005). All data sources, recommended distances *etc*. are possible to alter if specific values should become known. The approach is concentrated mainly on vessel traffic since it is predictable as well as the most significant source of noise in coastal areas, but other features such as wind-parks and oil drilling platforms may be included in the analysis if necessary.

The movement of large ships is quite predictable. Large ships tend to travel linearly along sign-posted lanes and use large, deep harbours. Smaller vessels are less restricted to lanes and have a different distribution and pattern of movement. The concentration of small vessels is normally highest near small harbours and decreases when moving away from harbours, as a direct result of a dilution-effect of an increasingly larger area. This partly segregated distribution of the two vessel types, a linear and a spherical movement pattern, respectively, thus allows the use of two data sets – navigational lines (large ships) and harbours (small boats), which combined to an overall noise exposure layer, may represent the relative likelihood of noise disturbance in an area.

Data requirements
- Polygon or raster layer of land / sea areas

- Location of harbours in the research area (points)

- Shipping lanes in vector (polyline) format, including depth information if available

Step-by-step process
1 Pre-process the shipping lane and land / sea data sets for the calculation of noise rasters

Shipping probably is the most prevalent and constant source of noise exposure. Class intervals and exposure distances are estimated based on published research articles, and are fully replaceable to match more specific needs.

If the shipping lane data include the information of channel depths or some other attribute indicating the probable size of passing ships, it is recommended to separate at least a few classes thus giving a more accurate result regarding the probable noise associated to various lanes; if no such attributes are available, it is possible to carry out the analysis by using a single, fixed noise distance for all lanes. The classification of lane channel depths and the attenuation distances of the noise are decided based on estimates found suitable for the vessel traffic in the Archipelago Sea, SW Finland, and may need re-evaluation to suit conditions in other research areas.

- Open the attribute table of your shipping lane data and make a new column to store the lane size class based on the channel depth.

- Classify the lanes to *e.g.* three classes, use the values suggested below or ones of your own.

- o Class 1: major shipping lanes and international routes, mainly used by large vessels. Channel depth > 8 m.

- o Class 2: regionally important shipping lanes, semi-large and small vessels. Channel depth 4–8 m.

- o Class 3: locally important shipping lanes, mainly small vessels. Channel depth < 4 m.

- Since this recipe mainly is focused on underwater noise, the location of islands in the area of noise influence should be taken to account to gain realistic estimations. For that reason, a creation of a *cost grid* based on the land / sea dataset is first needed.

  - o If your land/sea data is in polygon format, you should first create a new numerical column in the attribute table. Update all the sea areas to possess value 1, and all the land areas a considerably larger value, say, 100000. After that, convert the polygon layer to a raster theme (*Theme → Convert to Grid*). Do not choose too small cell size or your analyses will get too heavy but if too large cell size is chosen, small inlets or waterways are likely to disappear causing misleading results; when compiling this recipe, a cell size of 50 m was chosen and there was a need to manually make a couple of important channels open.

  - o If your land/sea data is in raster format, reclassify it (*Analysis → Reclassify*) so that all the sea areas gain a new value of 1 and all the land areas a considerably larger value, say, 100000.

2 Calculate class-specific noise rasters for vessel traffic on shipping lanes

The prediction of the distribution of the two noise sources need to be viewed as a proxy and is not an exact illustration of a real situation, thus approximately revealing the theoretical noise condition of an area. The resulting layer show the likelihood of noise disturbance between zero "0" indicating a relatively silent area (affected mostly by background noise) and one "1", indicating an area strongly affected by anthropogenic noise sources.

- Start the procedure from *e.g.* major shipping lanes and separate all class 1 lanes to be converted to a raster data set. In *ArcView*, you can select the features based on their class attribute and convert the selected features directly to a raster data set (*Theme → Convert to Grid*). It is recommended to choose the extent and the cell size corresponding to your cost grid. At this point, it is no matter what the actual cell values will be. The resulting raster will later be referred as *Raster1*.

- Calculate a *distance raster* data set so that it extends 5 km away from the shipping lane and takes the location of islands to account; this indicates the maximum distance for noise disturbance. In *ArcView* the raster may be calculated using the *Map calculator* (*Analysis → Map Calculator*) and entering the formula given below (presumptions: map units are meters and the maximum distance is 5000 units). For additional information on *e.g. CostDistance*-function, check the *ArcView Help*.

[Raster1].CostDistance([land/sea cost grid], nil, nil, 5000) ($\rightarrow$ *Raster2*)

It is possible to make a single command chain of the work phases creating *Raster 2-6*, but it is a demanding task that produces an exceptionally long expression (succeeded, but not recommended by the author).

NB. Archipelago landscapes generally are shallow with islands and scerries of varying size, and for that reason larger vessels do not usually depart from sign-posted lanes, thus making it irrelevant to expand the disturbance zone in order to cover all potential vessel fairways. Hence, the predicted noise distribution pattern of large vessels follows a linear pattern. In other areas, where large vessels are less restricted to follow the defined lanes, a larger buffer distance may be needed.

- To make the noise raster more realistic referring to the physical properties of sound wave attenuation, a logarithmic scale (base e) should be applied. The total disturbance zone will not be altered, but the disturbance effects induced by noise are weakening more rapidly than at a linear scale. The task can be accomplished using the *Map Calculator*, changing the scale subsequently to be between 1 (closest to the shipping lane) and 0 (far away from the shipping lane; the point beyond which the noise can no longer be interpreted as disturbing). Since logarithmic values are increasing concurrently with distance, the scale must be reversed in order to follow the attenuation of the noise raster.

First, logarithmic transformation: *[Raster2].Log* ($\rightarrow$ *Raster3*)

Then, check the minimum and maximum values of the grid. In *ArcView*, you can double-click the raster theme and select *Statistics* from the *Legend Editor*.

Rescale:

1.AsGrid – (([Raster3] – [min value].AsGrid) / ([max value].AsGrid – [min value].AsGrid)) ($\rightarrow$ *Raster4*)

- Now, a preliminary noise raster is created so that the noise values (0…1) are distance dependent at a logarithmic scale. The problem still is that there are *NoData*-values on the shipping lane originating from the logarithmic transformation (should be given value "1"), and on the surrounding marine areas not affected by the vessel noise (should be given value "0"). To correct the latter error, *NoData*-values of *Raster4* first have to be changed to "0". The task can be accomplished with *MapCalculator* by using a conditional formula that checks whether a cell value is assigned to *NoData*, and if the condition is found to be true, the value will be transferred to "0". All other values will remain unaltered. For more information, check the *ArcView* help.

([Raster4].isNull).con(0.AsGrid, [Raster4]) ($\rightarrow$ *Raster5*)

- To be able to correct the raster cell values on the shipping lanes (those having a value "0", which should be "1"), you have to reclassify *Raster1* (*Analysis* $\rightarrow$ *Reclassify*) so that all the cells possessing a numerical value (those locating on the lane) will be re-

classified to "1" while all *NoData* cells will be reclassified to "0". Alternatively, you are able to accomplish the task by using the *MapCalculator* as follows:

([Raster1].isNull).con(0.AsGrid, 1.AsGrid)   *(→ Raster6)*

- To calculate the final noise raster for lane class 1, sum Raster5 and Raster6 by using the *MapCalculator*. Check the result: raster cells locating on the shipping lane should all gain value "1", raster cells < 5 km from the lane should gain logarithmically decreasing values (1…0), and all the other cells (>5 km from the shipping lane, as well as land areas) should gain "0" values. At this point, there should not be *NoData*-values at all inside the research area. Save the result using an informative name.

- Repeat the steps above for lanes of classes 2 and 3. Recommended distances for noise disturbance are 3 km (class 2) and 1 km (class 3).

3 Calculate a noise raster combining all class-specific lanes

Finally, the calculation of one raster surface combining all three class-specific noise rasters is needed. The physics of sound waves do not support a direct summation of the three separate, class-specific raster data sets, because it would emphasize too much on locations where lanes of different classes join, and the purpose is to keep "1" as the maximum value. , if the arithmetical mean value of the same raster cell on three layers is calculated, it will give misleading results. Because of zero values, a direct multiplication operation is either no good.

However, a multiplication of "no-noise" (*1 – [noise value]*) values will give the desired result (clarified in Table 20).

Table 21   The effects of multiplicating "no-noise" values

Original noise value of a cell	Calculated "no-noise" value of the same cell	Effect induced by the cell when multiplicating cell values of several layers
0	1	No effect; if cells in all layers have this value, the resulting no-noise value will be "1" thus indicating silence (a zero noise value)
More than 0 but less than 1	Less than 1 but more than 0	Will make the multiplication result getting closer to zero, *i.e.* indicating more noise
1	0	Will make the multiplication result immediately turn to zero thus indicating maximum noise disturbance no matter what the cell values in other layers are

- Calculate a *"no-noise" raster* for each class-specific noise raster created at Step 2 by using the *Map Calculator:*

1.AsGrid – [noise raster Class x]

- Multiplicate the three *"no-noise" rasters* using the *Map Calculator* as follows:

["no-noise" raster Class 1] x ["no-noise" raster Class 2] x
["no-noise" raster Class 3]

- After multiplicating the "no-noise" values, the end result has to be turned to original "noise" values again. Use the *Map Calculator*:

1.AsGrid – [multiplicated "no-noise" raster]

As a result, a raster layer indicating the noise disturbance originating from shipping lanes will be created. Save the data set using an informative name.

4 Calculate harbour-specific noise rasters for small boat traffic

Compared with large vessels, small boats show a different movement pattern, as they are less restricted to shipping lanes and may spread from the harbour in a spherical pattern over a fairly large area. Thus are small boats predicted to be most concentrated near harbour locations, and a decreased probable noise influence is consequently predicted when moving away from the harbour. Since the noise disturbance range of a single small boat is predicted to be quite short, and the concentration of boats (number of boats per unit area) is predicted to decrease rapidly with increased distance from the harbour, the noise surface is estimated to fit a logarithmical scale.

An approach similar to the previous one is used to estimate the noise from boats.

- Add the harbour point data set to the view and visualize it on top of the cost grid (see Step 1). To be able to calculate the noise raster surfaces, it is required that all the harbour points are located on top of sea areas – if a point is situated on a land area, it has to be moved to the sea side of the shoreline.

- Open the harbour data set and select a single harbour point at time.

- Convert the selected harbour to a raster data set (resulting in a single raster cell) by using the function *Theme → Convert to Grid*; as a field for cell value you can use the ID number, for example (it does no matter at this stage). Select a quite small cell size but not smaller than in your cost grid (otherwise, analyses may not work).

- Calculate a noise raster so it extends 10 km away from the harbours and takes the of islands to account. This indicates the presumable small boat noise exposure surface originating from the harbours; it is limited to 10 km because it is assumed that longer distances are primarily travelled along shipping lanes, and after 10 km, the noise exposure originating from the harbours is insignificant in areas off the shipping lanes. Follow the procedure similar to Step 2: calculate a distance surface extending 10 km (consider the rasterized harbour point comparable to *Raster1*), make a logarithmical transformation, rescale the values between 0…1, correct *NoData* values to be either "0" (outside the 10 km radius) or "1" (the single cell just on the harbour location) and save the result.

- Repeat the procedure for every harbour point you want to take to the analysis.

5 Calculate a combined noise raster for all small boat traffic

Similar to the shipping lanes, the calculation of a raster surface combining all the harbour-specific noise raster data sets is needed. The procedure is analogous to Step 3 – first a *"no-noise" raster* for each harbour-specific noise raster is created, then all the rasters are multiplied, and finally, the multiplied "no-noise" raster data set is again converted to "noise" values by subtracting the raster from "1".

6   Calculate the combined noise raster and classify the result

The method to complete the final noise raster creation that combines the shipping lane traffic (Step 3) and small boat traffic (Step 5) is similar to previous steps and can be calculated using the *MapCalculator*:

*1.AsGrid – ((1.AsGrid – [noise raster from Step 3]) * (1.AsGrid – [noise raster from Step 5]))*

Classify the result to five classes; suggested intervals are presented in Table 21.

Table 22   Suggested intervals for classifying the final noise raster.

Cumulative raster layer value	Classification
0	Class 1 – No noise exposure, silent area
0.01 – 0.4	Class 2 – Low noise exposure
0.401 – 0.8	Class 3 – Moderate noise exposure
0.801 – 0.95	Class 4 – Significant noise exposure
0.951 – 1	Class 5 – Strong noise exposure, noisy area

Indicator in the Assessment of Management Performance
The tool visualises pressure factors in a coastal environment. The tool serves as an example on how any given socio-economic sea use can be combined with any given bio-physical feature in order to express the spatial distribution of vulnerability.

The noise layer can be visualised as such describing the predicted intensity of pressure, expressed as noise disturbance from vessels in areas, or in combination with specific sensitive habitats or species, *e.g.* marine mammals (seals) and birds.

Spatially, the human influence expressed as noise can be compared within and among zones. Special attention should be given to Class 1, which is suggested to indicate undisturbed, silent areas. The comparison of noise classes may be done by measuring the relative coverage of different classes, absolute number and the proportion of the different classes. Over time, the change of above mentioned measurements can be conducted.

Fig 18   Principle steps of performing the analysis Predicting the impacts of anthropogenic noise in the marine environment

Fig 19   *Sample images of performing the analysis* Predicting the impacts of anthropogenic noise in the marine environment

2.4.6 Potential dredging sites in shallow coastal areas

Description	Predicting potential dredging sites in shallow areas
Zoning purpose	To indicate the spatial distribution of potential sites that are susceptible to dredging
Target use / feature	Dredging / unspecified habitats and biological features in shallow areas
DPSIR indicator	Socio-economic pressure
Assessment indicator	Socio-economic in assessing the level of pressure. Preferable assessment of change: 5-10 years interval
Data used	Point data of shoreline buildings (houses/cottages) located <100 m from the shoreline, Polyline data of shipping / boating lanes, point data of harbours, depth raster model, slope raster model, wave exposure raster model, benthic substrate raster model
Principal steps	Predict the potential dredging sites in the vicinity of the buildings located near the shoreline, the site in the vicinity of the shipping/boating lanes, and the sites in the vicinity of harbours. Combine the results to a single layer indicating all the potential dredging sites.
Related tools	Habitat extraction tools, *e.g.* (2.2.5), Shoreline exploitation (2.4.1), Human influence on coastal lagoons (2.4.2) Shoreline erosion induced by navigational activities (2.4.7)
Accuracy	The accuracy is dependent on the quality of the data that are used.
Difficulty,1-5	3

Fig 20

The final result showing the predicted dredging areas

Predicted potential dredging sites

0   5 km

■ Potential dredging site

■ Dredging not likely

Dredging is a widespread anthropogenic activity that takes place in virtually all shallow aquatic areas. As defined by Herbich (2000), the purpose of dredging is to raise material from the bottom to the surface and pump it over some distance. The definition covers a broad range of different types of activities but in most cases the target of dredging involves navigational activities, *e.g.* deepening of shipping and boating channels and harbour areas. A second important use of dredging is the extraction of material for seafloor mining. The recipe described here is intended for assessments of dredging associated with navigational activities.

The recognition and prediction of potential dredging sites is important as it poses a substantial pressure on marine nature. As Newell *et al.* (1998) points out, dredging is mainly carried out in near-shore coastal deposits, where benthic production processes are of great importance in supporting *e.g.* the demersal fish production. In many areas, dredging is almost as common as marine traffic itself. In a research performed by Eriksson *et al.* (2004) it was concluded that all inlets in the Stockholm archipelago, Sweden, that were used as marinas, showed signs of dredging activities contributing to changes in inlet morphometry. Dredging is estimated to result in a 30–70 % reduction of species diversity, a 40–95 % reduction in the number of individuals, and in a similar reduction in the biomass of benthic communities in the dredged area (Newell *et al.* 1998).

The actual effects of dredging vary depending on the amount and type of dredged material and on the location of the activity. Effects from dredging include the direct disturbance and loss of habitats and organisms due to the extraction and re-locating of material. A rise in turbidity and altered visual conditions normally follows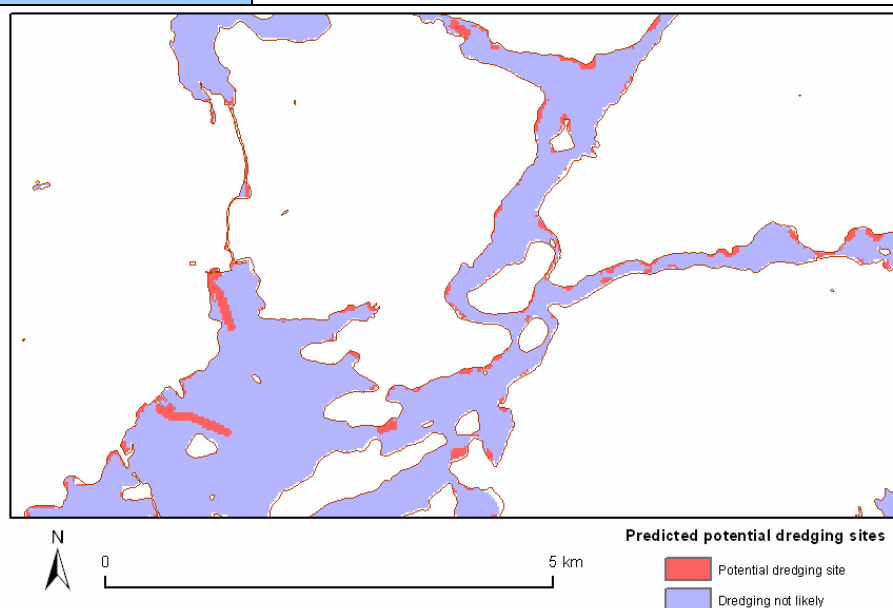 dredging especially where the dredged material includes fine material, *e.g.* mud. Altered visual condition may have profound impact on the flora and fauna of the impacted area. It should be remembered that in addition to the direct effects, dredging may drastically alter the physical and hydrological properties of sensitive habitats if dredging is used for *e.g.* deepening the shallow entrance of a coastal lagoon. In the worst scenario, the loss of key species and habitats following disturbance by dredging can lead to a collapse of the entire community even though individual species may be tolerant to the environmental disturbance (Newell *et al.* 1998). The effects of dredging, however, are not fully predictable – there is evidence of increased biodiversity on the dredged material disposal site resulting from higher sand content, greater sediment stability and increased habitat variety compared to the situation prior to the disturbance (Valente *et al.* 1999).

