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Baltic Coastal Ecosystem Dynamics and Integrated Coastal Zone Management

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Abstract

It is expected that the Baltic region becomes a major centre of economic growth and prosperity in Europe already during this decade (Bundestag 2000). Therefore, an Agenda 21 for the Baltic region (Baltic21) was developed to ensure a sustainable development. Especially the coastal ecosystems are subject to increasing anthropogenic pressure e.g. eutrophication, traffic, harbours, tourism or off-shore wind parks. Eutrophication remains the main ecological problem in the Baltic Sea and has serious negative social and economical consequences. Inner and outer coastal waters play an important role as buffers and filters for the Baltic proper. Consequently, the utilization and preservation of their self-purification capacity is of great importance. Combined results of our own coastal zone research and of the international workshop “Baltic coastal ecosystems: structure, function and coastal zone management” (Rostock University, November 2001) are presented here. Conclusions will be used for suggesting improvements in ICZM of Baltic coastal ecosystems.

1. INTRODUCTION

With the fall of the “Iron Curtain” and the planned extension of the European Union the Baltic Sea became a central European Sea with outstanding importance again. Trade and exchange increased and the historical unity of the Baltic region is on the way to be restored. Due to these changes, it is expected that the Baltic region (Fig. 1) becomes a major centre of economic growth and prosperity in Europe during this decade already (Bundestag 2000). The anthropogenic pressure on the coastal ecosystem will increase. Already 85 million people live in the Baltic drainage area and nearly 15 millions live within 10 km of the coast. The objectives of a sustainable development of the coast is synonymous with Integrated Coastal Zone Management (ICZM).

The Baltic Sea covers an area of 412.000 km², has a volume of 21.700 km^3 and an average depth of 52 m. The Baltic Sea drainage basin has a size of 1.745.100 km^2 and is about four times larger than the Baltic Sea. 48 % of the drainage basin are covered by forest, with low nitrogen and phosphorus loads to the Baltic Sea. Theoretically, these loads could keep the Baltic Sea in a mesotrophic stage. The high anthropogenic loads induce a shift to eutrophic conditions. Recent calculation by Elmgren & Larsson (2001) yield total annual nitrogen loads of 1.249.000 t and total annual phosphorus loads of 56.000 t. Despite successful combat measures, eutrophication is still the main problem of the Baltic Sea.

Figure 1: The Baltic Sea drainage basin (modified from BDBP 2001).

The river basin loads have to pass the inner and outer coastal waters before they enter the open sea. The high percentage of shallow water bodies with high productivity and transformation abilities are potentially efficient buffers and filters and for the Baltic proper.

These self-purification ability of coastal waters are a result of different processes: sedimentation, deposition, erosion, transformation or simply by transition, only diluting the loads and reducing the gradient. If the purification capacity is exceeded, coastal ecosystems can become a source of nutrients themselves. It seems that in the present situation the self-purification capacity is exceeded, but our knowledge is still limited or even lacking. A first more comprehensive approach to understanding these ecosystems was made by the BASYS project 1996/99. The collected data are urgently needed for a realistic calculation of the necessary reduction of the anthropogenic loads.

Due to the high morphological diversity of the Baltic coastal zone we can expect a great diversity in behaviour. Additionally, anthropogenic altered structures and loads have changed the buffering and filtering capacity of the coastal zones. This will be demonstrated in four different types of coastal zones, the

- open Pomeranian coast (Poland)
- semi-enclosed Greifswalder Bodden (Germany)
- basin-dominated Darss-Zingst boddens (Germany)
- river-dominated Neva Bay (Russia).

Generalized results will be given from the international WVU-workshop "Baltic coastal ecosystems – structure, function and coastal zone management" (Schernewski & Schiewer 2002) concerning

- the analysis of potential conflicts in the south-eastern Baltic as well as the compilation of requirements and future challenges in the coastal zone management
- the promotion of information exchange in the Baltic region, the discussion strategies for the establishment of a solid information base and the linkage of stakeholders involved in coastal zone management
- and the compilation of suggestions towards an improved ICZM in the Baltic region.

2. MATERIAL AND METHODS

We focus on the southern and eastern Baltic coast. Results are coming from long-terms studies and comprehensive experimental approaches in the Darss-Zingst boddens and Greifswalder Bodden 1968/2001, e. g.

