# 3. Congruent scales in economics, coastal engineering and morphology

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## Abstract

Complex human-environment systems are characterized by a diversity of components and local interactions among them that produce nonlinear feedbacks between different scales. Lack of understanding of micro-foundations of macro-phenomena (such as total economic value of the area or patterns of dune formation) can make coastal zone management and spatial planning policies inefficient and unpredictable. This research project aimed to understand what the links between micro and macro scales in economics and coastal morphology are. Two research projects (one with the focus on coastal morphology and another on economics) have generated knowledge and models that contribute to the understanding of this challenge. We focused on the Dutch coastal towns with 'outside-flood defense' areas, where the flood defense consisted of foredunes. In this case, the so-called safety line serves as a linking element between the two subprojects. The safety line is the line that is based on the estimated erosion line but can be adjusted (e.g. moved landwards) depending on the value of economic activities at risk. This report first briefly introduces the problem. Then the aim and results from both subprojects are discussed. Namely, the results of the economic land market modeling under various assumptions about individual behavior and implications for coastal policy are discussed. Further, a conceptual model regarding the impact of soft coastal engineering measures on foredune development over a range of scales is presented, which resulted from morphologic analyses of differently managed foredunes along the Dutch and Danish coastlines. Finally, we provide conclusions and some recommendations that resulted from this research effort.

## i. Problem

Coastal zone management (CZM) is a field where a variety of disciplines meet, such as coastal engineering, coastal morphology and economics. It requires insight into long-term coastal developments, both economically - to examine how economic activities can adapt to the dynamic coastal environment- as well as morphologically - to determine the space available for socio-

economic developments. CZM policy in the Netherlands aims at reducing risk, which is defined as the probability of a disaster (coastal erosion and flooding) multiplied by economic damage (Rijkswaterstaat, 2005a). In coastal areas with sandy shores this probability of disaster not only depends on the probability of occurrence of an extreme storm event, but also on the morphology of the coastal dunes that protect the hinterland. In the Netherlands, the dunes even act as a formal part of the flood defense system, in particular the foredunes.

Obviously, dunes are not static and their actual strength at the time of a future storm event depends on both long-term evolution of the dune area as well as short-term, small-scale developments. Direct economic damage depends on land use patterns and value of properties under risk, which, in turn, are the outcomes of individual microeconomic interactions in a land market. Thus, large-scale patters and macro-phenomena (e.g. economic values under risk or a position of the erosion line) are the emergent outcomes of numerous interactions at micro-level.

The challenge is to understand the links between different scales both in economics (subproject 1) and in coastal engineering and morphology (subproject 2), and to shed light into how this knowledge may help guiding CZM to reduce flood or erosion risk in coastal areas. The linking element between the two subprojects is the so-called safety line, which is based on the estimated position of the erosion line due to an extreme storm event, but which can be adjusted (e.g. moved landwards) depending on the value of economic activities at risk (Fig. D-3.1).

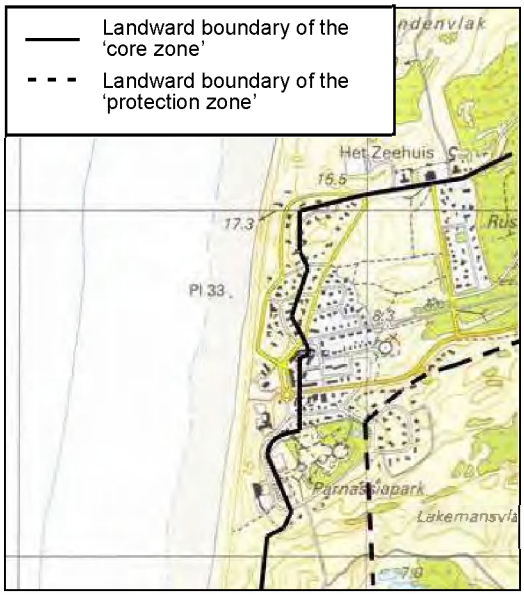



***Fig. D-3.1:*** *A coastal town under risk (source: Rijkswaterstaat (2005a).Sea-side town in the Netherlands with coastal protection zonation (safety lines) that affects the regulations regarding land-use and activity allocation. In this area the flood protection is provided by coastal dunes. The zonation is hence derived from a safety assessment of coastal dunes based on storm erosion calculations and economic value under risk. The 'core zone' refers to the zone that is currently part of the coastal defense against flooding. This zone has no legal protection level with respect to coastal erosion or flooding. The 'protection zone' is the zone that may become part of the coastal defense zone in the next 200 years due to expected rise in sea level.*