The effects induced by dredging are strongest in the close proximity of the dredged site, but there is evidence of impacts over longer distances. In a study by Quigley & Hall (1999) it was concluded that dredging had not only impacted the direct dredged site, but had affected the control area located 500 m away on the opposite side of the estuary. Another example indicated that the physical disturbance of dredging on the seabed was limited to a zone within approximately 300 m down tide of the dredge area, and that there was no evidence of suspended sediments falling to the seabed beyond this zone causing significant changes (Hitchcock & Bell 2004).

Some theoretical models are predicting that very fine sand particles may travel as far as up to 11 km from the dredge site, fine sand up to 5 km, medium sand up to 1 km and coarse sand less than 50 m, but biologically significant zone of impact is likely to be restricted to a few hundred meters (Newell *et al.* 1998). However, the effects of sedimen-

tation and other dredging induced changes in the benthic realm are dependent on the local conditions, if there is a dense network of dredged sites (frequency and intensity of the activity), and the total area affected by the activity. Models predicting density and total area of potential dredged areas may facilitate an efficient management of marine areas.

There are differing estimates on how long-lasting are the direct effects of dredging. Sánchez-Moyano *et al.* (2003) concluded that after a marked impoverishment of the macro-benthic community, as a result from dredging, the community re-established during a one-month period of follow-up. Despite having largely recovered, the community showed changes in the density of certain taxa years after dredging. Newell *et al.* (1998) summarize the recovery rates commonly being reported from six to 36 months, depending on the local environmental conditions, but there is evidence of much slower rates. Boyd *et al.* (2005) found that the effects of a long dredging history were still discernible on the composition of sediments and fauna even six years after cessation. Pagliai *et al.* (1985) suggested that, in the absence of other disturbances interacting to cause unpredictable effects, dredging may take place without long lasting or irreversible environmental impact; however, dredging tend to be frequent in same areas thus having cumulative effects disturbing the benthic ecosystem. Recovery times may be extended in cold waters at high latitudes where slow-growing organisms are present in the community (Newell *et al.* 1998).

The recipe described here is fully concentrated on dredging activities associated with maritime traffic and recreational boating, either in the form of maintenance dredging along lanes and in harbour areas or facilitating access to open water in near shore, shallow areas.

Three possible types of areas of potential dredging are recognized in the recipe: areas near public harbours, areas in the vicinity of navigational lanes, and areas close to houses or cottages located near shoreline. The prediction of whether a certain location is under risk of being dredged is then estimated by using additional data sets describing the marine conditions (depth, slope, benthic substrate and wind exposure).

Data requirements
- Point data of shoreline buildings (houses/cottages) located < 100 m from the shoreline

- Polyline data set of shipping / boating lanes, including the lane depth as attribute

- Point dataset of harbours

- Depth model, in raster format

- Slope model, in raster format (may be calculated based on the depth model)

- Wave exposure model, in raster format

- Benthic substrate data set (in soft / hard categories), in raster format

Step-by-step process

1 Predict the potential dredging zone in the vicinity of buildings located near shoreline

Dredging in the vicinity of buildings located near the shoreline is usually small-scale and performed for private purposes to facilitate the access by boat to the own shore. The amount of the dredged material at a single dredging site generally is small, but as the activity is very common and widespread, the total effects are substantial.

There are certain preconditions that significantly affect the dredging likelihood. First, the depth at the site must be shallow enough. Secondly, the slope of the bottom shouldn't be too steep; it would facilitate a fast re-sedimentation of the dredged area and the sediment type is dependent on the slope (a plain surface is generally softer than a steep surface). Moreover, building a pier is much more common than dredging at steep shores. Thirdly, the bottom substrate must be soft to enable dredging. If there is no data available on the substrate, or the mapping scale of the data is too low, the use of some substitutive data sets (*e.g.* wave exposure) is possible. Low exposure values normally mean that fine material can accumulate and form soft sediments.

The analysis described here is based on raster analysis – it is desirable that all the data sets have the same extent, cell size and cell location, or else the accuracy of the results may suffer.

- Reclassify the depth model. In this recipe, a suitable threshold depth was decided to be 1 m, but any other value may be adopted as well to fit local conditions. To perform the reclassification, select *Analysis → Reclassify* in *ArcView 3*, or *Spatial analyst tools → Reclass → Reclassify* in *ArcGIS 9*. Perform the reclassification so that depth values between 0…1 will be classified to "1", and all the other values to "0".

- Reclassify the slope model similarly to the depth model; the suggested slope threshold is 3°. Perform the reclassification so that slope values between 0…3 will be classified to "1", and all the other values to "0". Remember to include flat values to class "1" if they gain any other value from 0…3.

- Make a buffer zone around buildings located near the shoreline and rasterize the result. A suggested buffer value for building points is 100 m indicating the potential zone of dredging.

  o In *ArcView 3*, select the point data set and click *Theme → Create buffers* (NB! The distance units from *View → Properties* have to be defined). Create buffers at the specified distance of 100 m. Select not to dissolve barriers as it makes the process faster. Select buffers to be saved as a new theme (remember to assign a descriptive name).

  In *ArcGIS 9*, select *Analysis tools → Proximity → Buffer*. Define the input point data set, output data set and distance (Linear unit; 100 m). Other default values do not need to be changed.

o After creating the buffer polygon data set, open its attribute table. Make a new integer column to the table, and update value "1" for all cells – this is used just to assist in the proceeding rasterizing operation.

o Convert the buffer polygon data set to raster format, use the created integer column to define the cell values. In *ArcView 3*, select the data set and click *Theme → Convert to grid*. Preferably, keep the depth / slope model opened and select the grid extent and cell size to correspond the depth/slope raster (this will reduce the spatial errors of the end result). After converting the data set to grid, select *Theme → Save data set*, and save the result using a descriptive name. In *ArcGIS 9*, select *Conversion Tools → To Raster → Feature to Raster*. From the *Environments… → General settings* you may select the extent to correspond the depth/slope model.

o To get rid of *NoData*-values (important for later analyses), reclassify the raster layer once more. Define the value "1" to be remained as "1", and *NoData* to be reclassified to "0"

- Reclassify the bottom substrate data set. If the data available is accurate enough, it may be used without any additional processes. In that case, the only thing to do is to rasterize it, if needed, and to reclassify it (similarly as above) so that soft bottoms will be classified to "1" and hard bottoms to "0".

A "fine-tuning" of the substrate data set is often needed as the accuracy does not reach a level detailed enough, especially in heterogenic and complex coasts. The instructions below are an example how wave exposure data may be used to complete the defective substrate information in a way applicable for the complex, shallow and fairly sheltered areas of SW Finland / Stockholm archipelagos. The hypothesis is that if the exposure is low enough, the bottom is likely to be soft due to the slow water movement and the sedimentation of fine material, even if the substrate data would be indicating the bottom to be hard.

o Reclassify the bottom substrate data set so that soft bottoms will be classified to "1" and hard bottoms to "0".

o Reclassify the wave exposure data set so that low values will be classified to "1" and high values to "0"; a suggested threshold value is 4000 m (may require revision).

o Sum the two reclassified raster data sets created above (reclassified substrate data set and reclassified exposure data set). In *ArcView 3*, select *Analysis → Map Calculator*, and use the formula *[data set 1] + [data set 2]* to calculate the result. In *ArcGIS 9*, a similar calculation may be performed by using the *Raster Calculator*, on the *Spatial Analyst* toolbar.

o Reclassify the calculated sum so that values 1 and 2 (*i.e.* bottoms that are soft and sheltered, soft but not sheltered, or hard but sheltered) will be reclassified to "1"; value 0 may remain as "0" (areas of hard bottom that are

not sheltered) – this is now the data set to be used in the following work phase.

- Open all the four resulting raster data sets (*i.e.* reclassified depth model, reclassified slope model, rasterized building buffer zone and reclassified, possibly fine-tuned bottom substrate data set). Sum them all using the *Map Calculator* or *Raster Calculator*.

  After the summing operation, reclassify the result so that value 4 will be reclassified to "1", and all the other values to "0" – this indicates the area where all the conditions set above are fulfilled and is therefore a potential site for dredging. Save the data set using a descriptive name.

2 Predict the potential dredging zone in the vicinity of shipping/boating lanes

  In a zone near to shipping lanes there may be a great possibility of dredging, depending on the lane depth and the depth of the surrounding area. This step is sensitive to the accuracy of the depth information. An easy way to detect potential areas to be dredged is to compare the depth model, usually interpolated by using depth contours / points of sea charts, with the lane nominal depth. If the depth model suggests shallower water than the lane depth, a presumable area of future dredging has been found (depending, of course, on the accuracy of the depth information).

- Prior to the analysis, shipping lanes need to be transferred to a chain of points to enable the unambiguous joining of the depth information. A proper distance between the adjacent points is dependent on the accuracy of the depth model (there's no need to select a smaller distance than the pixel size); when compiling this recipe, a distance of 25 m was selected.

  In *ArcView 3*, polyline may be converted to points using the *Poly to points* extension, available at http://arcscripts.esri.com (visited July 2007). The extension has to be copied to the *EXT32*-folder and enabled selecting *File → Extensions*; it adds a *Convert to points* function to the *Theme* menu.

  In *ArcGIS 9*, you may load a *visual basic* script *Create points along lines or polygons* from http://arcscripts.esri.com (visited July 2007). The script needs to be run from *Tools → Macros → Visual Basic Editor* on the upper menu bar. The script has first to be imported to the editor, and running it requires that there's a pre-created, empty point shapefile in the current map document (in addition to the lane data).

- If using *ArcView 3*, check that shipping lane attributes indicating the lane nominal depth have been copied to the point data set.

  If using *ArcGIS 9*, there is a need to update the shipping lane nominal depths to the point data set created (attributes are not automatically copied to the resulting file). Join the point data set to the shipping lane data set by right-click the layer name on the layer list, and select *Joins and Relates → Join*. Make the join based on spatial location, and select that each point will be given all the attributes of the line that is

closest to it. Save the resulting point data set using a descriptive name, and continue working with it on the following steps.

- If not present, add an ID column to the point data set itemizing every point feature to enable further analyses (at least if using *ArcView 3*; not necessary if using *ArcGIS 9*). In *ArcView 3*, you may use, for example, an *Avenue* script *Autonumber a field* available at *http://arcscripts.esri.com/* (at least at the time this recipe was written). In *ArcGIS 9*, an easy way to create ID numbers between 1…n is to create a new integer field in the attribute table, and calculate the values by using the formula *[FID] + 1*.

- Update the values of the depth model to the point data set. In *ArcView 3*, select the point data set from the layer list and select *Analysis → Summarize Zones*. The field to define the zones with is the ID number and the theme containing variable to summarize is the depth model. After summarizing the zones, join the resulting table to the original point data set (use the ID numbers) in order to copy the depth values to the original table.

  Finally, create a new numerical column to the point data set attribute table, copy the depth model values there (*e.g.* by using the *mean*-column of the joined table – when summarizing operation is performed by using point locations, there is no difference between *min*, *max* and *mean* values), and remove the join to keep the point data set as simple as possible.

  In *ArcGIS 9*, there is a direct function to join the depth model values to the point data set that may be run from *Spatial Analyst Tools → Extraction → Extract Values to Points*. Continue the analysis by using this new, extracted data set, and make sure that all the original attributes (lane depths) have been copied to it.

- Open the point data set's attribute table and select all features that meet the condition: *depth model value < lane depth* – this comparison will pick up the conflicting points where there may be a need for regular and / or maintenance dredging. The selection may be done in *ArcView 3* by using the *Query* function, and in *ArcGIS 9* by *Select By Attributes*.

- After selecting the points that meet the defined conditions, buffer them (the selected ones) by *e.g.* 50 m (procedure similar to buffering the building points). In *ArcView 3*, make sure that *Use only selected features* is checked; *ArcGIS 9* will automatically use nothing but the selected features, but make still sure that the resulting polygon layer is correct.

- Make a new integer column to the buffer polygon attribute table, and update value "1" for all the cells. Convert the polygon data set to a raster and use the created integer column to define the cell values.

- To get rid of *NoData*-values (important for later analyses), reclassify the raster layer once more similarly to Step 1. Define the value "1" to be remained as "1", and *NoData* to be reclassified to "0". Save the result using an informative name.

3 Predict the potential dredging zone in the vicinity of harbours

Harbours are generally built at places with sufficient depth, but other conditions have an affect on their location (*e.g.* easiness of access, or shelterness). If there are shallow areas in the vicinity of harbours, the probability of dredging is substantial. In this recipe, it is assumed that there is a risk of dredging near every single harbour, no matter how deep the surrounding area is – this is a coarse assumption and quite often a realistic one if there is no specific information available on the minimum depth offered by the harbour.

- Decide a suitable distance to be buffered around the harbour points – 100 m was used when testing this recipe, but any other value may be suitable as well. Different buffer distances for separate harbours may as well be defined if available information (*e.g.* the size or importance of the harbour) supports such decision.

- Open the attribute table of the harbour point data set and create a new numerical column indicating the distance to be buffered. Update suitable buffer distances to the empty cells, using a single or several buffer distances.

- Buffer the harbour points (*Theme → Create buffers* in *ArcView 3*, or *Analysis tools → Proximity → Buffer* in *ArcGIS 9*). Select buffer distances to be decided based on the attribute table distance field.

- Make a new integer column to the buffer polygon attribute table, and update value "1" for all cells (see Step 1). Convert the polygon data set tp a raster; use the created integer column to define the cell values.

- To get rid of *NoData*-values (important for later analyses), reclassify the raster layer similarly to previous steps. Define the value "1" to be remained as "1", and *NoData* to be reclassified to "0". Save the result using an informative name.

4 Combine the preceding results to one layer indicating all the potential dredging sites

The final step is a combination of the three layers created above (results from Steps 1, 2 and 3) – make sure that all the *NoData* values have been reclassified to zero values or else there will appear holes in the final calculation result.

Use the *Map Calculator* or *Raster Calculator* to perform the summing operation (*[data set 1] + [data set 2] + [data set 3]*). After summing, you may reclassify values 1–3 to "1", zero values may remain as "0". The created data set indicates areas that are potential dredging locations (value "1"). It may further be cut to cover only sea areas, if needed.

If the three dredging drivers (near to shoreline buildings, near to shipping lanes or near to harbours) need to be separated, a summing operation may be performed *e.g.* using a formula *[data set 1] + ([data set 2] * 10) + ([data set 3] * 100)*. The resulting raster is then indicating if one or more drivers defining the potential dredging areas is present: if *e.g.* a resulting raster cell value is "101", it corresponds to an area

specifically recognized as being vulnerable to dredging due to shoreline buildings (value "1") and the vicinity of a harbour (value "100").

Indicator in the Assessment of Management Performance

This tool is a useful indicator for showing the spatial distribution of a common pressure factor in coastal areas. As this tool produces the potential sites that are under risk of being dredged based on specified environmental conditions, the temporal change cannot be assessed given that the conditions stay unaltered over time, *i.e.* if the input data used in the model is not updated or changed. It can be combined with specific features for assessing the state and change of state of the vulnerability of these features.

The tool can be applied as an indicator for other purposes. A first step in the assessment of management performance could be to validate the accuracy of the sites by cross-checking with remote sensing information or through field investigations. Spatially, areas showing high coverage of sites under risk of getting dredged may need stricter management in order to avoid extensive habitat deterioration.

Fig 21   Principle steps of performing the analysis Predicting potential dredging sites in shallow areas

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Fig 22   Sample images of performing the analysis Predicting potential dredging sites in shallow areas

2.4.7   Shoreline erosion induced by navigational activities

Description	Assessing the vulnerability of erosion sensitive shorelines to navigational activities
Zoning purpose	1. To identify shores that are vulnerable to erosion, especially regarding to the distribution of existing and planned navigational lanes. 2. To show the distribution of sensitive shores based on data query
Target use / feature	Navigational activities / sensitive shorelines
DPSIR indicator	Socio-economic pressure and biological state
Assessment indicator	Socio-economic in assessing the level of pressure and biological state. Preferable assessment of change: 5-10 years interval
Data used	Shoreline, land areas, navigational lanes, sea areas shallower than 3 m, in vector (polygon) format
Principal steps	Divide data to as small parts as needed, create direct fetch lines from the points along the shores, remove non-erosive lines and clip with shallow areas regarded as prohibiting wave action, sum length and number of fetch lines to be joined with each shoreline point, calculate potential erosion strength at sensitive shores
Related tools	Habitat extraction tools, especially habitats sensitive to unnatural waves and currents, Shoreline exploitation (2.4.1), Marine noise (2.4.5), Predicting potential dredging sites in shallow areas (2.4.6)
Accuracy	The accuracy is dependent on the quality of the data used.
Difficulty,1-5	4, due to large data sets
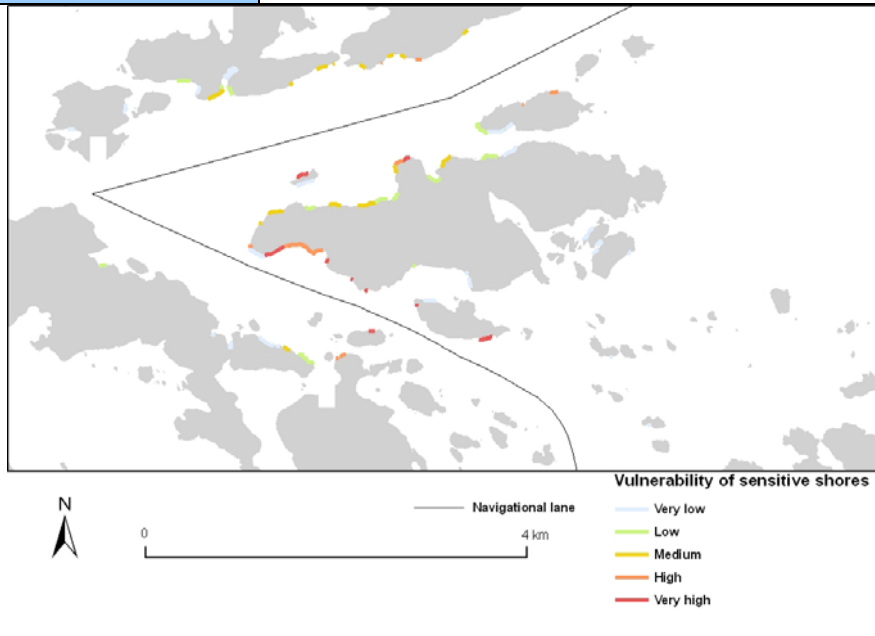
Fig 23

The final result showing a vulnerability assessment of the erosion sensitive shores in a part of Pilot Area 3. The five classes range from very low to very high vulnerability to erosion induced by navigational activities. Note that shores defined as insensitive are not included in the assessment.