- "Pelagial compartment experiments" (PEKOM), "Shallow-water compartment experiments" (FLAK), "Hypertrophy", and "Ecosystem boddens – organisms and metabolism" (ÖKOBOD)
- "Greifswalder Bodden and Oder estuary – exchange processes" (GOAP 1994/96)
- "Transport and transformation processes in the Pomeranian Bight – anthropogenic loaded transient waters between coastal zone and Baltic proper" (TRUMP 1994/1996)
- "Baltic Sea System Studies" (BASYS 1996/99)
- and "Baltic coastal ecosystems – Structure, function and management" (Schernewski & Schiewer 2002).

3. RESULTS

3.1 Polish Western Pomeranian Coast

In contrast to the German coast the western Pomeranian coast of Poland is morphological nearly uniform (see Figure 1).

We can expect that under the influence of the dominating south-west winds nutrient loaded waters from the Oder mouth will be transported to the east ("coastal jet"), forming a gradient of decreasing loads from west to east. But results from Furmanczyk & Musiliak (2002) shows, that the whole coastal zone is much more complex by forming "gates" and "nodules" along this coast (Figure 2).

These "gates" are underwater cross-shore gates up to 3 km wide. Inside the gates are wide channels caused by cross-shore current flows. The water flow is directed towards the open sea. In this way the "gates" increase the connection between coastal and open sea regions dramatically. The "gates" are stable for longer time, and they are present at the eastern German coast too.

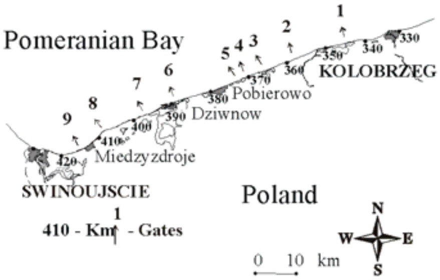

Figure 2: Location of "gates" along the Polish coast of the Pommerian Bight (Furmanczyk & Musielak 2002).

Such "gates" in the "coastal jet" will change the buffer and filter capacity of the coastal zone. But results on biological level are still missing.

3.2 North-Eastern German COAST

The much more morphological differentiated German coast is characterised by inner coastal waters, called “boddens” and “haffs”.

This is reflected by a gradient of DOC/POC-ratios (Figure 3). The lowest ratio of 1: 1 is found in the Darss-Zingst boddens (Görs et al. 2000; Estrum-Yousef 2001), the most eutrophic coastal waters in this region.

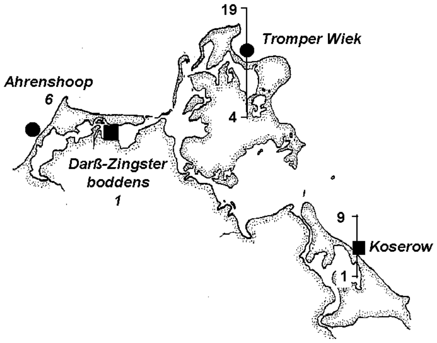

Figure 3: DOC/POC-ratios in different coastal waters (modified from Estrum-Yousef 2001).

The Greifswalder Bodden will be considered as the first prototype (Table 1). Two other coastal ecosystems are presented for comparison, the polytrophic Darss-Zingst Boddens and the still oligo-mesotrophic Salzhaff.

Table 1: Selected morphological - hydrological parameters of 3 German coastal waters of the Baltic Sea.

	Darss-Zingst boddens	Greifswalder Bodden	Salzhaff
Surface Area km^2	197.0	514.0	29.3
Volume m^3	387x10^6	3x10^6	67x10^6
Catchment km^2	1594	510	211
Surface/ Catchment area ratio	1:8	1:1	1:7
Mean depth m	2.0	5.6	2.5
Maximum depth m	12.0	13.5	10.0
Mean salinity PSU	4.5	7.5	10.5
Salinity range PSU	<5.0-15.0	<5.3-12.2	<5.0-15.0

The Greifswalder Bodden is a semi-enclosed water body with good exchange possibilities with the Baltic proper (Figure 4) and a surface / catchment-area relationship of 1:1. Therefore it has potential a natural mesotrophic status. Anthropogenic loads have changed it to an eutrophic status (see below). Before eutrophication starts, around 80% of the bottom was covered by macrophytes. The eutrophication has altered over the last 40 years the self-purification capacity.

In the 1980s the macrophytes covered 15% of the bottom only. The worst situation was found in eastern inner part, caused by greater anthropogenic loads and reduced exchange rates with the Baltic Sea.

Nowadays 10 years of restoration measurements results in first recovery, around 25% of the bottom surfaces are again covered by macrophytes.