Direct economic damage depends on land patterns and value of properties under risk (Rijkswaterstaat, 2005b), which, in turn, are the outcomes of individual microeconomic interactions in a land market (Alonso, 1964). However, the transition from micro-scale individual homeowners' behavior in a land market to macro-measures used by policy-makers is discontinuous, non-linear and may be associated with emergent effects and properties. This transition from micro-foundations to macroeconomic phenomena happens through the mediation of markets. Aggregation is usually possible by assuming a rational representative agent and the existence of a unique equilibrium. Moreover, the majority of economic models is aspatial. Few 2D models assume only two characteristics of the landscape (distance to the employment center and either environmental amenity (Wu and Plantinga, 2003) or hazard risk (MacDonald et al., 1987; Tatano et al., 2004) but not the latter two together). The challenge is to construct a model that can comprehend the direct modeling of a market (to allow tracking the micro-macro economic links) where agents with heterogeneous preferences and perceptions interact in the 2D landscape.

When dunes act as coastal flood defense, a short-term dune erosion model is used to predict the position of the so-called erosion line due to the occurrence of a predefined normative storm event. This erosion line controls to a large extent which part of the coastal area can be currently considered part of the flood defense. The assessment of the part of coastal area needed for long-term flood defense purposes (e.g., in 200 years) requires information on the future state of the coastal dunes, and in particular of the foredunes. Current knowledge about evolution of coastal dunes at the decadal time-scale is however limited. Moreover, where dunes act as coastal flood defense, their evolution will not only be determined by natural processes, but they will also be influenced to some yet unknown extent by human interventions (e.g. sand nourishments). Besides this lack of knowledge, the large-scale morphodynamic models that will be needed for long-term prediction of coastal evolution are generally spatially aggregated and do not provide the level of spatial detail required for dune erosion modeling (Van der Burgh et al., 2007).

### ii. Aim and results from economics and coastal morphology subprojects: Scales in economics in coastal areas

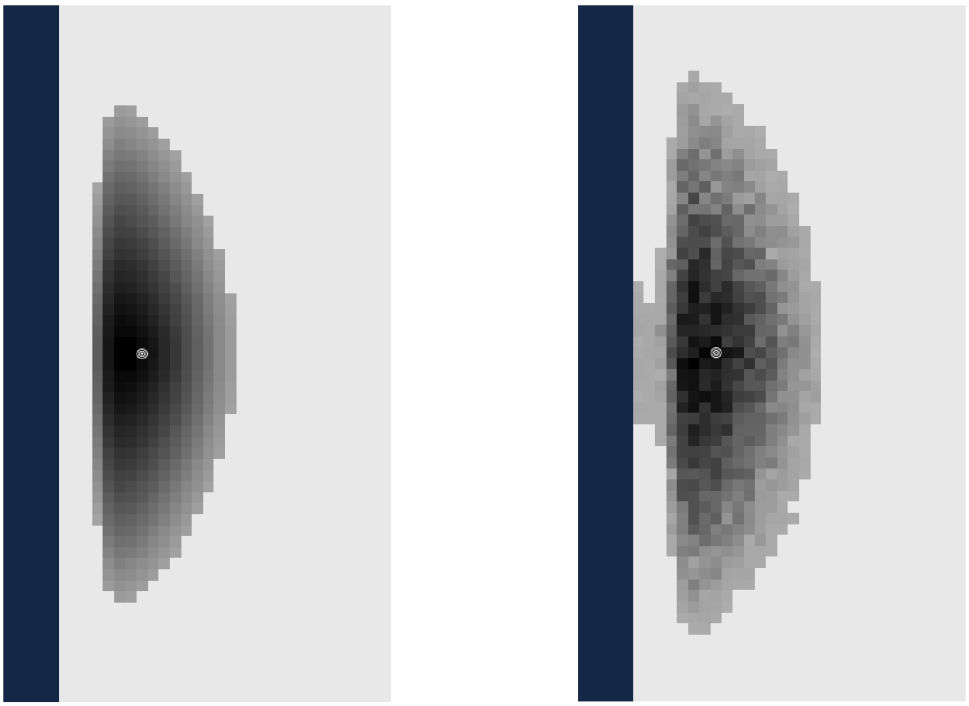
Aim:

The main aim of this subproject was to get insights into how aggregated economic phenomena in coastal area (land patterns and land prices that determine direct economic damage in the case of a coastal disaster) emerge from interactions of individual agents (e.g. households) in a land market.