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Navigational activities are performed all over the world but they tend to be concentrated to certain locations and areas covered by archipelagos, where all the transportation to islands has to be performed by vessels of various sizes. Depending on the population potential, transiting transport and recreational values, there may be frequent bypassing traffic of passenger, car and cargo ferries and smaller, often privately owned recreational boats. The consequences to the marine nature are in general most severe along shipping lanes, but in addition to lane areas, medium-sized and small boats may induce negative effects on *e.g.* aquatic vegetation (Eriksson *et al.* 2004) over extensive areas, as these types are less restricted to shipping lanes.

Unnatural waves and currents from navigational activities have been reported to impact a range of marine environments and species (*e.g.* Rönnberg 1975, Fagerholm, 1978, Lindholm *et al*. 2001, Roos *et al.* 2004) and several marine habitats recognised by the Habitats Directive. One significant effect of navigational activities is the erosion of sensitive shores by waves and water movements originating from bypassing vessels (Granath 2004). The magnitude of the effects is strongly dependent on the vessel type, its velocity, and the type (sensitivity) of the shore. As the speed of a vessel increases, the velocity of the water mass that is displaced by the moving vessel also increases resulting in higher waves and strong water currents. The type of the material (grain size) and the slope of the shore determine the sensitivity to erosion, but shores tend to naturally form according to the prevailing conditions of the environment. High exposure areas with high erosion are characterized by shore types insensitive to erosion, such as boulders and rocky shores, as most of the fine material has been eroded by natural waves and currents. In areas where low natural erosion allows fine material to accumulate, the shores are sensitive to unnaturally induced erosion.

In the Stockholm archipelago it has been measured that fast passenger ferries generate extremely high wave energy levels of up to 20 times higher than those of a small-boat, and up to eight times higher than the levels of large cruise ships in speed-limited lanes. At many sites, wave erosion along the heavily used lanes has removed soil from the shoreline resulting in vertical bluffs of 0,5 m or more (Granath 2004). Erosion may also have economical implications considering the high value of real estates and plots of land on the shore zone. Erosion may cause economic loss due to blemishing of the shoreline and, in extreme situation, due to the direct loss of large masses of land.

Measuring and quantifying shoreline erosion by field investigations need resources. However, GIS-based applications offer tools to make cost-efficient assessments of the effects of erosion by using commonly available data sources – shoreline/land data, depth information and shipping lanes. The detailed steps below describe how the shoreline is first transferred to a series of points, a general erosion exposure for each point is produced by calculating fetch lines between the shoreline points and the shipping lanes analogous to the procedure developed by Ekebom *et al.* (2003), and the results are corrected by overlaying them with shallow areas that decrease the wave power. Users should understand that all values, distances *etc.* presented here are fully changeable if found necessary, or if the analysis is performed in an area with conditions not corresponding to the northern Baltic Sea. A further

calibration of the resulting values should be made on the shore type / grain size information, especially if the possible effects of some planned shipping lanes will be investigated. The analysis described below is quite heavy and time-consuming, but *e.g.* the number of fetch lines may be decreased and/or distance between points increased in order to make the procedure faster.

The tool focuses on sensitive shores, while it is recognised that other features may be of equal importance concerning the effects of navigational activities. The same approach may be used for assessing many of other sensitive features, this being an example that may be applicable for other situations.

The work phases and instructions presented below are only suggestions how to perform the analysis; users are encouraged to alter methods if needed. Instructions are biased towards *ArcView* (version 3.3) and *ArcGIS Desktop* (version 9.2) software because they were used in this example, but other GIS programs should be capable of doing approximately the same tasks. Part of the work phases are guiding and partly optional, but because of the amount of computer work included to the recipe, the procedure aims first at getting rid of irrelevant features and only after that completing the heavier analysing tasks.

Data requirements
- Shoreline, in vector (polyline) format

- Land areas, in vector (polygon) format

- Navigational lanes, in vector (polyline) format

- Marine areas shallower than 3 m, in vector (polygon) format

Step-by-step process
1 Pre-process the shoreline data

   The calculations of the vulnerability to erosion are based on single points located on the shoreline and for that reason the shoreline data has to be converted to a series of points (if not already available). The recommended way to produce this preliminary point data is to create a chain of evenly spaced points along the shoreline, but points may be located on the polyline nodes as well (however, it may result in highly variable distances between the adjacent points). The amount and the spacing of the points determine the laboriousness of the analysis – the higher is the number of points, the more detailed will the results be but the process will also become heavier and slower to run. Distance of less than 5 m between the adjacent points is not recommended. In less heterogeneous environments the spacing can be increased.

   In *ArcGIS Desktop*, there is a ready function to convert polyline nodes to points (*feature vertices to points*), but it requires an *ArcInfo* license. Another way to complete the task

and to space points evenly on the shoreline (also accessible by using an *ArcView* license) is to run a *Visual basic* script *Create points along lines or polygons*, available at *http://arcscripts.esri.com* (visited in April 2007). The script may be run via *Tools → Macros → Visual basic editor*. For *ArcView 3*, similar scripts are also readily available.

After converting the shoreline to points, make sure that there is an ID number column in the attribute table. If not, you can easily create it in *ArcGIS* by adding a new integer column and performing the calculation [FID] + 1 (producing ID numbers beginning from "1"). In *ArcView 3*, you may use an *avenue* script *Autonumber a field*, available at *http://arcscripts.esri.com* (visited in April 2007).

2 Create and process fetch lines from points along shoreline

After converting the shoreline to a point data set, fetch lines for each point have to be created in order to calculate the erosion exposure. After producing all the possible fetch lines, unimportant lines will be removed and the remnants will be cut not to extend behind the nearest shipping lane.

- Divide the whole point data set to smaller parts by using shipping lanes as cutting lines (continue splitting to even smaller sets if needed). By doing that, you will get several subsets of shoreline points that cover an area not cut by any shipping lane, *i.e.* if your source data includes only one shipping lane and some shoreline segments on the both sides of the lane, the minimum number of subsets will be two. Check that the original ID numbers will remain on all subsets.

- Run the *Radiating lines* extension available at *http://arcscripts.esri.com* (may only be run by using *ArcView 3*; web address visited in April 2007). Process the subsets of points created in the previous phase. A bearing interval of 4° and a maximum line length of 1500 m were found suitable when testing the recipe. Save the fetch line data sets by using descriptive names and make sure that original point ID numbers are attached to the attribute tables.

- The amount of fetch lines created may be vast, and for that reason, all irrelevant lines should be removed. First, remove all fetch lines from every fetch data set that are not in contact with shipping lanes (all lines pointing landwards, and lines not extending to the nearest shipping lane). The task may be completed by spatially selecting the fetch lines that intersect with the shipping lanes, switching the selection and deleting all features that remain selected after the switching.

- The next task for reducing the amount on fetch lines is to delete all lines that go through land areas (islands, capes etc.) prior to crossing the shipping lane – they are regarded as non-erosive fetch angles.

    o Subset your land area polygon data set similar to the point and fetch line data sets – a single subset for all the areas separated by shipping lanes

- Buffer all land subsets by a small, negative value (buffering inwards) – that will make sure that wrong lines will not be selected and small spatial inaccuracies, if present, will not affect the selection results. A buffer value of -10 cm was used when testing this recipe. Note that all buffering functions may not accept negative values, but at least *XTools* extension for *ArcView 3* (available at *http://arcscripts.esri.com*) is capable of performing the operation.

- For each of the fetch line data sets, select lines that intersect with the corresponding land polygon subset by spatial selection, or selecting by theme in *ArcView 3* (land polygons will not be present on the opposite side of the shipping lane because of the subsetting). This selection should pick all the fetch lines that intersect with land between the point of origin and the shipping lane. Check the selection result and if correct, delete all the selected features.

- Now, each of the fetch line data sets should contain only the lines that intersect with a shipping lane and do not cross any land areas. The next part is to cut away all the residuary parts of the fetch lines that are behind the nearest shipping lane, *i.e.* the section between the shipping lane intersection point and the end point of the fetch line.

  - For every subset of fetch lines / land polygons, create a polygon (manually) to be used for erasing the excessive parts of the fetch lines. The polygon should cover all the areas that remain behind the nearest shipping lane as viewed from the shore to be analysed.

  - After creating the polygons, perform the erase operation for each fetch line subset. Erase may be executed *e.g.* by using the *ArcGIS Desktop* (requires an *ArcInfo* license), or the *XTools* extension for *ArcView 3*, available at *http://arcscripts.esri.com* (visited in April 2007). The operation may last a considerably long time, so be patient.

- In the resulting fetch line layer, there may be lines that cross the shipping lane twice and, therefore, the ending section have penetrated outside the erase polygon. Those sections need to be separately deleted as they still are attached to the initial fetch lines as multipart subfeatures.

  - First, fetch lines need to be converted from multipart to singlepart features in order to separate the erroneous sections. The task may be completed by *Multipart to singlepart* function, either using *ArcGIS Desktop* or *ArcView 3* (the *XTools* extension).

  - After making all the fetch line segments as single part features, select all lines that intersect with the corresponding shore point data set (spatial selection, or select by theme), and switch the selection – now all those erroneous lines should be selected. Delete them and check that original point ID numbers still are within the line data set attribute table.

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- Finally, combine the fetch line subsets to a single data set and calculate the length of each line. Note that there may be "length"-column already present in the attribute table, but because of the erasing functions and other procedures, new values has to be calculated as the original length column probably contains false values. In *ArcGIS Desktop*, lengths may be calculated directly to the attribute table by using the *Field calculator* and typing a proper formula (check the "help" section of the *Field Calculator*), and in *ArcView 3*, the easiest way is to use the *XTools* extension.

3   Clip the fetch lines with shallow areas

As shallow areas decrease the energy of waves, their presence has to be accounted for when assessing the total erosion effects. In this recipe, "shallow" is interpreted as being a marine area less than 3 m deep.

The task is to clip the fetch lines with the shallow area polygons to create a new data set, a fairly easy task that may be completed using either *ArcGIS Desktop* or *ArcView 3* (*GeoProcessing Wizard* or *XTools*). The only drawback of the clipping operation is its heaviness as the target in this case, even if performed in subsets, still may be a quite extensive data set – the operation can take some time. Remember that the purpose is not to replace the fetch line data set created at Step 2, but to create a new, clipped set – both of them are needed at later stages. After clipping, calculate the lengths of the clipped lines similarly to Step 2 and check that ID numbers still exist on the attribute table.

4   Add the number of the fetch lines and the summed length of lines to the original shoreline point attribute table

Fetch lines have now been produced and clipped to the correct extents, and shallow areas have been extracted. The next phase is to insert this information to the original shoreline point data set. For each shoreline point ID there is likely to be several fetch line inputs. The purpose of this step is to provide shoreline points with information of 1) total number of the fetch lines, 2) the summed length of all the point-specific lines, and 3) the summed length of all the point-specific lines that are clipped by the shallow areas.

- Begin with the fetch line data set completed at Step 2; open the attribute table of the first subset. Either with *ArcView 3* or *ArcGIS Desktop*, summarize the field containing original point ID numbers by the sum of the length column – the resulting table should present the number of separate fetch lines relating to each point ID, and the sum of their length values.

- Open the attribute table of the original shoreline point data set, and make a join between the summarized table and the point data set's attribute table by using point ID numbers. Copy the number of fetch lines and their summed lengths to new columns (create the columns first and name them as you will), and remove the join.

- Proceed with the fetch lines clipped by shallow (<3 m) areas: summarize the point ID field by the sum of the length column, join the resulting table to the corresponding

shoreline point data set, copy the summed length values (no need to copy the number of the lines) to a new column and remove the join. Now, the shoreline points should contain all the needed attributes.

5   Calculate the potential erosion pressure for each shoreline point

Now you are ready to quantify the potential shoreline erosion pressure. The formula below is a modified version of the approach introduced by Sundblad *et al.* (in prep.). It includes the number of fetch lines connecting a shoreline point and a shipping lane, the total length of the lines and the length over shallow areas, but lacks the line lengths over underwater rocks as well as the wave energy factor to distinguish different ferry types as recognized in the original formula. The purpose of the modification was to make the procedure simpler and reduce the number of input data sets without altering the result too much, but the original formula may be used as well if all the data needed is available.

$$Erosion\ level = \frac{n}{\left(\dfrac{(L_{tot} + (L_{3m} * 1,5))}{n} \right)} * 1000 \, ,$$

where L_{tot} the total length of fetch lines of a certain shoreline point and L_{3m} is the length of lines over shallow areas.

6   Classify the level of potential erosion of sensitive shores

In order to enable the assessment of vulnerability of the shoreline, the predicted strength of erosion need to be linked (overlaid) with the distribution of sensitive shores, or other sensitive features. The interpretation and classification of the results depend on the type of the shore and its sensitivity to erosion. If the erosion assessment is combined with the information indicating the sensitivity of a shore to artificial erosion (*e.g.* based on the shore material and slope), it may be evaluated where the effects may be most pronounced and which shores are vulnerable.

The information on shore type may be queried from different sources. In this case we used the CORINE data base and national studies on shore type (Swedish SAKU project). Sensitive substrate types are classed as shores having moraine substrate, which basically includes shores that are vegetated with trees and brushes. Sand, gravel, boulder and rocky shores are not included as they are defined as insensitive to this type of erosion. Slope was derived from a Digital Elevation Model and set to >7 degrees. The combination of the two attributes results in an output that may be sensitive to the kind of pressure presented here.

NB. Other type of habitats that are defined as sensitive to the pressure may include the features, which are not included in this example (sand, boulders, and rocky shores). A full erosion analysis will require that all types of sensitive habitats and environments are included.

Table 23   Suggested class values for potential shoreline erosion in the Baltic Sea at sensitive shores (moraine shores with slope >7 degrees, after Kukkonen 2004).

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Class	Erosion level
No indication of erosion	0 – 10
Low indication of erosion	10 – 25
Moderate indication of erosion	25 – 50
High indication of erosion	50 – 100
Very high indication of erosion	over 100

Indicator in the Assessment of Management Performance
This tool is a useful indicator for showing the spatial distribution of a common pressure factor in shallow coastal areas. As this tool shows the potential sites that are under risk of being eroded due to navigational activities, the change can be assessed only an indication after is given that the navigational activities have changed in the area. The strength of the erosion may be combined also with other relevant sensitive features for assessing the state and change of state of the vulnerability of these features.

The tool can be applied as an indicator for other purposes. A first step in the assessment of management performance could be to validate the accuracy of the location of the vulnerable sites by cross-checking with remote sensing information and field investigations.

In addition to describing the present situation, the results may be used to show potential hot spots of erosion in areas where new shipping lanes have been planned.