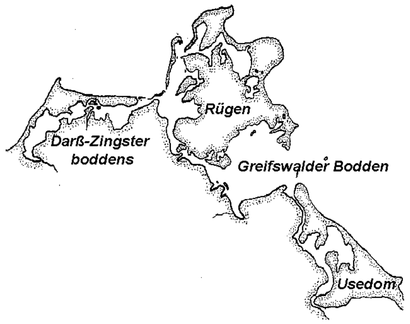

Figure 4: The German north-eastern Baltic coast.

Greifswalder Bodden – eutrophication process:

- Increase of nutrient concentrations
- Increased growth of phytoplankton
- Reduced light for submerse macrophytes
- Reduction of growth depht
- Loss of slow-growing red and brown algae
- Loss of eel gras communities
- Increase of fast-growing green and brown algae
- Increased sediment mobility and turbidity
- Expansion of mud covered bottoms.

Benthon:

Eastern bodden

- Sandy bottoms, dominated by high abundances and divers molluscs and ostracods.
- Dominant ostracod species *Cytheromorpha fuscata*.

- Western bodden
- Muddy bottom, dominated by low abundances and low divers molluscs and ostracodes
- Dominant ostracod species *Cypredeis torosa*.

Complete different are the Darss-Zingst boddens (see Table 1). The reduced water exchange rates with the Baltic Sea led to a more "autonomous" ecosystem. That is favoured by the basin dominated substructure (see Figure 4).

Such ecosystems are very sensitive to eutrophication (Schiewer 1998). A stepwise degradation in the water quality tooks place over the last 50 years (Figure 5):

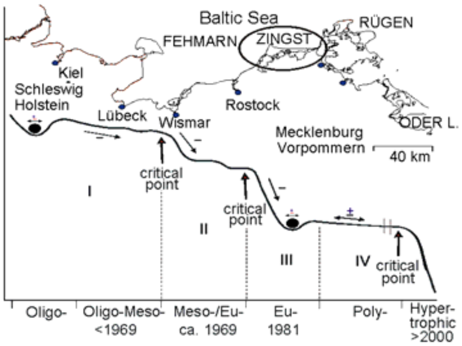

Figure 5: The Darss-Zingst boddens: stepwise Barther Bodden eutrophication.

- Step I: Oligo-mesotrophic before 1969. Nutrient limitation, low phytoplankton biomass and dominance of diatoms. Dominance of submerse macrophytes (charophyceae) in shallow parts.
- Step II: Meso-to eutrophic 1969/89. Nutrient limitation, mainly nitrogen; higher phytoplankton biomass and dominance of green algae and cyanobacteria. Dominance of submerse macrophytes (charophyceae and potamogetoneceae) in shallow parts.
- Step III: Eu-to polytrophic. Changes from nutrient to light limitation. Dominance of nano- and (pico)-phytoplankton (cyanobacteria and green algae) and microbial food webs. Dramatic loss of submerse macrophytes.
- From the end of the 1980s the most important feature was that the anthropogenic enhanced microbial food webs are concentrated on a very active fluffy sediment layer (Schumann et al. 2001).
- Step IV:Polytrophic. The change to hypertrophy is prevented by restoration. Change from light to nutrient limitation will be expect in the next 5 years. Observed are already first recoveries of submerse macrophytes (*Potamogeton pectinalis* and some charophyceae).

The general consequences of this massive eutrophication are:

- dominance of nano- and (pico)-phytoplankton
- dominance of microbial food webs
- enhanced turnover of organic matter
- accumulation of POC (aggregates, fluffy sediment layer)
- higher remineralisation rates
- stronger "self"-eutrophication
- increase of stochastic reactions and reduced predictability
- enhanced ecosystem stability
- increased efforts for restoration
- reduced buffer and filter capacity for the Baltic proper.

By this degradation of the self-purification becomes the Darss-Zingst boddens a load source for the Baltic Sea.

3.3 The Neva Bay

The Neva Bay (Vadim *et al*. 2002) is the eastern part of the Gulf of Finland (Figure 6). In contrast to the other water bodies concerned, the Bay is dominated by freshwater of the Neva river. Selected characteristics are shown below. In spite of the high nutrient load the trophic status is meso- to eutrophic. Caused by extremely high freshwater inflow and the short residence time it is a transition zone, reflecting the Neva river. Part of the load is realised as productivity in the Neva estuary and the eastern Gulf of Finland.