Results:

To accommodate more spatial and agent heterogeneity and to allow the study to be spatially explicit, we adopt an agent-based approach, which helps to understand the effects of relaxing some of the conventional economic assumptions and their implications for coastal risk management policy. The newly developed model (ALMA) combines advantages of spatial economics and cellular spatial simulation models covering the methodological gap between the two (Parker and Filatova, 2008). We performed several sets of experiments with the model. Firstly, a structural validation of ALMA against conventional analytical urban model was successfully performed (Filatova et al., 2009a). Secondly, the simple urban model is extended to

account for heterogeneous attributes of the landscape (environmental coastal amenities and flood/erosion risk in addition to distance to the employment center) to replicate the structure and complexity of a typical Dutch coastal town (Fig. D-3.1). Thirdly, we add heterogeneity among economic agents in order to move beyond the representative agent concept. Experiments with agents heterogeneous in their levels of flood risk perception demonstrate that individuals who underestimate coastal risk drive land market into economically inefficient high risk zone (Fig. D-3.2).



a) Representative agent b) Heterogeneous agents

***Fig. D-3.2:*** *Land rent gradients (the darker the color the higher the land price) in a coastal town with spatial amenities and disamenities: a) representative rational agent model is usually used in economic models for policy decision support. It also shows the boundary for economically efficient allocation of urban developments. b) Agents with heterogeneous flood risk perception (average risk perception in the population is equal to the one of a representative model).*

This implies that a representative agent model normally used for policy decision support would underestimate developments in the flood-prone zone and, consequently, the direct flood damage (Filatova et al., 2009b). As a next step, we analyze the changes in the outcomes of a coastal land market due to the shift of the erosion line, i.e. increase of a probability of erosion because of climate change (Filatova, 2009). Finally, a survey, which explores coastal flood risk perception and location choices, was carried out in 2008 in the Zeeland province. The surveys analysis shows that coastal flood risk perception is low, while coastal amenity is an important factor. These factors affecting decisions to buy properties in flood-prone areas are likely to bias efficient coastal land market outcomes. The land market model parameterized with the actual survey data about individual risk perception of Dutch population shows that all the area seawards from the erosion line will be developed magnifying economic values at stake (Filatova et al., submitted).

### iii. Scales in coastal engineering and morphology along dune protected coastlines

Aim:

This subproject aimed at improving the knowledge on decadal-scale variability of human-altered foredunes and to improve the understanding of the impact of coastal management strategies on the evolution of the foredune system on the long-term.

Results:

To improve the knowledge on decadal-scale variability of human-altered foredunes several case studies were performed on the decadal evolution of foredune morphology under various regimes of dune management in similar as well as different environmental settings. Study sites were located along the Dutch coast and the Danish Coast.

EOF-analysis of a large data set of repeated elevation measurements across the foredune along the Dutch west coast showed that these highly managed foredunes, where measures generally aimed at stabilization of the foredune, were still quite variable in shape at the decadal timescale (Bochev-Van der Burgh et al., submitted, a). In areas where dune management measures were most intensely applied, the shape of the foredune appeared to be more variable in time than in areas where hardly any measures were applied. This could be explained by the reactive nature of the dune management strategy applied at these sites, i.e. measures were only applied when changes occurred. Hence, the most dynamic areas were most intensely managed. Also, the applied measures essentially mimicked small-scale natural recovery processes When the coastal management strategy was more pro-active in nature and measures were not restricted to the dune area itself, i.e. beach and offshore nourishment were applied, the impact on dune morphology appeared to be more pronounced (Bochev-Van der Burgh et al., 2009; Bochev-Van der Burgh et al., submitted, b).

An analysis of similar coastal management strategies in different environmental settings (Wadden Island coast), as well as a comparison of foredune behavior in a situation with and without management measures (Danish west coast), led to the formulation of a conceptual model regarding the impact of soft coastal engineering measures on foredune behavior over a range of scales (Fig. D-3.3). The underlying concept is that coastal engineering measures that are generally applied to dunes with flood defence functionality usually have a natural counterpart but at varying levels in the coastal system hierarchy.