STEP 1

Shoreline (polyline) → Convert to points → *Shoreline, as points* → Calculate ID numbers → *Shoreline points, ID numbers calculated*

STEP 2

Shipping lanes

Land areas

In subsets, finally combined

Divide to subsets → *Shoreline points, in subsets*

Create radiating lines → *Fetch lines from every shoreline point* → Remove lines not in contact with shipping lanes → *Remaining fetch lines*

Remove lines that go through land areas → *Remaining fetch lines* → Cut residuary parts behind the shipping lanes → *Remaining fetch lines*

Remove double-crossing line parts → *Fetch lines relevant for shoreline erosion* → Calculate lengths → *All fetch lines, lengths calculated*

STEP 3

Shallow areas → Clip with shallow areas, calcul. lengths → *All shallow fetch lines, legths calculated*

STEP 4

Summarize using point IDs → *Summary table*

Summarize using point IDs → *Summary table* → Join summed lengths of fetch lines → *Shoreline points, all attributes updated* → Join the count of fetch lines and summed lengths

STEP 5

Calculate potential erosion level → *Shoreline points, potential erosion calculated*

STEP 6

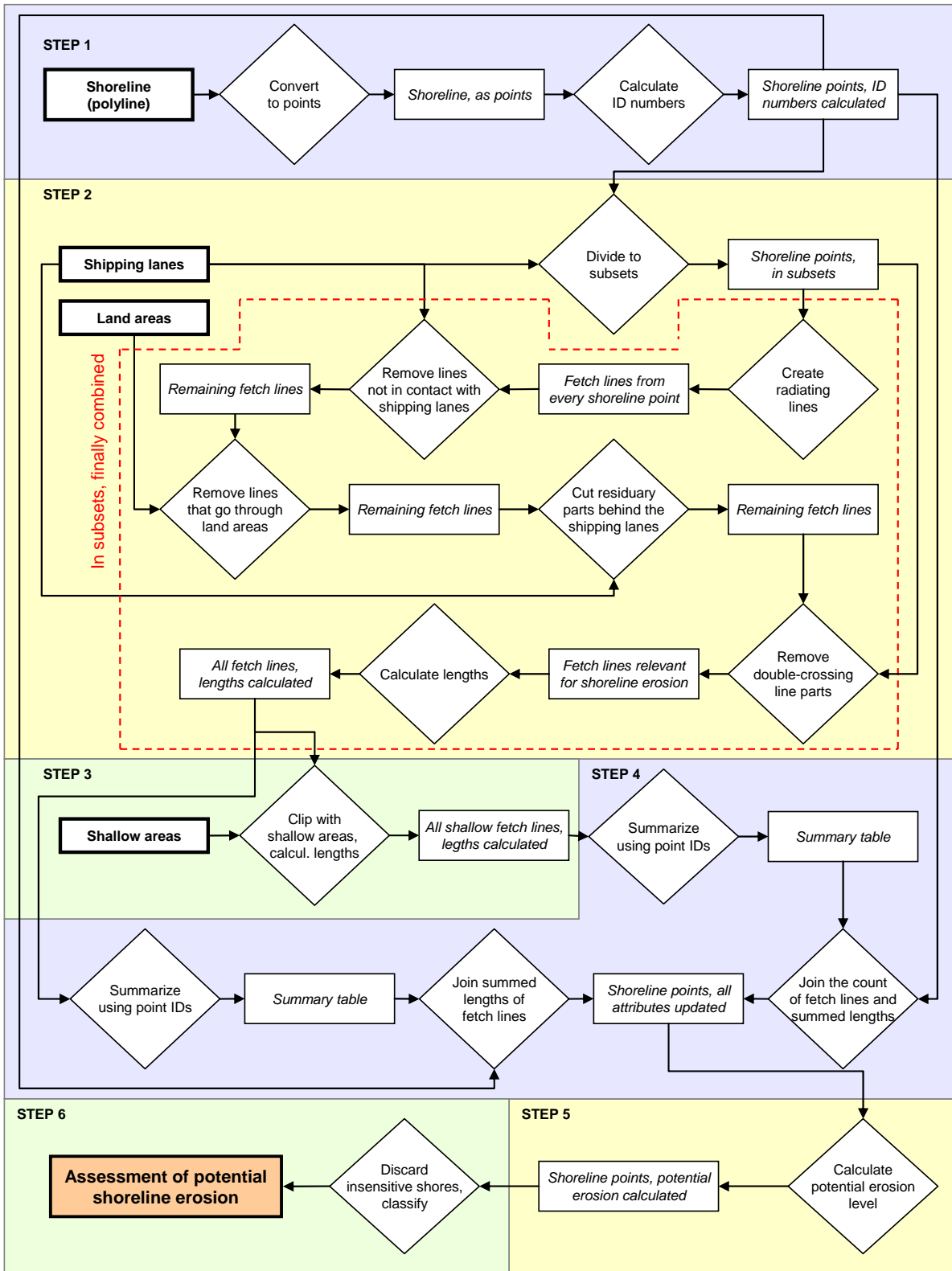Assessment of potential shoreline erosion ← Discard insensitive shores, classify

Fig 24 Principle steps of performing the analysis Assessing shoreline erosion induced by navigational activities

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Fig 25   Sample images of performing the analysis Assessing shoreline erosion induced by navigational activities

2.5 Socio-economical – Sate

2.5.1 Effects of marine management activities on fishing

Marine nature conservation may have effects on other sea uses as resources become regulated and protected. Commercial fishes are one of the most important marine resources. As fishing is a major sea use, it is likely to be highly affected by marine management measures. In order to fully meet the goals of a balanced management, the assessment of management performance should provide information regarding the effects of management on both resources as well as uses. The fishing intensity and importance normally varies among areas. Thus, a spatial approach in assessing the management effects on fisheries is justified. The focus of this example is on the spatial aspects of an assessment, *e.g.* what GIS data can be considered and what differences in marine areas, offshore and near shore, are there to be considered in an analysis. The description should be viewed as a guideline of the approach and methods required when dealing with the socioeconomic effects of zoning on professional and recreational fishing in the Baltic Sea setting.

An assessment of management performance can be conducted using a Socio-economic Impact Assessment (SEIA), which provides information of the effects that management will have on the uses in a defined area (Table 24). The outcome of a SEIA may be useful in minimising the negative effects of the management, including effects on fisheries. Detailed definition of tools, methods used and ways of conducting a SEIA are found in *e.g.* Anon (2005).

Table 24   A short description of central elements of the process of SEIA (Anon 2005).

Step	Description
Scoping	Establishing the time-frame and defining the area of impact, identifying key stakeholders, how they potentially are affected, methods and available information to be used in the analysis
Baseline profiling	Defines the ongoing activities and their current state and location in the area of impact, *e.g.* number of fishers, gear type, target species, catch, fishing area etc
Direct impact	Level and range of impact change of those directly affected conducted by collating and analysis of existing or new data, *e.g.* qualitative and quantitative interviews and surveys of target groups
Indirect impact flow-on	Changes in economic activity and income in a region and of those indirectly affected, changes to population and provided services *etc.* May include regional profiling of the impact, various surveys and modelling of impact

SEIA of commercial and recreational fishing

Marine management, including the use of MPAs, may have a range of effects on commercial as well as on recreational fishing. Commercial fishing may include all possible direct and indirect activities, from the actual fishing to the selling of the final products, including aquaculture. Recreational fishing is defined as *e.g.* business operators in the tourism sector, equipment and bait sellers and the active recreational fishers. Table 25 gives a summary of the SEIA of commercial and recreational fishing.

Table 25   A comparison of the SEIA of commercial and recreational fishing, respectively, regarding who are involved, what will be impacted, what data will be needed) and the level of impact (Anon 2005).

	Commercial fishing	**Recreational fishing**
Scoping (of what will change)	level of income & employment, business value, community well being, operating costs, service provision	leisure value, available food for household, level of income & employment, business value, well being, operating costs
Baseline profiling (of who will be affected and of the state)	fisheries licences, catch data, surveys of license holder, ports of landing, suppliers & retailers	new and existing surveys of recreational fishers, fisheries licence, interviews with recreational fisheries associations
Direct impact	assess the level of state change of above parameters within area of impact	

Additionally, an evaluation of the response, due to change of state, of fishers may be required, as the reallocation of effort, species, equipment, time and area may be of importance concerning the management performance.

Data requirements and sources

The socio-economic effects of marine management on fisheries may vary depending on where *e.g.* the MPA is situated in relation to the fishing activities, what restrictions and limitations there are, gears used, how many active fishers there are, and what species are caught (Anon 2005). The potential effects likely differ depending on whether the area is situated offshore or near shore. Hence, the data needed and the sources of data may vary depending on the properties of the area of impact and in relation to the fishing activities (Table 26).

Table 26   A comparison of central properties of an offshore (Case Study 2) and near shore area (Case Study 3), which, parallel to Table 23, may be relevant concerning the data needed in a SEIA of fisheries.

	Case Study 2 Offshore	**Case Study 3 Coastal near shore**
System	Pelagic	Shallow coastal archipelago
Important species	Cod	Herring, perch, pike-perch, white-fish
Important habitats	Pelagic spawning habitat for cod	Varying nursery areas for several coastal species
Gears	Long distance trawling vessels	Usually small coastal boats, gill-nets
Fishers	International vessels	Mostly local fishers
Importance for professional fishing	High	Low, but with potential large local importance
Importance for recreational fishing	Of less importance	Proportionally more important
Problems associated with fishing	Over-fished cod population Poor recruitment	Seals, exploitation of nursery areas, aquaculture, professional vs. recreational fishing
Water ownership structure	National-international water	Complex private water ownership structure, national-international water
Regulations	Restrictions through the EU Common Fisheries Policy	Various small areas under national regulation

Most biological advice pertaining to commercial fisheries is based on data that is collected from the fishery itself or through biological surveys. From the industry, data is collected regarding landings, effort, species, size and age. Data for landings by species is registered when the fish are sold, and this data is readily available via a given nation's fisheries statistics. However, for a number of commercially important species the actual catch is much larger than the landings (due to discard), and therefore data for these species is collected directly on selected vessels. In addition, The Baltic International Bottom Trawl Survey Database (BITS) includes research vessel data (mainly cod and flounder) from national fishery laboratories around the Baltic Sea from 1991 until present.

Fisheries data gathered through discard surveys, logbooks and national surveys are gathered by national fisheries institutes and uploaded to an international database called Fish-Frame, while internationally coordinated surveys such as BITS are coordinated by ICES. Information on recreational fisheries, however, is not collected on regular basis. Surveys and interviews targeting recreational fishers are usually needed in order to gain the information required regarding *e.g.* numbers of fishers, catch sizes, species *etc*. in a given area. Hence, potential management effects on recreational fishing may be more laborious to assess. Table 27 gives examples of potential sources of statistical and other information regarding commercial and recreational fishing.

Table 27   Potential major sources of information related to commercial and recreational fishing in Germany, Sweden, Åland, Denmark and Finland.

Source	Information
German Fishery Association	Commercial interest
German Offshore angling society	Recreational interest
Federal Agency for Agriculture and Food	Implementation of fishery regulations
Danish Fishermen's Association	Commercial interest
Danish Sport Fisherman's Association	Recreational interest
Danish Directorate of Fisheries	Implementing fishery regulations
Danish Institute for Fisheries Research	Fisheries statistics, stock monitoring, research
Federation of Finnish Fisheries	Aquaculture, commercial fishing
Finnish Fishermen Associations	Aquaculture, commercial fishing
Finnish Employment and Economic Development Centres	Socio-economy, fisheries
Finnish Game and Fisheries Research Institute	Fisheries statistics, stock monitoring, research
Åland Department for Trade and Industry / Fisheries Section	Sustainable fishing, monitoring
Swedish Board of Fisheries	Fisheries regulations and control, stock monitoring, research

A spatial approach

All four elements of the SEIA include spatial applications. Scoping is the first step of the analysis and includes spatial elements such as defining the coverage of the management effects, *i.e.* the area of impact, and collection of spatial data. The baseline profiling may be conducted using GIS, *e.g.* by creating polygons of areas attributing number of fishers, gear type, *etc*. The direct as well as the indirect impact steps both have spatial dimensions as the impact of management can be predicted to decrease with the distance from *e.g.* a no-take zone.

There are some notable differences in offshore and coastal areas regarding the capability of fishers to use areas, which may be important information when assessing the management effects. Near shore areas often are proportionally more important areas for recreational fishing compared with offshore areas, mainly because of logistics and accessibility and because there is a relatively larger pool of potential recreational fishers in coastal areas. Near shore, coastal commercial fishing usually is conducted using small boats, which only cover small areas compared with the large vessel used in the open sea fishing (Tschernij & Kämäräinen 2003). Small boats are less capable of following the seasonal movement of fish. Thus coastal fishers are more likely to be affected by effects which may arise from factors such as if *e.g.* the target species is migratory or stationary, if the major fishing area constitutes spawning, nursery or feeding areas, *etc*. The complex water ownership structure of Swedish

and Finnish waters may restrict fishers to defined sites where they are allowed to fish. The state of fishing can be seriously affected if the management sets limitations within certain fished areas while alternative areas are inaccessible due to the water ownership structure.

One key issue in estimating the impact of the feed back of management effects on any use in an area is to predict the level and coverage of the pressure induced by the use. In this sense, a pressure factor can be viewed both as a state factor and depending on the situation, *e.g.* fishing is a major socio-economic pressure factor on a range of resources, but it is a socio-economic factor describing the state of fishing in an area. Regardless of the pressure and/or the state being biophysical, socio-economical factors or management measures, they spatial coverage may be compared with the coverage describing the state of the targeted factor. An example of a parallel view of a factor and the use in different indicators is given using recreational fishing as the factor (compare the present description with the tool Indicator of marine management effects on fishing, where recreational fishing distribution is defined as a pressure factor). The spatial coverage of the state of recreational fishing, in terms of activity and intensity, can be predicted by estimating the location, frequency and abundance of fishers in an area as accurately as possible. Fishermen often choose a fishing site that provides the maximum yield (Hunt 2005) and abandon areas that do not satisfy their expectation of quality (Lewin *et al.* 2006). However, they usually use a restricted area due to logistic reasons, whereby a prediction of the likely distribution may be mapped.

Preferably, after predicting the likely distribution, the potential overlap between *e.g.* popular fishing grounds and the predicted management effects can be estimated by an overlay analysis. Fig. 26 illustrates a predicted pressure distribution exemplified with recreational fishers in an archipelago landscape. To indicate the potential spatial variation in the management effects on fishing, polygon or raster layer of land / sea areas, location of harbours (points), location of built-up areas or other type of population data in polygon or raster format are used to calculate the distance matrix of the harbours weighted with population data (potential pool of fishers) of the harbour influence area. In addition, fishers leaving from their private shore can be modelled using data of shoreline-locating houses and cottages. The result may be classified as a layer illustrating the potential state of recreational fishing in the area. Additionally, the information may be combined with data of the distribution of important fishing sites in order to isolate high quality fishing grounds/sites, where the potential management effects likely are very high. Consequently, in this example, the largest pressure effects on the state of important habitats for fish are at the most popular fishing locations, which are situated in areas with high fishing intensity, and where the potential management effects have the largest socio-economical implications for the recreational fishers.

See recipe for *Predicting the effects of recreational fishing on sensitive habitats* (2.4.4) for a full description on how the analysis is conducted using GIS.
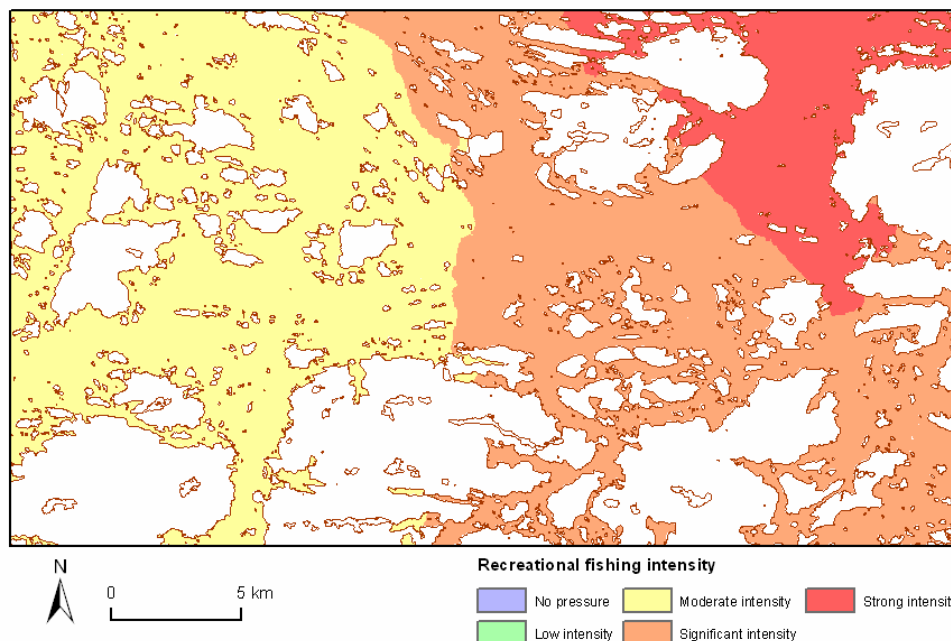
Fig 26 An example of a predicted socio-economic sea use distribution describing the state of recreational fish-ing. The indicator can be used in the assessment of management performance assuming potentially larger management effects on the fishing in areas where the intensity is high. Compare with the tool In-dicator of marine management effects on fishing, where recreational fishing distribution is defined as a pressure factor.

Indicator use in the Assessment of Management Performance
The tool visualises the potential management effects on sea uses in a coastal environment. The tool serves as one example on how specific socio-economic sea uses can be used in or-der to express the spatial distribution and the likely magnitude of management effects. Hence, the magnitude of effects is dependent on the extent and diversity of the sea uses.

Spatially, the potential overlap between *e.g.* popular fishing grounds and the predicted management effects can be estimated by an overlay analysis. The predicted management effects can be compared within and among zones and / or compared with baseline values (profiling).

Over time, the scoping and profiling steps may reveal to reveal the long-term effects of management on socio-economic use.

2.5.2   *Economic value of marine areas – exemplified for recreational activities*
Marine areas are utilised by a great range of activities, which interest in the marine nature and its resources vary. The economy associated to these activities is often misinterpreted,

underestimated or totally ignored, because the complete economic valuation of marine areas is a highly complex task due to numerous interconnections and difficulties in defining monetary values for unknown or poorly known elements. Especially, the determination on what the ecosystem itself is worth in terms of value of the provided goods and services in challenging. However, on a certain level, there is a possibility to estimate the economic value of a marine area. The result may be speculative but offer a way to express the importance of marine areas in other than biological values.