Selected characteristics of the Neva Bay:

Area (km^2)	329
Volume (10^6 m^3)	1200
Mean depth (m)	3.5 – 4.0
Maximum depth (m)	12.0 (ship channel)
Catchment area (km^2)	304 000
Area/catchment relation	1:920
Average freshwater inflow	79 000 (10^6 m^3 a^{-1})
Residence time (d)	5.5
Salinity (PSU)	freshwater
Nutrient input (t a^{-1})	3 300 total P 24 000 total N
Chlorophyll a (µg l^{-1})	2.1 – 19.7
Primary production	
Phytoplankton	720 (mg C m^{-2} d^{-1})
Metazoa (mg ww l^{-1})	< 1.1
(rotifers, copepods, cladocerans)	
Seston (mg dw l^{-1})	14.5 – 28.9
Macrozoobenthos	<134 (g ww m^{-2})

Macrofauna species.......................210 (number)
Trophic status .... meso-to eutrophic

Changes took place after the construction of the storm-surge barrier in the estuary in the 1980s. It changed the natural hydrodynamics in the Neva Bay, which resulted in:

- sedimentation, wetlands forming and development of emergent macrophytes, *mainly Phragmites australis* Trin. and *Scirpus lacustris* L. and
- overwhelming growth of *Cladophora glomerata* (L.)

in the northern area of the Bay. The last should be change the ecosystem structure and function at least in the northern part of the Bay. Consequently, the self-purification capacity will be altered, but experimental data are not yet available.

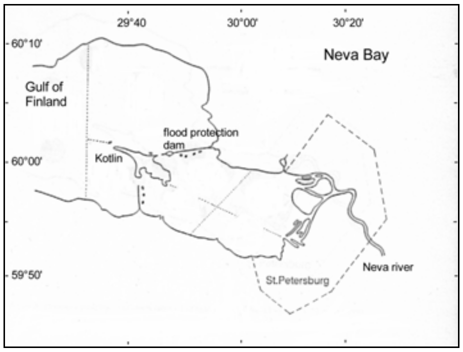

Figure 6: Neva Bay (Panov et al. 2002)

3.4 Coastal Zone Management

As shown by these selected examples the "self"-purification ability of the inner and outer coastal waters of the Baltic Sea is very different. It depends on different measures.

„Self-purification" of Baltic coastal waters - important measurements:

a) Morphology and hydrology
- Mean depth
- Surface/catchment area
- Exchange with the Baltic Sea
- River inflow
- Water residence time

b) Physical-chemical processes
- Salinity
- Nutrient loads
- Sedimentation/resuspension
- Accumulation

c) Biological processes and regulations
- Changes in phytoplankton, e.g. decline of diatoms
- Phytoplankton versus submerse macrophytes dominance
- Grazing versus microbial food web dominance
- Formation of fluffy sediment-layer
- Decline of diversity
- Deterministic versus stochastic regulation
- Stepwise changes of trophic levels

In general, the influences caused by anthropogenic increased nutrient loads are more pronounced in "autonomous" shallow waters. River-dominated coastal zones, however, are often subject to structural changes with dramatic effects on the ecosystems. There are first signals of recovering from eutrophication in different regions, but in future more attention has to be paid to diffuse loads.

Besides eutrophication, potential pollution, harmful algal blooms and the intrusion of non-native species from other brackish or fresh waters world-wide into the Baltic Sea are further important problems. There are a lot of gaps in the ecological knowledge of coastal ecosystems, e.g. there is an urgent need for a more detailed investigation and calculation of the self-purification ability of the coastal zone along the salinity gradient. It should also consider the time - and season-dependent transport, sedimentation, deposition, transformation and degradation of organic matter and nutrients.

Many utilisation conflicts are known, but detailed and comprehensive overviews of the use, especially of coastal waters, are lacking (Figure 7). Even, a clear definition of the coastal zone is missed (Obenaus & Köhn 2002).

In the past, non-integrated exploitation of the natural resources, including the self-purification capacity, have caused unfavourable changes or even the destruction of natural potentials. It is the complex overlapping pattern of uses which demonstrate the urgent need for ICZM. As an example we will show the possible interactions of tourism (Schernewski & Sterr 2002) with other uses in the coastal zone (Figure 8).

The EU Water Framework Directive and the intended extension of regional planning towards coastal waters in Germany are important changes with significant impact on ICZM.

4. DISCUSSION

The self-purification capacity of the coastal waters is the last barrier before pollutants and nutrients enter the Baltic proper. The unique coastal ecosystems play an important role in determining the amount of natural and anthropogenic loads for the open sea.