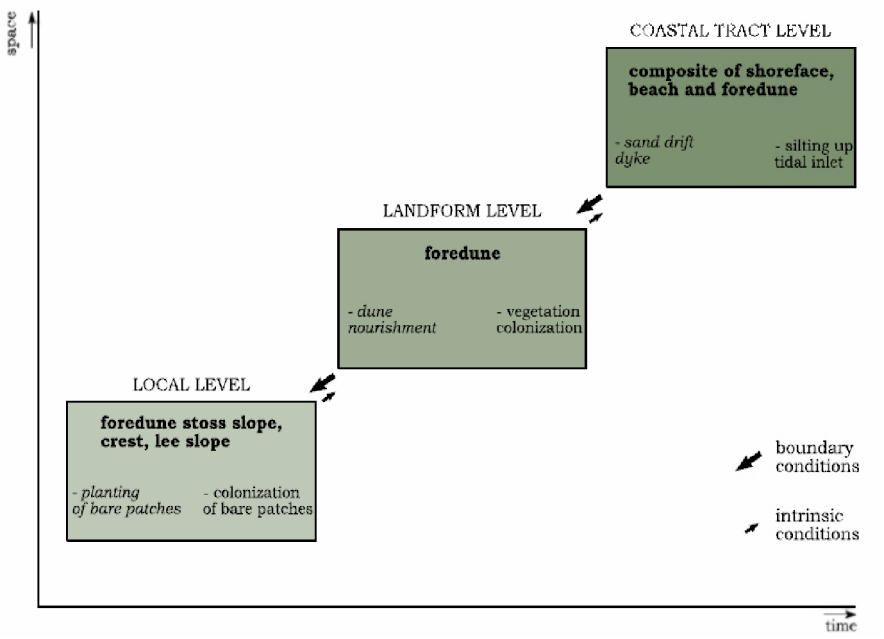



***Fig. D-3.3:*** *Conceptual model on congruent scales in foredune morphodynamics and soft coastal engineering measures*

These natural counterparts provide insight in the extent of impact (temporally and spatially) that may be expected from certain measures in a given environmental setting.

### iv. Conclusions and Recommendations

### Economic subproject

A new spatially explicit land market model structure facilitates the coupling of economic models with the 2D morphological and ecological ones. The novelty of the ALMA model is that it combines the advantages of the analytical urban economics, cellular automata and spatial econometrics models by allowing direct modeling of a land market for heterogeneous agents in a 2D heterogeneous landscape. Thus, it serves as a computational laboratory to explore land patterns and land prices in a coastal land market emerging under different assumptions about individual economic behavior. Specifically, the outcomes of a land market parameterized with the results of our survey, which showed that in the Netherlands coastal flood risk awareness is low and attractiveness of coastal amenities is high, can be quantified and visualized in a 2D landscape.

We conclude with the following implications of this study for coastal risk management: 1) importance of accounting for individual and spatial heterogeneity: the conventional economic models used for policy making and decision support (general equilibrium or econometric ones – both assuming a representative agent), might misrepresent the aggregated behavior of the real-world economic agents that are highly heterogeneous. Our simulations showed that individuals with low flood risk awareness drive urban developments in coastal areas into the zone that a representative agent considers economically inefficient. Thus, potential damage from natural hazards in coastal towns might grow beyond the level anticipated by policy makers, especially in the outside-dikes areas in the Netherlands. This result holds even if erosion line shifts, i.e. probability of hazard increases due to climate change; 2) low flood risk awareness biases

microeconomic decisions in a land market, and leads to inefficient land use outcomes and increase of risk in hazard-prone areas. Thus, measures to increase flood risk awareness at the individual level (such as risk communication, financial and technical instruments) can be employed by policy makers to reduce total flood risk along with traditional flood defense measures.

### Coastal engineering and morphology subproject

The insights derived from understanding links between scales in coastal engineering and morphology in the case of dune protected coastlines, contributed both to the issue of translating information between scales as well as to guiding CZM by realizing coastal management measures at an appropriate scale. Regarding the translation of information from one scale to the other, it was suggested that EOF decomposition of observed dune profiles could provide simple but realistic dune shape functions to redistribute forecasted dune volumes from spatially aggregated large-scale morphodynamic models into realistic dune shapes in order to improve the knowledge on the possible future position of erosion lines due to extreme storm events. Regarding guiding CZM, the following insights were derived for dune protected coastlines. When proposed (soft) coastal engineering measures mimic natural processes that act at a higher level in the coastal system's hierarchy its impact on the foredune morphology (hence coastal safety) will not only be more pronounced, but it is also expected to control which, or whether, additional lower level measures are still needed.

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