In this recipe, a few practices appropriate for the calculation of economic value are presented and demonstrated in GIS maps, but the approach is not attempting to be holistic, following the total economic value described below. The aim is to estimate the economy associated with a marine area for a few activities related to recreation, which mode in turn may vary depending on the area. The values are given for a specific unit of area, and this value per area can then be used in a MSP process to find out the areas of high economic value for specific activities. This type of information will help to minimise the economic loss due the planning, and minimise costs of planning. Short descriptions of other relevant activities are presented in the recipe.
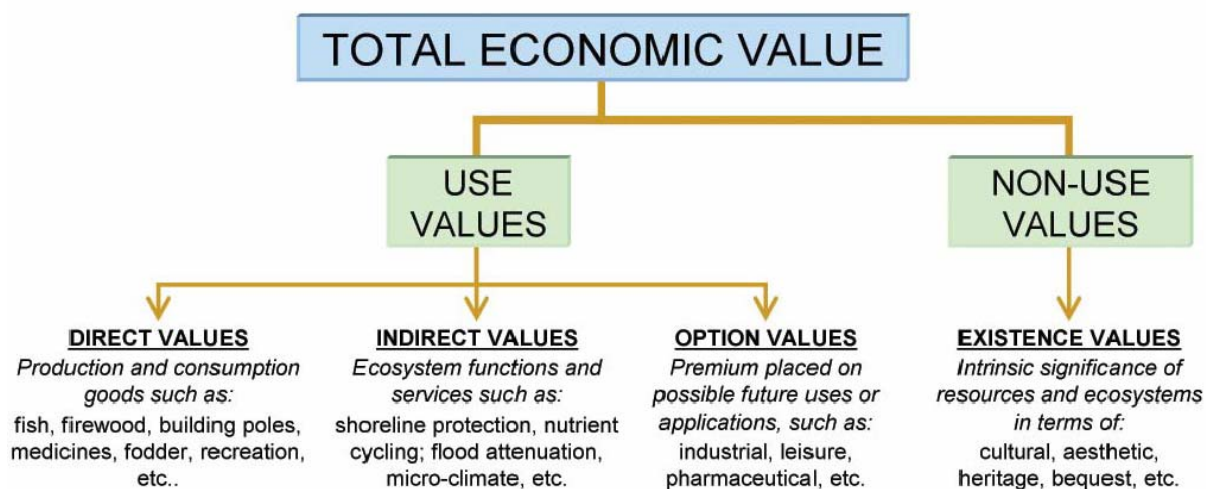
Fig 27 Components of the total economic value, redrawn from Emerton (2006).

One way to evaluate the economic value is a concept called *total economic value* (*e.g.* Pearce & Moran 1994; Barbier *et al.* 1997; Morling 2004; Emerton 2006). It consists of several components, which combined are intended to describe all the economy-related interests that are of importance on the particular area (Fig. 24). As Emerton (2006) states, the concept may be categorized to *use values* and *non-use values*, the first of which can further be divided to *direct*, *indirect* and *option* values.

Direct values mean the raw materials and physical products used directly for extraction, production, consumption and sale. Indirect values include, for example, ecosystem func-

tions which maintain and protect natural and human systems and provide essential life support. There have been attempts to valuate the biodiversity and ecosystem services, but as Hoagland *et al.* (2005) points out, the task is highly difficult. The procedure may be straightforward at a conceptual level – the economic value is equivalent to the net present value of goods and services that flow from uses and non-uses of the resources and the environment – but the calculation of this kind may only be descriptive and necessarily anthropocentric. There has also been criticism that the concept of total economic value actually fails to include services provided by the ecosystem. For example, measurements will understate the "true" economic value because of the probable failure to measure primary life support functions, and the valuation does not capture, nor is it designed to capture, the intrinsic values of the nature (Pearce & Moran 1994). Morling (2004) also highlights the fact that a reason why biodiversity and ecosystem services are often excluded from the economic calculus is because they are regarded as "public goods", that is, one person's use of it does not preclude anyone else's and secondly, it is impractical to exclude other people from using it. In spite of these limitations, some researchers have estimated the values for ecosystem services and capital, *e.g.* Costanza *et al.* (1997) concluded that the coastal ecosystems' goods and services worldwide are worth 12.6 trillion dollars, and the open oceans' 8.4 trillion.

For practical reasons, most of the research related to the economic value of a certain area is concentrated on definite industries and impacts that may easily be measured in financial terms. Hoagland *et al.* (2005), for example, estimated the value of economic activities associated with the marine area in NE United States by using data of fisheries, shipbuilding, water quality, tourism and real estate from several government databases. As a result, for coastal counties from Maine to North Carolina, having a population of 40 million, they concluded that the best upper bound estimates for economic activities associated with the marine area are $339 billion in total output impacts and $209 billion in value-added impacts (both direct and indirect effects). A different approach is presented by Colgan (2003) – he suggests that the economy of marine areas and its value is consisted of construction work, living resources, minerals, ship and boat building, tourism and recreation, transportation, activities of federal, state and local governments, real estate industry and research / development. In addition to studies aiming at the calculation of overall economic value, there are numerous of surveys of more constrained marine matters. For example, Bohnsack *et al.* (2002) estimated that bluefin tuna anglers affected total economic output of $4.6 million and resulted in 126 full and part-time jobs in 1997 in Hatteras, North Carolina. Another study by Storey & Allen (1993) concluded that the economic impact of marine recreational fishing by residents in Massachusetts totalled $545 million as direct expenditures, provided 16 000 jobs and resulted in $246 million in income, $20 million in state tax receipts, and $29 million in local tax receipts. These examples indicate that the value of marine areas in terms of economics may be significant.

It should be noted that it the economic value only provides a snapshot of the present situation. As the conditions change, the economic state and the relationships arising from current the setting change as well. An example would be the establishment of a marine protected area – if a MPA prohibits diving in a particular site and this is the only area where

divers go in the region, indirectly impacted industries may include boat building or scuba gear manufacturing, and finally induce effects on spending of households as income increases or decreases (Dalton 2004).

For the evaluation of monetary values of habitats and other biological features, their economic value can be correlated. In the study "An Assessment of the socio-economic costs & benefits of integrated Coastal Zone Management" (the European Commission, November 2000) the economic benefits for estuaries or sea grass-habitats are evaluated and transferred to monetary values. The inclusion of socio-economic data can foster a better understanding for the importance of these normally hidden services of habitats and be used in the zoning process, mapped and brought to discussion.

The recipe – how to calculate economic value
This recipe will not introduce step-by-step instructions how to commit the analysis of direct economic value as the procedure may vary greatly depending on the resources available and the scope of the analysis. The desired scale is also an important decision to be made – selecting a more detailed level than municipalities seldom is possible, and often the required outcome is to calculate the total value of a single, large marine area.

Below there are given some examples and ideas of data generally of rather high availability and that can be utilised in GIS to show maps of economic value of specific activities in specific marine areas. The three illustrated examples are made for Archipelago Sea, SW Finland, and analysed on a municipality level. Readers should remember that the examples are demonstrations indicating the direct economic value related to the marine area, not an approach to assess the total economic value. Detailed instructions and examples of the actual calculations are given in the literature cited above.

- COMMERCIAL FISHING. The value of fishing may be separated to two parts: commercial and recreational fishing, both of which may be economically highly significant. Commercial fishing statistics, often on a quite general level, may be available *e.g.* from governmental offices or ministries, ICES or Eurostat. In addition to the value of the catch itself, the calculation of the economic importance should include the costs of labour and the equipment needed for fishing, possibly extending to services needed by fishers and the existence of fish-processing industries. Not exemplified here.

- RECREATIONAL FISHING. The economic effects of recreational fishing are often underestimated as the value of the catch is not so easily evaluated, and under no extensive official monitoring, but at least in terms of the value of fishing permits, gear needed for fishing and especially the use of different services on another ways, recreational fishing may be seen as highly significant matter. The value (or at least the number) of fishing permits is often quite easily available from governmental offices or fishing associations, often classified to relatively small areal units. The value of the gear and services may normally be evaluated only by making assessments, but some statistics may *e.g.* offer information on the purpose of travelling of hotel guests. Not exemplified here.

- COMMERCIAL SHIPPING. This is an obvious and important sea use that has a great economic potential. However, the economic impacts of importing and exporting goods, carrying passengers and running different harbour businesses are affecting to a large region thus making the calculation of their area-specific value difficult. The importance of a certain harbour in terms of import and export may be evaluated from *e.g.* governmental statistics, but more important matter would be the various harbour-related companies and their economic value. If decent statistics are not available, the simple ways should not be forgotten: companies may be picked out from a company register or catalogue, and their value may be evaluated using the number of employees. One should remember to include different activities related to dockyards and construction/maintenance of ships. Not exemplified here.
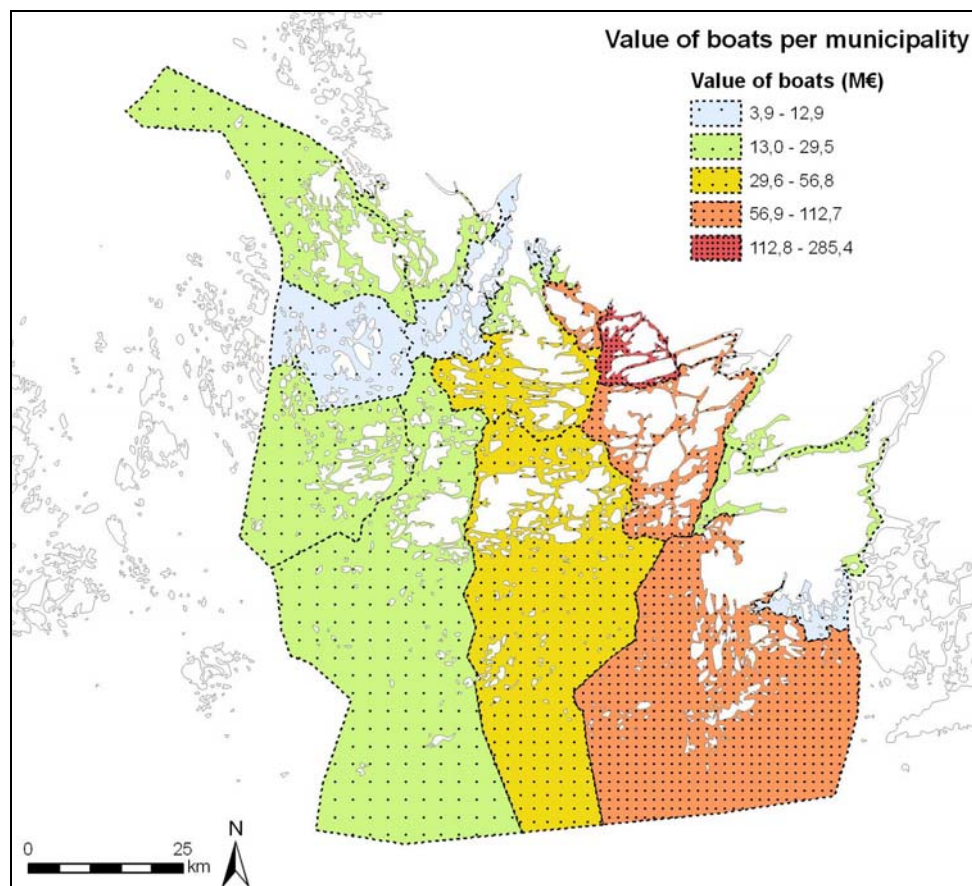
Fig 28 Estimated value of boats per municipality in SW Finland year 2007. The total number of boats has first been evaluated by using the official boat register and an estimate of the quantity of boats not registered, and the value has finally been calculated by checking the average boat price from a catalogue of boats in sale. Finally, the value of rowing boats (quite seldom sold in catalogues) has been added by counting the number of shoreline-locating summer cottages (using a GIS software and relevant data set) and estimating that there is on average one rowing boat per cottage. Note that the population and the total area of a municipality will both affect the result.

- RECREATIONAL BOATING. Recreational boating does not include labour costs similarly as commercial shipping, but its value and especially secondary effects are vast. In addition to the effects of boating, an important economic matter is the boats themselves. An example (Fig. 28) from the Archipelago Sea, SW Finland is presented below, showing the estimated value of the fleet of small boats in the municipalities of the area. Similarly to commercial shipping, the value of docks / small boat harbour activities, repair shops and boat shops should be included.

- RECREATIONAL HOUSING / COTTAGES. Recreational houses / cottages along the shores may be evaluated in terms of real estate value (Fig. 29). Marine areas are highly valued areas for recreation and without the sea, the total number of houses/cottages would probably be much lower. The number of cottages and their average value is quite easily available from on sale –catalogues.
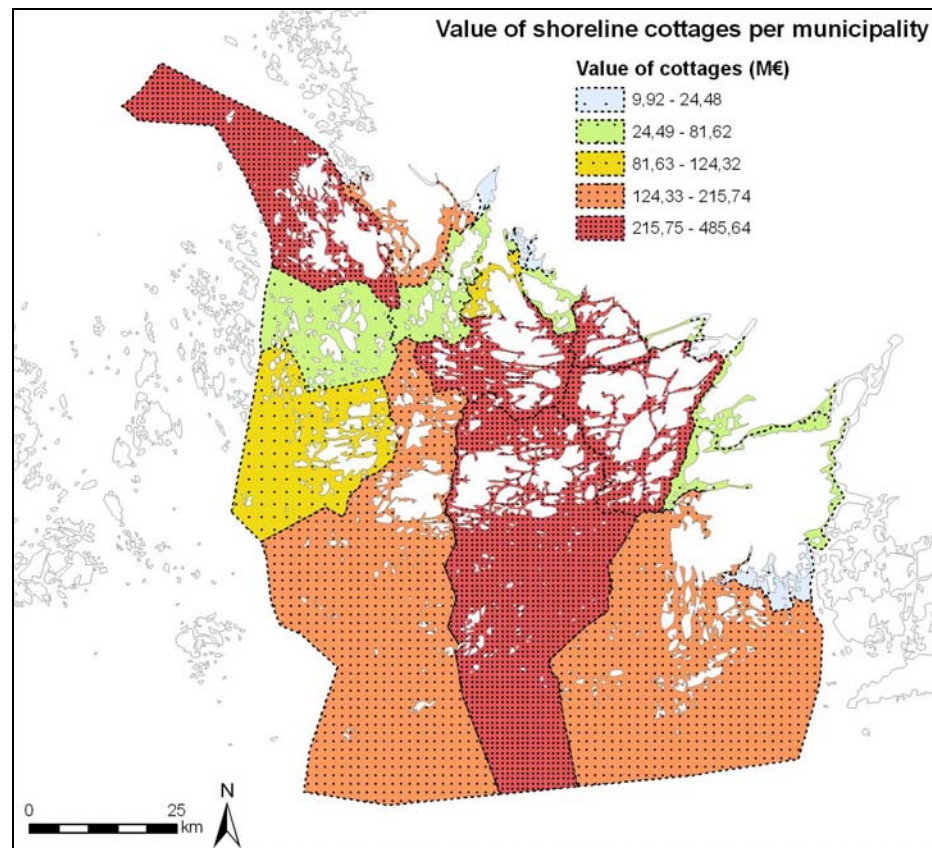
Fig 29 Estimated value of cottages located at the shoreline per municipality in SW Finland. The total number of cottages has been queried from GIS data, and the average price of a single cottage has been evaluated using information of cottages on sale. Note that the population and the total area of a municipality will have an affect on the result.

- • THE VALUE OF TOURISM. The economic input of tourism is not easy to evaluate as part of it is included to other categories as well (recreational boating and its effects may be seen as a part of tourism). However, as a separate category, tourists may be considered as a driving force and potential to hotels, restaurant, travel agency and shops. From that point of view, a decent way to investigate the economic value of tourism is to check some statistics of companies having assumable relationships with tourists. In lack of accurate statistics, a secondary option is to *e.g.* browse a company catalogue, possibly giving information of the labour force. Internet has also proven to be a very effective tool. In addition to companies, *e.g.* statistics of the visitors on MPAs or national parks may provide information of the importance of tourism. (Fig. 30)
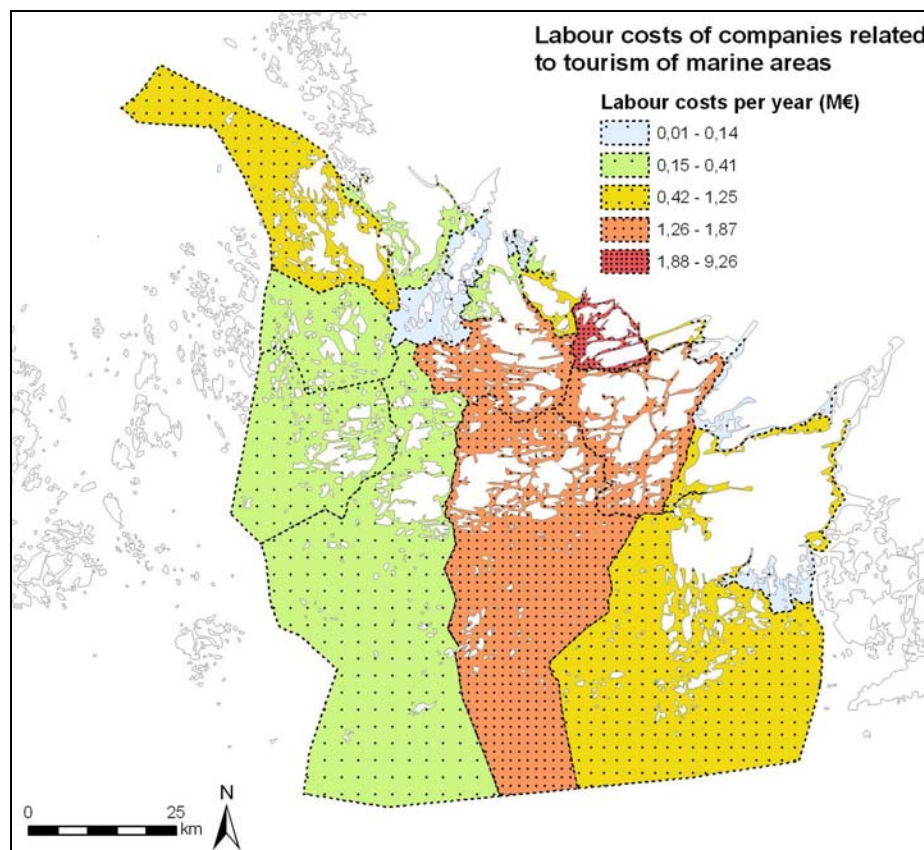
Fig 30 *Estimated value of labour costs of companies related to tourism in marine areas. All relevant companies and the number of labour force in the coastal municipalities have been collected using public catalogues and internet, the number of employees has been multiplied by the estimated average salary and a factor (1 – 100 %) has been implemented for the assessed degree of proportional dependence on marine tourism (i.e. a restaurant located on mainland may have factor of 1 % indicating a weak dependence on marine tourism. An archipelago-oriented travel agency may be totally dependent on marine tourism thus having a 100 % factor). The approach is experimental and does not include secondary value-added effects. It demonstrates a simple procedure how to make an assessment of a complicated phenomenon. Note that the population and the area of a municipality will have an affect on the result.*

- TAXATION COSTS. Taxation costs of municipalities are a somewhat tricky part to be included to the economic importance of marine areas as the degree to which they are related to the marine environment cannot be that easily determined. In addition, they may already be included to other categories of the economic total value (*e.g.* if the value-added effects of marine tourism are calculated). If, however, taxation costs are included to the analysis or their importance is evaluated on some relevant way, it is usually rather easy to gain such data – governmental statistics usually give the information needed at the municipality level. Not exemplified here.