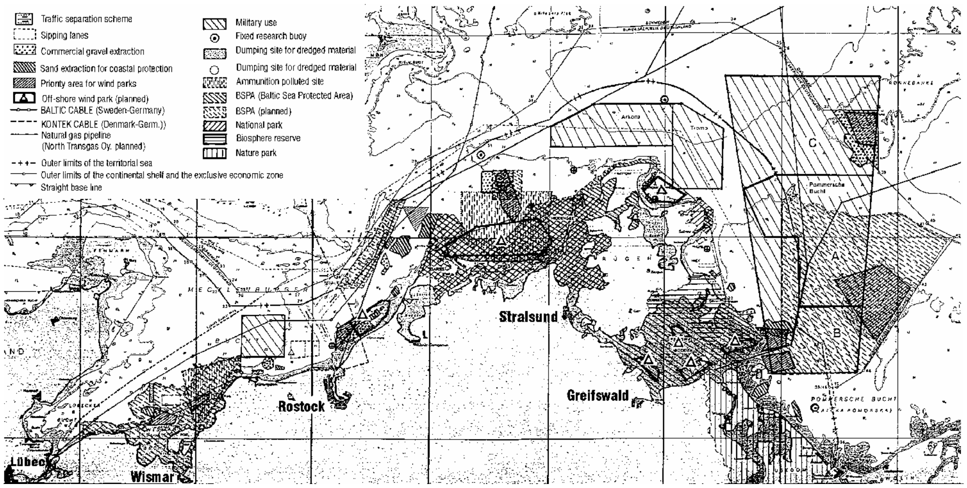

Figure 7: Important uses and user needs in the Baltic coastal zone of Mecklenburg-Vorpommern (Obenaus & Köhn 2002)

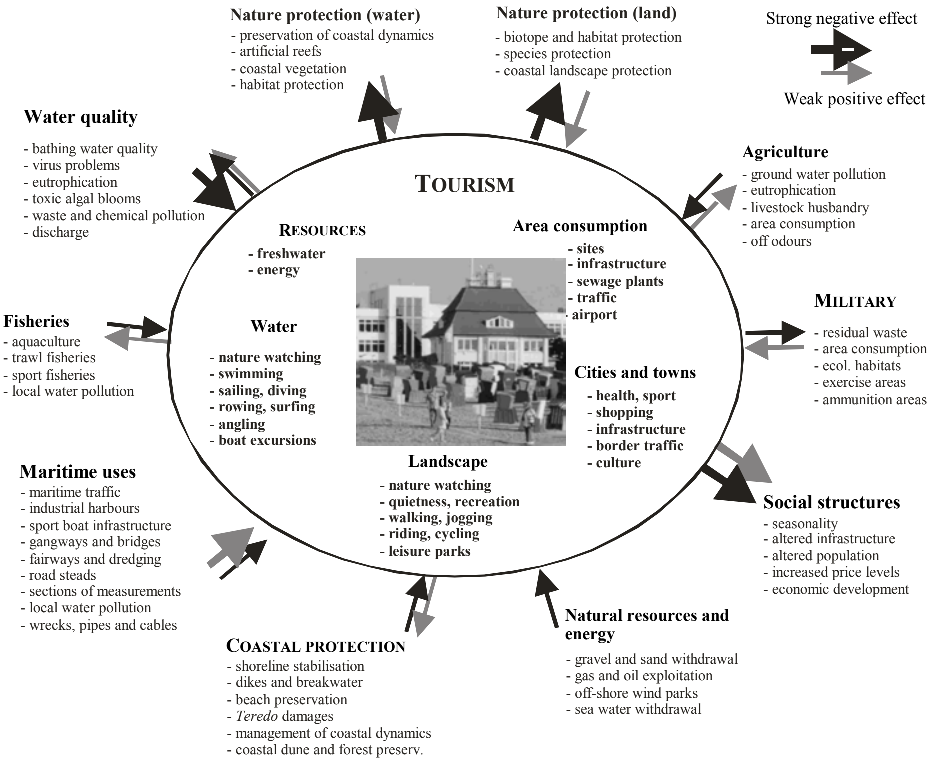

Figure 8: Interaction of tourism with other users in the coastal zone (Schernewski & Sterr 2002).

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The sedimentation, transformation and transition capacities of the coastal zone are very different. Only regional detailed analyses will give relevant results.