- THE USE OF RESOURCES. In addition to fishing, other resources to be included to the analysis are *e.g.* wind and wave energy (the present and the potential value), sand / gravel uptake and oil / gas industry. Some of these activities (especially if the future potential is intended to be assessed) are not so easy to evaluate, but at least party they are available from the governmental statistics or from the internet. Not exemplified here.

Application in Marine Spatial Planning
The above examples all can be applied in the Marine Spatial Planning process as information on the spatial distribution of economic value, which is crucial in order to estimate to which extent the implementation of the plan will affect the economy in the area. Clearly, the three illustrated examples are showing a fairly comprehensive estimate of the recreational aspects of the economic value (recreational boating and cottages, and tourism related companies). This information is useful in assessing which effects an implemented plan of zones will have on the recreation in the area, especially in terms of change in the associated economy.

Considering the MSP effects on recreation, the information exemplified here can be used separately to analyse the management effects on each activity in each unit of area (municipality in these examples). The management effects will vary depending on which activity may be targeted with the plan and which the decision is in each zone, and to which extent a zone overlap with the analysed area (municipality). For example, if a decision in a zone is stating that coastal development, including new cottages, is regulated, the cost may be calculated taking in account the market price in the area.

The information of each activity can be combined to show the overall picture of the economy. For example, the classes may be ranked (1-5) and then summarised in to a map showing the cumulative and / or mean relative economy associated with recreation in each municipality (Fig. 31). If information is available for other relevant activities, the similar approach may be used to get an evaluation of the direct economy and the effects management decisions will have.

Optimally, the information should be compared with the other components included in the total economic value (see above). Goods and services provided by the ecosystem are difficult to determine in economical terms because they cross boundaries, but indirectly, the conservation needs and biological values (habitats and species) of an area may express of

the value of the area. Option and existence values may be related to the conservation of areas, and indirectly these values may influence the recreation in positive terms.
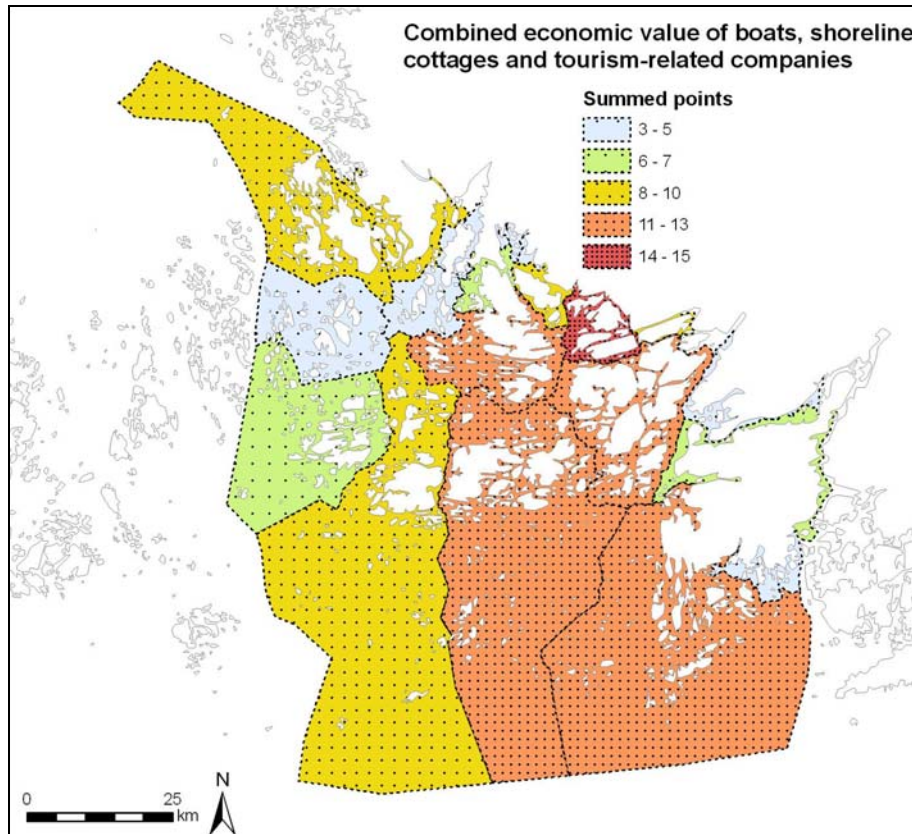
Fig 31 Combined economic value of the three maps above (value of boats and shoreline cottages, and labour costs of tourism-related companies). Each single map has been classified (1–5) similarly to class categories shown on map layouts, and all the class values have been summed to a single point value (3–15) indicating their cumulative economic importance.

2.6 Governance – Stakeholder interaction

2.6.1 The interaction between authorities and stakeholders

The indicator of the level of interaction or the lack of interaction between authorities and stakeholders includes all type of communication between the two and it measures the actual measurable as well as the perceived level and quality of the interaction. A representative participation enhances the level of co-management, minimizes the conflicts, and increases the likelihood that conflicts are resolved.

Information of the communication interaction and the content of the communication are of paramount importance when determining how well a marine area is governed. The contacts to authorities are indicators of the activity and the opinion among people that are affected by the management. It can be seen as a measure of the management enforcement compliance by resource users (see recipe 2.6.2, below) and planning transparency and it is an indicator which is mainly aimed at communication conducted during the planning process. Of course, the same approach is used in the communication during the implementation process. A detailed description of the rationale, practical considerations and suggestion on methods and presentation of results is given by Pomeroy *et al.* (2004).

Three BALANCE reports deal with the involvement of and communication with stakeholders (Feucht & Lamp 2006, Feucht & Lamp 2007 and Haldin 2007). Readers are encouraged to read these reports in connection to this section.

Data requirements

A list of relevant stakeholders in the area of interest facilitates the use of this indicator. Other basic information is the provided financial and/or time budget and personal resources for the communication process. This indicates the significance of the stakeholder communication or the invested effort. Existing data on communication can be compiled from several types of sources and/or through interviews with authorities and stakeholders.

The number of communication may vary from a few meetings to several hundred contacts through e-mails. Information on topics, conflict issues and solutions are crucial knowledge that helps in evaluating the communication. According to Feucht & Lamp (2006) the stakeholder activities may be divided to communication, public hearing, participation, capacity building and consultation.

The lack of communication or a solely one-way communication may indicate problems with the quality of the interaction. Place and time of meetings, number of attendants and their interests as well as geographical location (geo-referenced information) can provide additional information on spatial elements. Information may include:

- Number and/or frequency of different communication types per year, per topic, per stakeholder group. Potential type of communications includes relevant meeting minutes and notes, telephone call records/notes, e-mail correspondences and authority home page feed-back

- Number of involved stakeholders *e.g.* number of persons attending a meeting, number of persons giving statements or answering questionnaire surveys sorted according to their interest.

- Refined methods of stakeholder participation and satisfaction, as described in Pomeroy *et al*. (2004) and Feucht & Lamp (2006), include defining key stakeholders sorted by their interest and by the impact the management have on them and asking them about the level of satisfaction with the participation

- Spatial position of communication (geo-referenced: physical address, lat-long, area, region, and municipality). As a rule the information should be as detailed as possible without conflicting with the integrity of the source

- Date, place and time of communication

- Nature of communication – positive/negative feed-back, topic and/or conflict discussed, state of planning process, complaints against conservation areas/zones proposals/decisions

- Feedback and input from stakeholder *e.g.* via interviews *e.g.* number of meetings, involvement in decision-making, transparency, satisfaction with results and outcome. Existence of conflicts and type of conflict can be monitored through interviews with key authorities and stakeholders

- Name of the observer/interviewer

- Capacity building and education activities carried out for stakeholders and interested people: No. of participating stakeholders/people, no. of seminars, courses, workshops, excursions

Step-by-step process

The information can be summarised into a report. The information can when necessary/possible be spatially visualised to increase the knowledge on how the management

is influencing different areas in the area of influence and to pin point areas of conflict or positive feed-back.

1 Create the observation points

Define longitude and latitude or corresponding geo-referenced information to columns in your dataset in a GIS, which can be done either using existing information or by manually pointing out site descriptions on the map. Since errors might occur, check the positions by putting the observation points on a map. Writing errors are usually very easily visualized by doing this. For each row, define a column for each of the information included from section 'Data requirements' above.

2 Make a map

Data can be visualized on a map in many different ways. Different numbers and frequency of can be visualized by *e.g.* different sized circles, different sized bars, different colours, points with numbers as label and so on. Zero data may be equally important as the information of number of meetings. Classification per defined area might be a useful tool for visualization, *e.g.* using a grid-system of defined size. A classification with five categories can help in visualising the relative differences among defined areas *e.g.*:

Class 1: no to very low level of given parameter of communication interaction between stakeholders and authorities

Class 2: low level

Class 3: moderate level

Class 4: high level

Class 5: very high level

Class limits need to be adjusted based on the prevailing conditions in the area, including any other area that one wishes to make comparisons with.

Indicator in the Assessment of Management Performance
The use of this tool, capturing the interaction, as an indicator may be useful in assessing the quality of the interaction between stakeholders and authorities and its change over time. Differences in the results gathered from the authorities and the stakeholders, respectively, may indicate important aspects concerning the perceived level of the communication interaction, which is an important aspect in any planning and management.

The spatial element of this indicator may include visualisation of areas with high numbers of stakeholder complaints, areas of conflict, areas with very little interaction and areas where the communication is good and all parts are satisfied with the progress. Tradition-

ally, comparisons are illustrated in graphs, but by using the classes suggested above, comparisons can also be visualised on a map.

A temporal change of the indicator may suggest that the number has of interaction changed or that the type has changed. The change in number of complaints and conflicts can be monitored over time to assess the progress of dealing with and solving them. Equally is the level of satisfaction assessed over time, in order to determine the success and performance of the management (Pomeroy *et al.* 2004).

2.6.2 *Compliance with management plans*

An indicator of the compliance with management plans include all types of legislation, regulations and restrictions that are implemented in a plan and the level to which these are understood and followed. Compliance in relation to sustainable development of marine resources is highly dependent on the willingness of users to acknowledge and adapt to the decisions of plans that restrict the activities to different zones. The knowledge of existing management plans and the understanding of what the implementation of them means are important aspects to the users. Hence the communication interaction has a central part for the compliance (see the previous recipe, 2.6.1). This is mainly an indicator aimed to monitor the implementation process and the results of the planning process. Stakeholder awareness, liability, acceptance and cooperation are key considerations according to Feucht & Lamp (2006).

In other words, this is an indirect expression of how well the managers can communicate the occurring enforcement, and, hence, a consequence of the interaction with the stakeholders. It is a measure of the degree to which stakeholders acknowledge the restrictions and how well the regulations are followed within implemented zones. Whereas the previous indicator concentrates on the actual interaction process of communication, the present indicator can deal with the concrete physical results of the compliance, *e.g.* in terms of harmful, illegal and/or un-reported activities and uses encountered in marine and coastal areas.

The compliance of users and stakeholders can be assessed through surveillance and monitoring of coastal and marine areas. The aim of this recipe is to exemplify a general approach how to use the indicator. The same approach may then be used with other activities. The analysis can be conducted in several ways. The general idea is to collect information on all occurring potentially harmful activities and/or activities under legal regulation in different zones using a variety of methods, and cross-reference the findings with the compliance with the plan using information from various sources; in this case it would be an authority responsible for the permission. The sources of data and methods to collect data may vary depending on the objective of the study. The example below, which concentrates on one specific activity, is not exhaustive, as a comprehensive coverage of the diversity of ongoing activities and sea uses is not practical within the frame of this work.

Data requirements
- A list of relevant resource users and stakeholders in the area of interest facilitates the use of this indicator.

- -Resource users in coastal and marine areas can be monitored as the number, coverage of interest, magnitude and/or duration of activities over a specific period of time, *e.g.* on a yearly basis. Analysis of remote sensing data, field investigation data, interviews with key persons and studies of other sources may reveal ongoing and/or historical activities such as dredging, extraction and dumping.

- -Records provided by relevant environmental and surveillance authorities for assessment of the legal status of the activity.

- -Information about the liability of stakeholder activities in the area, *e.g.* no. of infringements against the zoning regime, no. of petitions or law suits.

- -Another aspect would be, how well the management regime is adapted by resources users regarding their commercial activities, *e.g.* no. of private public partnerships) no. of new businesses linked to the management.

- -In some cases the cooperation of the managing authority and stakeholders can also indicate how well the management regime is accepted. No. of cooperation agreements, no. of volunteers, evaluation meetings, on-site committee etc. can provide useful information.

- -Additional information and basis for further assessment analysis may be models created for showing areas with conditions that more likely than other areas are under risk of having/allocating specific activities.

Step-by-step process
1. Create observation points

- -The regulation and restriction compliance by the known resource users is assesses through a cross-reference with records provided by relevant authorities to reveal the status of the activities, *i.e.* reveal whether the activity's legal status is OK or un-official/un-registered/ not allowed and/or illegal.

- -Cases, including those not complying, may be geo-referenced by defining longitude and latitude or corresponding information that can be attributed to a geographical position to columns in a dataset in a GIS, either by using existing information or by manually pointing out cases on the map.

- -An additional approach may be to use models showing areas with conditions that more likely than other areas are under risk of having allocating specific activities. Taking the dredging activity as an example, areas with shallow water near the shoreline with piers,

cottages and houses near shore, soft bottom substrate, harbour areas, houses and cottages inside Coastal lagoons (HD habitat 1150) in land uplift areas are conditions that can be incorporated in to a model visualising areas that potentially may be dredged in the future. The recipe of how to proceed with the model of potential dredging areas is presented above (recipe 2.4.6).

2. <u>Make a map</u>

Data on the level compliance can be visualized on a map in the same way as described in the corresponding section of the previous recipe (2.6.1). Potential class intervals, 1-5, could express very low to very high number of encountered activities not complying with existing managements plans.

A model showing areas with conditions that more likely than other areas are under risk of having/allocating specific activities The models allows for quantification of the total coverage of sensitive areas, hot-spot areas with high density of areas for better planning and coordinating of management efforts, and be used to for overlaying with known activities to assess level of overlap and future direction of development.

Table 28   An example of management compliance in the exploitation of Habitats Directive marine habitat Coastal lagoons (code 1150).

Name	HD type 1150 Lagoons exploitation
Type of involved use/interest	Nature conservation of HD habitat, recreation,
Goal	Monitor the level of exploited habitats
Indicator	Measure of unreported, illegally exploited lagoons
Pressure	Physical exploitation and deterioration of HD habitats
MSP relevance	Indicates the how well exploitation is managed
Data requirement	Aerial photo, GIS-models, inventories, land-ownership, authority reports of illegally exploited habitats
Method and analysis	Combining / overlaying data. Data can be modelled or found in digital maps, remote sensing, and authority data-base
Result	Identify distribution of lagoons & identify exploited habitats
Presentation	Graphic & spatial presentation of illegally exploited class A habitats

Indicator in the Assessment of Management Performance

This tool may be used in assessing the compliance by resource users. The level of compliance is an indication of the management efficiency, explicitly a measure of how well the legislation and regulation of plans are communicated to the resource users and stakeholders.

Level of management compliance may be visualized on a map as the spatial distribution of encountered cases not complying. Such separation of cases based on the geographical distribution may indicate areas where the governance is good, and areas where the governance need improving. Traditionally, comparisons are illustrated in graphs, but by using the classes suggested above, comparisons can also be visualised on a map.

The temporal aspect of the indicator can be used to assess the development of the management efficiency over time. A temporal increase of compliance, less numbers of encountered activities not complying, may indicate that the management has succeeded in communicating the enforcements to the resource users in different zones.

3   EXAMPLE OF THE LINKAGE OF RELATED TOOLS

Different indicators may be compared with each other according to the extent to which the same aspects are measured. A comparison gives an opportunity to validate the accuracy of the indicators and the possibility to combine information from different perspectives. Ideally, two indicators are related if they share common attributes and contribute with alternative views that increase the basis of information. In Fig. 32, two examples of the relationship between pairs of socio-economic and biophysical indicators, respectively, are illustrated. The examples show a general, large-scale indicator and an indicator operating on a site-specific, habitat level.

The communication indicator classifies islands according to their accessibility and communication standard, expressing the driver of overall pressure without emphasising too much on the presence of buildings, whereas the lagoon pressure indicator classifies anthropogenic influence on a site-specific level, especially regarding presence of buildings. The relationship between the two indicators seems relatively clear and suggests that lagoons situated in areas with a high communication standard probably are under high pressure due to human influence, and the potentially unaltered lagoons are found in areas with low communication standard (Fig. 32, upper). The positive correlation between the two indicators probably stems from the presence of houses and cottages for recreational use, which either directly or indirectly are elements of both indicators. The relationship suggests that large scale driver factors and site-specific pressure are linked, which should be accounted for in the MSP. A parallel and simultaneous use of linked indicators thus provides a wide basis of information and enables the identification of the source (driver) as well as the pressure factor, both affecting the environment expressed on different scales.

The lagoon tool (2.2.5) is used for delineating coastal lagoons, whereas the heterogeneity tool is used as a general proxy for biodiversity, *i.e.* the spatial variation of environmental conditions in an area. The relationship shows that lagoons likely are found in heterogeneous areas, and are proportionally most abundant in the rarest areas with the highest heterogeneity (Fig. 32, lower). By definition, lagoons normally have a long and heterogeneous shoreline, a characteristic which seems to be reflected by the heterogeneity indicator. The relationship suggests that areas indicated as having high overall heterogeneity value are more abundant in valuable habitats, such as the prioritised HD habitat Coastal lagoons 1150.

The implication for management is that heterogeneous areas are likely hot spots of several types of important habitats and possess high biodiversity.
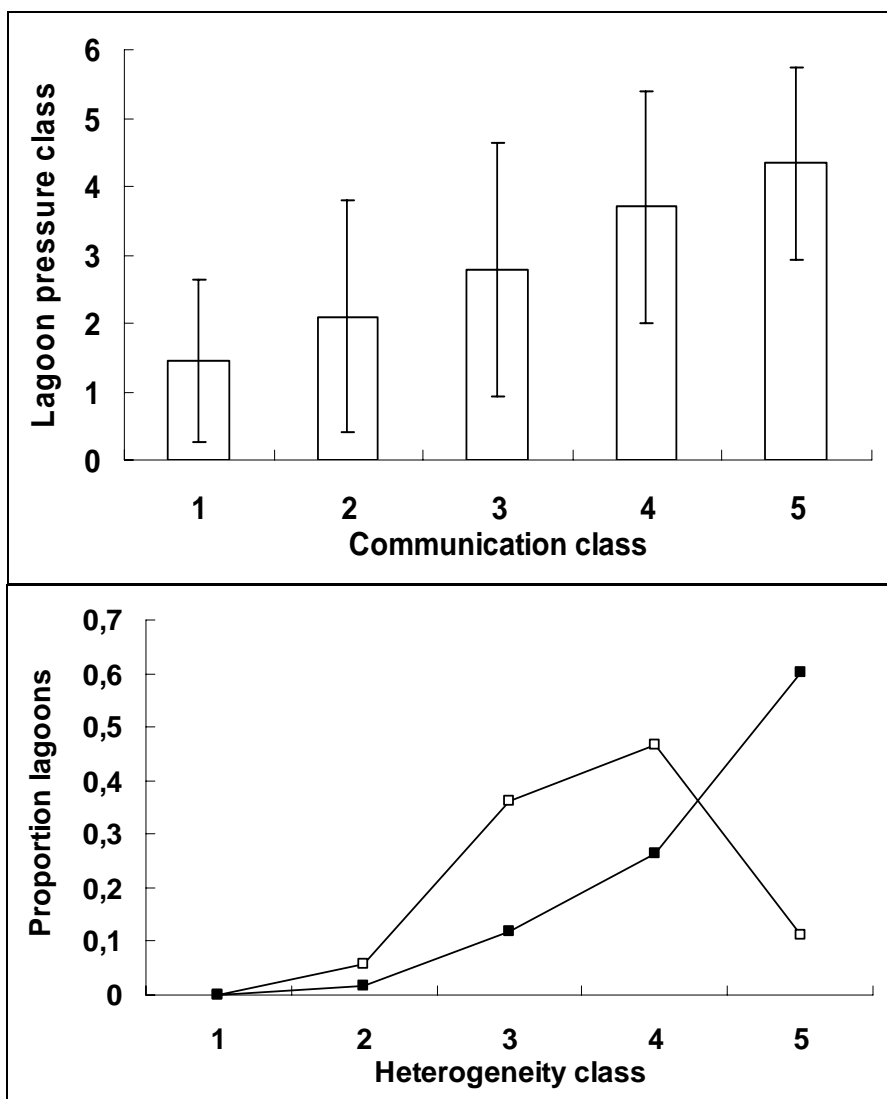
Fig 32   The relationship between the indicator of the pressure on lagoons, mean values and S.D., and the indicator of communication infrastructure (upper). The absolute (open squares) and the relative (filled squares) proportion of sites found using the lagoon habitat tool in relation to the heterogeneity indicator (lower).

4 A SHORT HOW-TO GIS STEP SECTION

This is a collection of general hints how to complete a few common steps used in the GIS recipes that may be of help at least for those who are not so familiar with the 'GIS world'. The selected how-to steps are useful for different situations. All the described steps may be regarded as starting points for, and preparations of, more complicated procedures. In addition to the general introductions, more specific instructions for *ArcView 3.x* and *ArcGIS Desktop* are attached. However, readers should understand that the procedures advised here are only suggestions how to accomplish a specific task in one way – there may still be several other alternatives to reach the similar result.

How to calculate ID numbers for a feature data set (shapefile)?
ID numbers are essential in many GIS recipes as a unique attribute – a number that is specific for and identifies every single feature in a shapefile. Two separate features cannot share the same ID. In some analyses the presence of IDs is not crucial, but when the procedure involves combining different data sources and joining their attributes, an ID column normally is a necessity. In most cases, an ID attribute field is created in the beginning of the analysis, prior to making any permanent changes to the data set.

In *ArcView 3.x*, an ID column of the attribute table may easily be created by using one of the several applicable scripts available at http://arcscripts.esri.com/. In *ArcGIS Desktop*, a practical way to calculate ID numbers to a new column is to utilise the FID column (a unique number for each feature, begins from zero) that should be present in every shapefile – the FID column itself is not recommended to be used for the purpose as the numbers change to fill the gaps every time some points, lines of polygons are removed from or added to the data set. If the purpose is to gain ID numbers between [1…n], the procedure to complete the task is to calculate [FID] + 1 by using the *Field calculator*, or by the *Calculate field* function in the *Data Management Tools*.

How to create a point data set representing the centroid points of a polygon data set?
Quite often there is a need to convert a polygon data set to centroid points – the purpose may be, for example, to join attributes of two data sets of different scales, or to find out the most suitable location to extract an area-specific value from an underlying, continuous raster surface. A centroid point data set may even be used as a simplification for a complicated polygon surface.

In *ArcView 3.x*, the easiest way to construct a centroid point data set is to download the *XTools* extension (available at http://arcscripts.esri.com) and use the existing function *Convert shapes to centroids*. In *ArcGIS Desktop*, those utilising the *ArcInfo* mode are able to perform the task by *Feature to point* tool, and those having the *ArcView* mode are able to download some suitable script from http://arcscripts.esri.com. Another possibility in *Ar-*

cGIS that can be used to find out the x and y coordinates of the centroid points (not directly to construct a new data set), is to create a new column in the attribute table and use the *Field calculator*. The calculation formula needed may be found by pressing the *Help* button and reading the section for calculating the centroid coordinates (the VBA script code may be copied from the help and pasted to the *Field calculator*). Note that the *Advanced* button has to be checked and the corresponding variable need to be typed in the lower text box (see *ArcGIS Desktop* Help: Calculating fields in attribute tables). In *ArcGIS*, there is a tool called *Add XY Coordinates*, but it only works with point data and therefore is not applicable for calculating polygon centroid points.

How to calculate the number of single features sharing the same attribute?
The calculation of the number of separate features sharing the same attribute is a basic procedure in several tasks. Along with being an intermediate phase in a longer analysis, the purpose of the calculation may be to produce statistical information of the final product, *e.g.* to reveal how many single patches there are in the whole research area that are classified with the same code. If the data set is small, the calculation may be possible to perform manually, but in case of larger sets there is a need for an automatic function.

In both *ArcView 3.x* and *ArcGIS Desktop*, the procedure is quite similar – the appropriate column in the attribute table is selected, and the *Summarize* function is utilised. If the summarizing is performed without any additional specifications, the resulting table will reveal the count of single features relating to the defined attribute. The *Summarize* tool is, however, capable of producing more detailed results if needed; in addition to the count it can, for example, calculate the sum of all polygon areas having the same attribute value (assuming that the area values have been calculated to the attribute table).

How to update area / perimeter / length to the attribute table?
The calculation of area / perimeter / length for polygon or linear features is presumably one of the most common operations in GIS, but performing it may not always be so trivial. In marine issues the calculation may be carried out, for example, to figure out the area of an island or to calculate the length of a shipping lane. One important issue to be remembered when performing the task is the effect of the nominal scale – the results may be highly dissimilar depending on whether the mapping scale of the original data is 1 : 10 000 or 1 : 100 000, for example.

In *ArcView 3.x*, the most convenient way to calculate area / perimeter / length is to use the *XTools* extension (available at http://arcscripts.esri.com). In *ArcGIS Desktop*, the desired calculations may be performed directly by updating the values to an empty attribute column by using the *Calculate values* tool. Similarly to the instructions given for centroid points, the appropriate calculation formula may be found from the *Help* section of the *Calculate values*. Note that the *Advanced* button has to be checked.

How to create a polygon grid (a network of polygon square cells)?
The creation of a polygon grid is a usual starting point for a GIS analysis as it offers a good base for storing and summarising results originating from several substeps. A polygon grid is in a way a similar construction to a raster data set – information is stored in a square-cell body indicating no variation inside a single cell – but the advantage of the polygon structure compared to the raster is the capability to store several attribute values for every single feature / grid cell. The appropriate cell size is dependent on the purpose of the analysis and the desired scale in which to present the results, but one should keep in mind that a small polygon size causes the analysis to be fairly heavy and slow, and easily misses the point of being a summarising surface.

In *ArcView 3.x*, several suitable scripts are available at http://arcscripts.esri.com, and their use is recommended. In *ArcGIS Desktop* version 9.2 there is a tool *Create fishnet* that is lacking in the previous versions. If the tool is unavailable, suitable scripts may be found at the web address given above, but there are other ways to complete the task. Those using the *ArcInfo* mode are able to create a linear framework of polygon borders by first digitizing the seed lines for both vertical and horizontal directions and then copying parallel features from the lines, and finally using the *Feature to polygon* tool to make the data set polygonal. It is possible to convert a raster data set to a square-cell polygon set (available in *ArcView* mode), but it of course requires that every adjacent raster cell possess a dissimilar value (otherwise the polygons created may contain larger areas than just one cell).

How to update polygon-specific statistics from a raster surface?
In certain situations it may be necessary to update polygon coverage with information regarding the underlying raster surface values – the purpose is to store certain raster cell statistics to the polygon attribute table. For example, if a polygon grid like the one described above has been constructed for a certain sea area, there may be a need to update the minimum and maximum depth values for each polygon based on a raster-format depth model. Or, it may be crucial to get information of the spatial extents of a raster data set (*i.e.* how large area of each polygon is covered by raster cells having other values than *NoData*), or to find out the predominant raster cell value on the area defined by a polygon.

The solution for the problem is simple but not always obvious: the appropriate tool to be used is *Summarize zones* in *ArcView 3.x* and *Zonal statistics* in *ArcGIS Desktop*, both requiring the Spatial analyst extension. If an ID number or a corresponding single-polygon identifier is selected as the attribute to define the zones, the raster statistics are constructed for every single polygon feature. Similarly, if a column possessing classified polygon values is defined to be the zonal identifier, a set of raster statistics is created for every class (but not for every single feature).

How to combine / join the attributes of polygon data sets of different sources / scales?
Sometimes there may be a need to combine the attributes of several polygon data sets to a single set, but quite often there are differences in the spatial extents or nominal scales of the data sets making the process complicated. In case that polygon borders are absolutely con-

gruent, a direct spatial join may be possible, or if they share a common unequivocal attribute (a municipality code, for example), they may be joined by attributes. If the preconditions of the last sentence are not met, there still are other possibilities to carry on the task.

If the two polygon data sets are at least approximately spatially similar and there is no substantial difference in the number of polygon features, a one-to-one spatial join by using centroid points may be the solution to the problem. In other words, one of the two data sets is first converted to centroid points (as described above), assuring that the attribute information will not disappear, and finally the centroid points are spatially joined to the polygons of the second data set. The procedure assumes that the centroid of the first data sets falls inside the polygons of the second set, but usually this is not a problem if the two data sets are at least approximately similar. If *ArcGIS Desktop* is used, a direct spatial join between points and polygons is possible, but *ArcView 3.x* allows only polygons to be spatially joined to points (*i.e.* the final product is the centroid point data set containing attributes of the polygon data set). However, if polygons contain an ID attribute (or similar), the attributes of the resulting centroid data set may be rejoined to the polygons thus resulting a polygon data set that contains the attributes of both sets.

How to calculate a distance raster, and make it sensitive to barriers?

Some GIS analyses may require construction of a distance raster (a raster data set indicating the shortest distance to a location defined by the user). The hypothetical problem may be to calculate a distance to the nearest shipping lane in a marine area, or to the nearest shoreline. Occasionally there may be a need to take some barriers to consideration, for example, if a waterway distance from point A to the nearest harbour, point B, is to be modelled, all the islands between A and B must be regarded as barriers in order to end up to realistic results.

A straight-line distance without observing barriers is an easy task to complete – in *ArcView 3.x* it may be completed by using the *Find distance* tool, or in *ArcGIS Desktop* by *Euclidean distance* tool, both requiring the Spatial analyst extension. If the barrier locations are to be included to the analysis, it must be performed on a different way – by utilizing the *Cost distance* tool (in *ArcView 3.x* may be run via the *Map calculator*). In addition to the data set containing the locations indicating the zero distance, a *cost grid* is needed. The cost grid in this specific case is a raster data set containing cells having a value of "1" (indicating the areas to be included to the distance calculations), and cells having a larger value to the defined maximum distance, or *NoData* (indicating the barriers). The *cost distance* tool is then run normally by using these two data sets (possibly defining the maximum distance to be calculated), and the result indicates the distances to the user-defined location by taking the possible barriers to account.

How to extract statistics from a raster data set using a "moving window" approach?

A "moving window" approach (or *Neighborhood statistics* in *ArcView / ArcGIS*) for extracting statistical information is a useful procedure that results in a raster data set with each cell possessing a statistical calculation (minimum value, maximum value, mean value, median value, sum, range, standard deviation, majority or minority value) based on the input

data set values within a predefined distance. The amount of opportunities to be calculated is vast, but a simple example will demonstrate the procedure. Say, that the areas of the presence of a certain species are known, but there's a need to make a more generalized visualization of the "hot spot" areas. The first task is to classify the input data set to "1" (representing the presence areas) and "0" (representing the absence or no data areas). Next, a "moving window" analysis is performed selecting the sum to be calculated at a circular distance of *e.g.* 5 km. The cell values of the resulting data set will represent the amount of presence cells in a 5 km radius (absence / no data cells having a zero value do not affect the sum). The output data set may further be multiplied with the true cell size to calculate the real extents (not just the count of cells).

The analysis may be performed for rasters as well as for line and point shapefiles – raster statistics are calculated based on the cell values, shapefile statistics based on an attribute in the attribute table, respectively. In *ArcView 3*, the tool may be found from the *Analysis* menu (the input file has first to be selected on the *View*). In *ArcGIS 9*, there are different tools in the *Neighborhood* menu of which the *Focal statistics* may be used for raster data sets, *Line statistics* for polyline data sets and *Point statistics* for point data sets.

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Web sources

ESRI's website for downloadable scripts and extensions: http://arcscripts.esri.com/

MapInfo's website for downloads: http://extranet.mapinfo.com/support/downloads/ (not tested by the author).

Annex 1. A literature based summary of GIS tools that may be useful in Marine Spatial Planning.

Interests/Use	Goal	Indicators	Threats	Methods	Data requirement	Result	Reference
Nature conservation,, shipping, infrastructure, recreation etc	*Define what the tool does in relation to MPA zoning*	*Define the measurable variables*	*Environmental threats the tool is designed for*	*Short description of methods*	*Specify tool's need of data type*	*Data output desired. What does the tool perform*	*Author , year, title, publication*
Infrastructure, Nature conservation	Using landscape assessment tools to identify conservation strategy	land use	increasing land use	GIS, GIA	GIS layers on ecological parameters (*e.g.* sensitive species, habitats) and threat parameters (*e.g.* protection status, development pressure)	Identifies a greenway network	Weber, T. & J. Wolf 2000. Maryland's green infrastructure - using landscape assessment tools to identify a regional conservation strategy. Env. Monit. Assess. 63: 265-277.
Infrastructure	Mapping of agricultural and urban land use by multi criteria evaluation to improve spatial decision making.	land use		ArcView Model Builder, Multi Criteria Evaluation (MCE)	GIS layers, expert group	A strategy for land use based on GIS models and expert group decisions.	Hossain, H., A. Hood, V. Sposito and S. Cook
Infrastructure	Scenarios, visualisations of potential changes related to different policies	land use/land cover ratio	increasing land use	farm models, GIS			Lauber, S. et al. 2004. Combining farm models and GIS to examine farm structure, land use and effects on landscape. Grassland Sci. Eur. 9: 100-102.
Infrastructure	Scenarios, visualisations of potential changes related to different policies	land use/land cover ratio	increasing land use	farm models, GIS			Jansen et al 2005. An interdisciplinary approach to regional land use analysis using GIS with applications to the Atlantic Zone of Costa Rica. Aqricult. Econ. 32: 87-104.
Infrastructure	Identify conservation priority areas for a species	species habitats, and distribution, population size, vulnerability	land use, disturbance of species	Remote sensing, GIS	GIS layers on ecological and threat parameters	Evaluation of reserves, sugges-tion for zoning to reduce disturbance	Smith, A. P., N. Horning & D. Moore 1997. Regional biodiversity planning and Lemur Conservation with GIS in western Madagascar. Cons. Biol. 11: 498-512.

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Annex 1. Continued.