On the other hand, there is a basic approach for coastal zone management and restoration, considering the restoration of the catchment area, supporting the self-purification capacity and establishing adequate measurements for water quality assessments.

Basic approaches for coastal zone management and restoration:

a) Restoration of the catchment area

Direct intervention by

- Rehabilitation of hot spots
- Reduction of small point loads by low-tech treatment plants
- Using best managing practice, e.g. critical area planning, crop rotation, streamside vegetative buffers, and nutrient management
- Changing of land use
- Re-establishing of water exchange activities.

b) Supporting the self-purification of the coastal ecosystem

- Enhancement of the existing self-purification potential by
- Ensuring the multivalent use of the coastal ecosystem
- Establishment of critical loads
- Precautionary principle in industry and agriculture
- Minimum standards for waste water treatment
- Restrictions of use for sensitive water-management areas
- Establishing marine parks to provide reserve stocks for recolonization
- Adequate legislation for environment protection
- Education of the public.

c) Adequate measurements for water quality assessments

- Use of the EU- directives for the protection of inland surface water, transitional waters, coastal waters and groundwater for
- Preventing further deterioration and enhancing the status of aquatic ecosystems and terrestrial ecosystems and wetlands directly depending on the aquatic ecosystem
- Promoting sustainable water use based on a long-term protection of available water resources
- Contributing to mitigate the effects of floods and droughts.

If we want to have real success, the development of an ICZM is imperative. But this process is difficult and time consuming. In the next future the focus should be on 3 main deficits in the Baltic Sea Region (Schernewski & Schiewer 2002):

1. Experiences with democratic decisions and stakeholder involvement in decision making are rare in most Baltic countries. Often, decisions are following the hierarchical structure. Sometimes even necessary laws are missing.
2. Discrepancies and the lack of communication between scientists, administration, managers and decision makers are immense and additionally hampered by language barriers. Spatial planning (Kannen 2002) should take the lead in coastal management (Figure 9). Universities can and have to play an important role as mediators.
3. The most important task are the establishment of an international Baltic ICZM forum and the creation of internet-based information network as well as databases for ICZM.

5. CONCLUSIONS

It is stressed that the Baltic coastal ecosystem is unique, as it is characterised by high diversity in structure and function. Consequently, ICZM can be efficient only, if the regional differences are considered and respected.

There is an urgently need for a more comprehensive approach to understanding and managing the

- self-purification ability of the coastal zone along the salinity gradient
- time- and season-dependent transport, sedimentation, deposition, transformation and degradation of organic matter and nutrients
- joint sustainable development as well as Integrated Coastal Zone management (ICZM).

In general, a well-developed gradient of floral, faunal and micro-organismic elements ranging from the river mouth down to the light compensation point of the coastal water seems to be the best guarantee for efficient self-purification and protection of the Baltic proper.

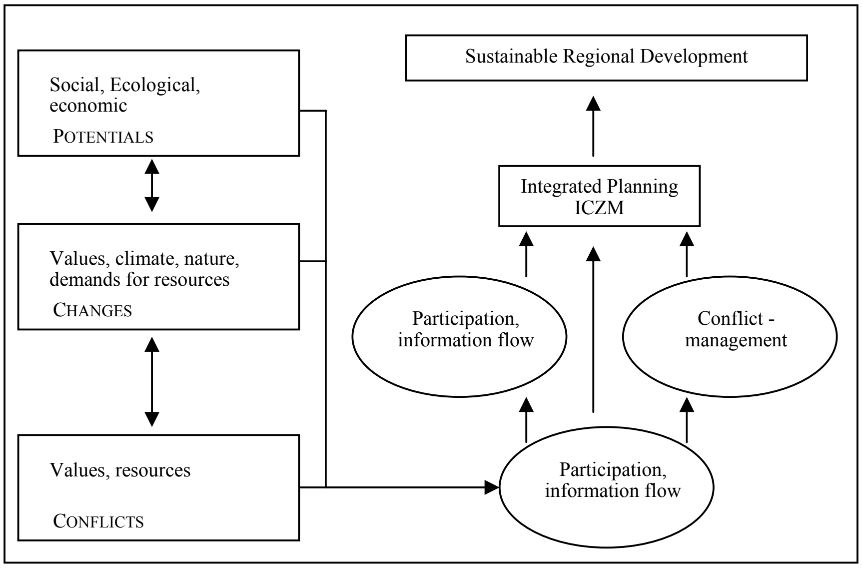

Fig.9: ICZM in the context of regional planning (adapted from Kannen *et al*. 2002).

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