Interests/Use	Goal	Indicators	Threats	Methods	Data requirement	Result	Reference
Infrastructure	Predictions of urban growth in terms of land use change	urban growth scenarios	Increased urban growth, land use change	GIS based integrated approach (regression models, relative probability model, involving experts)	Sattellite images (Landsat TM Imagery), GIS layers, grids of predictor variables, data for variables in models, expert group	Time-Series map of predicted urban growth in a region from 1973-2030.	Allen, J. & K. Lu 2003. Modeling and prediction of future urban growth in the Charleston Region of South Carolina: a GIS-based integrated approach. Cons. Ecol. 8(2):2
Infrastructure	Evaluation of sustainable development in coastal areas	land use change, urban growth	Increased urban growth, land use change	GIS, DSS (Decision support system)	socioeconomic data (population counts, growth rates, economic growth), GIS layers on land use patterns	Simulations of socioeconomic and land development scenarios	Carvalho, A. 2002. Simulation tools to evaluate sustainable development in coastal areas. In: Littoral 2002. The changing coast. EUROCOAST/EUCC, Porto-Portugal Ed. EUROCOAST-Portugal. ISBN 972-8558-09-0
Infrastructure, Nature conservation	Measure of important habitats for certain species	species distribution, distance to infrastructure such as roads, buildings,	urbanisation	Remote sensing, GIS, logistic regression	high resolution satellite images (AVHRR), GIS layers (habitats, topography, infrastructure)	Shows relationship of species distribution, distance to infrastructure	Osborne et al. 2001. Modelling landscape-scale habitat use using GIS and remote sensing: a case study with great bustards. J Appl Ecol 38: 458-471.
Infrastructure, Nature conservation	Habitat loss identification	changes in land use, development of industry	expansion of industry, loss of habitats (mangrove)	Remote sensing, GIS	Aerial photographs, GIS layers on land use, field work (questionnaire)	Identifying habitat destruction due to increase in aquaculture	Dahdouh-Guebas, et al. 2002. Recent changes in land-use in the Pambala-Chilaw lagoon complex (Sri Lanka) investigated using remote sensing and GIS: conservation of Mangrove vs. development of shrimp farming. Env. Dev. Sust. 4: 185-200.
Nature conservation	Re-zoning of Great Barrier Reef Marine Park	biological and threat indicators	Insufficient nature conservation	MARXAN site selection + economic data public submissions	presence/absence input data	A suggestion on re-zoning of a MPA	Lewis, et al. 2003. Use of spatial analysis and GIS techniques to re-zone the great Barrier Reef Marine Park. Coastal GIS Workshop, Univ. Wollongong, Australia.

Annex 1. Continued.

Interests/Use	Goal	Indicators	Threats	Methods	Data requirement	Result	Reference
Nature conservation	Site selection for an artificial reef	areas under pressure from industry, shipping, recreation (unsuitable vs suitable areas)	increasing sea use	GIS, empirical site selection tools	GIS data layers on industry, shipping, recreation and habitats	Optimal selection of a site for an artificial reef.	Wright, R., S. Ray, D. R. Green and M. Wood 1998. Development of a GIS of the Moray Firth (Scotland, UK) and its application in environmental management (site selection for an "artificial reef"). Sci.Total Env. 223: 65-76.
Nature conservation	Assessment of the regional conservation status of genetic diversity	genetic diversity vs land use	habitat loss	GIS	environmental data (*e.g.* national parks, major streams, major roads), genetic data in spatial form	Populations genetic variation protected, identification of areas where genetic sampling is needed	Ji, W. & P. Leberg 2002. A GIS-based approach for assessing the regional conservation status of genetic diversity: an example from the southern Appalachians. Env. Manag. 29: 531-544.
Nature conservation	Conservation prioritization based on vegetation and phytosociological characteristics	vegetation measures (patch size, cover), phytosocial (species richness)	decreased diversity due to fragmentation	remote sensing, GIS	satellite pictures, vegetation maps in GIS, calculations of diversity measures	Diversity measures in relation to habitat characteristics	Amarnath et al. 2003. Diagnostic analysis of conservation zones using remote sensing and GIS techniques in wet evergreen forests of the Western Ghats - an ecological hotspot, Tamil Nadu, India. Biodiv. Cons. 12: 2331-2359.
Nature conservation	Identify representation of different habitats in MPA	number and area of habitats in different zones,	Lost habitat due to low protection	UV- video, clustering, GIS	habitat maps, areas of different zones in zoning plan	Data for assessment of occurrence of different habitats	Stevens, T. & R. M. Connolly 2005. Local-scale mapping of benthic habitats to assess representation in a marine protected area. Mar. Fresh. Res. 56: 111-123.
Nature conservation	Identification of areas of interest for conservation	presence of species, coverage	Insufficient nature conservation	species collection, GIS database	species presence data	More biological data for planning of protected areas	Funk, et al. 1999. Testing the use of specimen collection data and GIS in biodiversity exploration and conservation decision making in Guyana. Biodiv. Cons. 8: 727-751.
Nature conservation	Application of Coastal GIS	several different sectors (biological, use, economical)	Insufficient nature conservation	GIS	GIS data sets	Suggestions of application of Coastal GIS	Zeng, et al.. Coastal GIS: Functionality versus applications. Int. Arch. Photogrammetry and Remote sensing 34: 343-356.
Nature conservation	Conservation status assessment of a species	presence of a species within protected areas	Insufficient nature conservation	GIS	presence data of species, protected areas	Evaluation of conservation status of a species.	Chefaoui, et al. 2004. Potential distribution modelling, niche characterization and conservation status assessment using GIS tools: case of Iberian Copris. Biol. Cons. 122: 327-338.

Interests/Use	Goal	Indicators	Threats	Methods	Data requirement	Result	Reference
Nature conservation	Application of GIS in Coastal Zone Management			GIS			Fedra, K. & E. Feoli 1998. GIS technology and spatial analysis in coastal zone management. EEZ Technology 3: 171-179.
Nature conservation	Predicting abundance of a key species, the eel grass	biological indicator of the distribution of eel grass	Eutrophication affects visibility, increases filamentous alga	Query of parameters/an overlay of conditions of potential distribution	Select areas based on : Soft, sand substrate, depth 0,5-10 m, sheltered-moderately exposed, slope <10 degrees	Substrate type, wave exposure, topography and depth information,	Wennberg, S. & Lindblad, C. (eds) 2006. Sammanställning och analys av kustnära undervattenmiljö (SAKU). Rapport 5591 Naturvårdsverket, ISBN 91-620-5591-7. Analysis of coastal marine habitats. SEPA
Nature conservation	Bladder wrack function as key habitat for a range of organisms	biological indicator of the distribution of bladder wrack	See above	See above	Exposure, depth, substrate, geo-referenced abundance and depth distribution	Models of potential coverage, abundance and depth distribution	Isaeus M. PhD thesis 2004. Wennberg, S. & Lindblad, C. (eds) 2006. See above
Nature conservation, Military areas	Conservation of a species group	number of species	habitat loss	GIS	land use, vegetation maps, soil condition, slope, areas in military use	Focus on sites with appropriate landscape features for conservation of species/ group	Vanderpoorten, A., A. Sotiaux and P. Engels 2005. A GIS-based survey for the conservation of bryophytes at the landscape scale. Biol. Cons. 121: 189-194.
Nature conservation, Shipping	Identify vulnerable marine environments for two endangered whale species	areas with acoustic pollution	Loss of vulnerable areas	GIS	Maps on valued ecological features (VEF), identification of vulnerable VEF, prediction of VMA with ecol. classification	Identification of geographic areas for management and conservation purposes.	Zacharias, M. A. & E. J. Gregr 2004. Sensitivity and vulnerability in marine environments: an approach to identify vulnerable marine areas. Cons. Biol. 19: 86-97.
Nature conservation, Socio-economic	Identify priority areas on which to focus conservation efforts (biological and socioeconomic evaluation)	values on endemism, species richness, habitat, biogeographical & evolutionary processes, ecological functions	increased urban growth, infrastructure and exploitation of natural resources	GIS	biological spatial data, socioeconomic data	Priority areas for nature conservation	Ibisch, et al. 1999. Identification of conservation priorities in the Bolivian Amazon. A new biological-socioeconomic methodology using GIS. Deutscher Tropentag, Berlin, Session Biodiversity, Nature conservation and development.

Interests/Use	Goal	Indicators	Threats	Methods	Data requirement	Result	Reference
Recreation	Management of biophysical effects of tourism	degraded area, change in species composition, area of erosion, number of species, number of complaints and reduces visitors numbers due to crowding, noise	vegetation degradation, erosion, decreased biodiversity, effects on species, crowding, pollution, noise, damage	classification of natural assets visited by tourists, identification of indicators, management guidelines	environmental data, data on threats	Indicators of environmental change due to tourism, guidelines for management	Ward, J., K. Hughey & S. Urlich 2002. A framework for managing the biophysical effects of tourism on the natural environment in New Zealand. J. Sust. Tourism 10: 239-259.
Recreation	Evaluation of potential impact of tourism in the natural environment	as above	as above	GIS	environmental data, data on threats	Sustainable tourism planning	Bahaire, T. & M. Elliot-White 1999. The application of Geographical Information System (GIS) in sustainable tourism planning: A review. J. Sust. Tourism 7(2).
Recreation	Identifying areas with potential for ecotourism	Areas suitable and not suitable	as above	GIS	resource inventory, ecotourism criteria, GIS for ranking of sites	Areas suitable for ecotourism	Boyd et al 1994. Identifying areas for ecotourism in northern Ontario: application of a Geographical Information System Methodology. J. Appl. Recreation Research 19: 41-46. Boyd, S. W., & R. W. Butler 1996. Seeing the forest through the trees: using GIS to identify potential ecotourism sites in northern Ontario. In: Harrison, L. C. & W. Husbands (ed) Practicing responsible tourism: international case studies in tourism planning, Policy and development, pp. 380-403. Wiley & Sons, New York.

Annex 1. Continued.

Interests/Use	Goal	Indicators	Threats	Methods	Data requirement	Result	Reference
Recreation	Alternative development strategies identifying conflict in land use planning for tourism		conflicts in land use decisions	GIS-based decision support system	GIS data layers, expert and decision maker groups		Feick, R. D. & B. Hall 2000. The application of a spatial decision support system to tourism-based land management in small island states. J. Travel res. 39: 163-171.
Recreation	Measures for developing sustainability of tourism in protected areas	*e.g.* indicators of wear on the terrain, amount of waste, vegetation changes	increased negative impact on the natural environment due to tourism	visitor surveys, indicators	field data on indicators, visitor surveys	Development of indicators for measuring sustainability of tourism	Kajala, L., J. Erkkonen & M. Perttula 2004. Measures for developing sustainability of nature tourism in protected areas.
Recreation	Management of visitors flow	number of visitors	loss of habitat, wearing of nature	GIS	GIS layers on nature conservation, threatened species, land use, master plans, infrastructure, traffic, outdoor recreation opportunities		Kopperoinen, L., P. J. Shemeikka & V. Lindblom 2004. Environmental GIS in the management of visitors flow.
Recreation	Visualisation of tourist values in GIS			GIS (3D-models)	existing walking tracks in GIS, 3D-models, digital aerial photography	Virtual fly-through of existing natural and man-made features, landscape sensitivities, terrain and conservation assessment	Knox, D. 2004. 3D terrain visualisation and virtual fly-through for tourism conservation using geographic information systems. Bachelor of Technology thesis, University of Southern Queensland, Faculty of engineering and surveying, 106p.
Recreation, Culture	Calculation of tourism carrying capacity at natural and cultural sites	cultural, natural indicator proximity to roads, airports, monuments, biological & visual quality	Increased tourism causing negative impacts on nature	GIS	GIS data layers on cultural and natural elements	Internet based geographical data service	Lo Tauro, et al. 2005. Preservation and valorisation of cultural and environmental resources and information systems, an investigation into a Web GIS. In: M. Schrenk (ed) CORP 2005 & Geomultimedia05.

Interests/Use	Goal	Indicators	Threats	Methods	Data requirement	Result	Reference
Recreation, In-frastructure	Predictions of land use change due to tourism	land use change	increased tour-ism activities	GIS, multivariate logistic regres-sion model	GIS data layers (building permits, parcel maps, spatial variables for prediction of likelihood of development)	Tools for assessing land use change at local scale (a tourist destination)	Allen, et al. 2002. A GIS based analysis and prediction of land use change in a coastal tour-ism destination area. In: Miller, M. I., J. Auyong & N. P. Hadley (eds). Proceedings of the 1999 International symposium on coastal and marine tourism: balancing tourism and conservation. Vancouver, Canada.
Shipping	Identify change in vegetation and erosion due to dredging of lanes	changes in vegeta-tion, changes in erosion	Increased ero-sion and changes in vegetation	Remote sensing, GIS	Data for erosion models, classified vegetation maps	Model of erosion, and NDVI (Nor-malized Difference Vegetation Index)	Thomson et al. 2004. Short-term vegetation succession and erosion identified by airborne remote sensing of Westerschelde salt marshes, The Netherlands. J. Rem Sens 25: 4151-4176.
Shipping, Nature conservation	Identification of shipping activities in ATBAs (Areas to be avoided)	number of vessels in ATBAs	Ship traffic in vulnerable areas (ATBAs) based on bio-logical values	GIS	LANDPAR data for vessel tracks	Vessels operating in ATBAs could be identified and notified about the ATBA.	Galasso, G. 2000. Olympic Coast National Marine Sanctuary Area to be Avoided (ATBA) education and monitoring program. Marine Sanctuaries Conservation Series MSD-00-1. U.S. Department of Commerce, National Oce-anic and Atmospheric Adm, MD, 35p.

About the BALANCE project:

The BALANCE project aims to provide a transnational marine management template based on zoning, which can assist stakeholders in planning and implementing effective management solutions for sustainable use and protection of our valuable marine landscapes and unique natural heritage. The template will be based on data sharing, mapping of marine landscapes and habitats, development of the blue corridor concept, information on key stakeholder interests and development of a cross-sectoral and transnational Baltic zoning approach. BALANCE thus provides a transnational solution to a transnational problem.

The work is part financed by the European Union through the development fund BSR INTERREG IIIB Neighbourhood Programme and partly by the involved partners. For more information on BALANCE, please see www.balance-eu.org and for the BSR INTERREG Neighbourhood Programme, please see www.bsrinterreg.net

The **BALANCE Report Series** includes:

BALANCE Interim Report No. 1   "Delineation of the BALANCE Pilot Areas"
BALANCE Interim Report No. 2   "Development of a methodology for selection and assessment of a representative MPA network in the Baltic Sea – an interim strategy"
BALANCE Interim Report No. 3   "Feasibility of hyperspectral remote sensing for mapping benthic macroalgal cover in turbid coastal waters of the Baltic Sea"
BALANCE Interim Report No. 4   "Literature review of the "Blue Corridors" concept and its applicability to the Baltic Sea"
BALANCE Interim Report No. 5   "Evaluation of remote sensing methods as a tool to characterise shallow marine habitats I"
BALANCE Interim Report No. 6   "BALANCE Cruise Report - The Archipelago Sea"
BALANCE Interim Report No. 7   "BALANCE Cruise Report - The Kattegat"
BALANCE Interim Report No. 8   "BALANCE Stakeholder Communication Guide"
BALANCE Interim Report No. 9   "Model simulations of blue corridors in the Baltic Sea"
BALANCE Interim Report No. 10   "Towards marine landscapes of the Baltic Sea"
BALANCE Interim Report No. 11   "Fish habitat modelling in a Baltic Sea archipelago region"
BALANCE Interim Report No. 12   "Evaluation of remote sensing methods as a tool to characterise shallow marine habitats II"
BALANCE Interim Report No. 13   "Harmonizing marine geological data with the EUNIS habitat classification"
BALANCE Interim Report No. 14   "Intercalibration of sediment data from the Archipelago Sea"
BALANCE Interim Report No. 15   "Biodiversity on boulder reefs in the central Kattegat"
BALANCE Interim Report No. 16   "The stakeholder - nature conservation's best friend or its worst enemy?"
BALANCE Interim Report No. 17   "Baltic Sea oxygen maps"
BALANCE Interim Report No. 18   "A practical guide to Blue Corridors"
BALANCE Interim Report No. 19   "The BALANCE Data Portal"
BALANCE Interim Report No. 20   "The reproductive volume of Baltic Cod – mapping and application"
BALANCE Interim Report No. 21   "Mapping of marine habitats in the Kattegat"
BALANCE Interim Report No. 22   "E-participation as tool in planning processes"
BALANCE Interim Report No. 23   "The modelling *Furcellaria lumbricalis* habitats along the Latvian coast"
BALANCE Interim Report No. 24   "Towards a representative MPA network in the Baltic Sea"
BALANCE Interim Report No. 25   "Towards ecological coherence of the MPA network in the Baltic Sea"
BALANCE Interim Report No. 26   "What´s happening to our shores?"
BALANCE Interim Report No. 27   "Mapping and modelling of marine habitats in the Baltic Sea"
BALANCE Interim Report No. 28   "GIS tools for marine planning and management"
BALANCE Interim Report No. 29   "Essential fish habitats and fish migration patterns in the Northern Baltic Sea"
BALANCE Interim Report No. 30   "Mapping of Natura 2000 habitats in Baltic Sea archipelago areas"
BALANCE Interim Report No. 31   "Marine landscapes and benthic habitats in the Archipelago Sea"
BALANCE Interim Report No. 32   "Guidelines for harmonisation of marine data"
BALANCE Interim Report No. 33   "The BALANCE Conference"

In addition, the above activities are summarized in four technical summary reports on the following themes 1) Data availability and harmonisation, 2) Marine landscape and habitat mapping, 3) Ecological coherence and principles for MPA selection and design, and 4) Tools and a template for marine spatial planning. The BALANCE Synthesis Report "Towards a Baltic Sea in balance" integrates and demonstrates the key results of BALANCE and provides guidance for future marine spatial planning.