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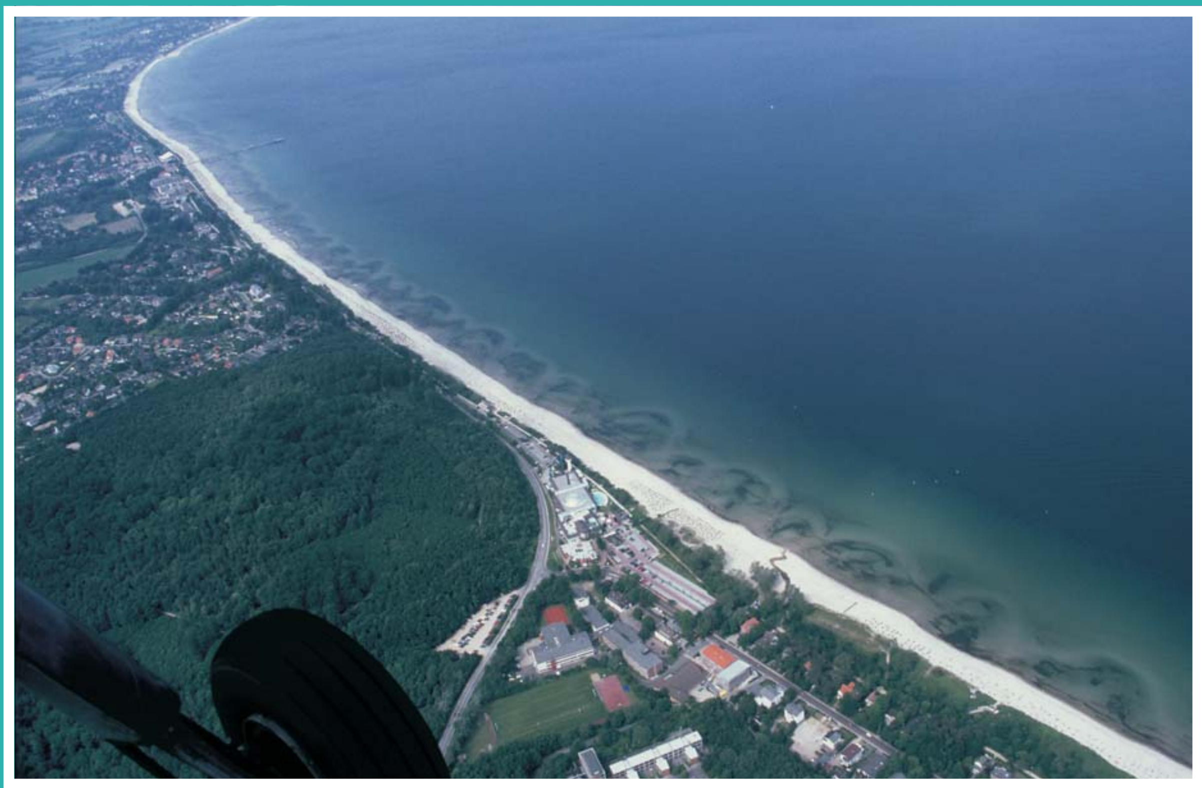
From Brazil to Thailand - New Results in Coastal Research



Editors:
K. Schwarzer, K. Schrottke & K. Stattegger

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From Brazil to Thailand - New Results in Coastal Research

Editors:

Klaus Schwarzer, Kerstin Schrottke & Karl Stattegger

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Photo front: Inner Lübeck Bay (Timmendorf to Haffkrug) showing a crescentic nearshore bar system (Photo: Klaus Schwarzer)

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Vorwort der Herausgeber

Die 27. Jahrestagung des Arbeitskreises „Geographie der Meere und Küsten" (AMK) fand vom 24.-26. April 2009 in Kiel statt. Schon mehrfach waren Einrichtungen der Christian-Albrechts-Universität zu Kiel Gastgeber dieser Veranstaltungsreihe, doch erstmals waren das Institut für Geowissenschaften (IfG), AG Sedimentologie, Küsten- und Schelfgeologie, gemeinsam mit dem Exzellenzcluster „Ozean der Zukunft, AG Meeresspiegelanstieg und Küstenerosion" die Ausrichter. Dieser Standort an der Kieler Förde hat einen besonderen Bezug zur maritimen Forschung. Von hier aus nahmen viele Bereiche der deutschen, aber auch der internationalen Meeresforschung ihren Ursprung. Der Stellenwert der marinen Forschung in Kiel wird auch dadurch unterstrichen, dass hier 1987 das Forschungszentrum für marine Geowissenschaften GEOMAR gegründet wurde, welches sich am 1. Januar 2004 mit dem ehemaligen Institut für Meereskunde zum Leibniz-Institut für Meereswissenschaften IFM-GEOMAR vereinigte, welches heute seinen Hauptsitz an der Schwentinemündung auf dem Ostufer hat. Keine andere Stadt der Welt kann auf eine Tradition von über 300 Jahren interdisziplinärer Meeresforschung zurückblicken und in keiner anderen Stadt kann man mit ein bisschen Glück vier Forschungsschiffe (POLARFUCHS, LITTORINA, ALKOR und POSEIDON) nahe der Innenstadt an der Institutspier des IFM-GEOMAR gleichzeitig versammelt sehen.

Die aktive Arbeit im Arbeitskreis findet ihren Höhepunkt in einer alljährlichen Tagung. Die Vielzahl der im Küstenbereich aktiven Disziplinen schlug sich diesmal in 26 Vorträgen und 10 Postern nieder, die neben der geowissenschaftlichen Seite auch die Ingenieurwissenschaften und die Biologie einschlossen. Aber auch die Umsetzung und Nutzung der im Feld und im Labor erarbeiteten Daten durch die unterschiedlichsten Bundes- und Landesbehörden und Einrichtungen der Wasserwirtschaftsverwaltung ist in den Vorträgen vertreten. Beispielsweise wurden Risikoabschätzungen für den Küstenraum, mit seinen Flussmündungen sowie das Datenmanagement auf nationaler und internationaler Ebene diskutiert. In diesem Band werden 17 der insgesamt 36 Beiträge vorgestellt.

Der Veranstaltungsort in Schleswig-Holstein, als einziges Bundesland an zwei Meeren gelegen, führt fast automatisch zu den regionalen Schwerpunkten Nord- und Ostsee. Aber auch die Elbe, als die südliche Begrenzung von Schleswig-Holstein findet ihren Raum in den Vorträgen. Hamburg, als eine der größten Hafenstädte Europas an der Elbe gelegen, präsentierte seinen Fluss und die damit zusammenhängenden vielfältigen Herausforderungen. Hier wird die interdisziplinäre Zusammenarbeit besonders deutlich. Auch andere Küstenregionen Europas und der Welt wurden in Vorträgen und Postern präsentiert. Inhaltlich waren die Themen vielfältiger Art, sie handelten von Sedimentumlagerungen in Flussmündungen bis hin zu Kulturlandschaftsänderungen an der Küste durch Biokraftstoffproduktion. Als ein weiterer fachlicher Schwerpunkt kristallisiert sich seit einigen Jahren die Tsunami-Forschung heraus.

Stets ist auch eine Exkursion mit der AMK-Jahrestagung verknüpft. Es gibt in Schleswig-Holstein wohl keine bessere Lokalität für die Darstellung des großen Spektrums der Küstenforschung als die Nordseeinsel Sylt. Von der natürlicher Küstenentwicklung der Wattbereiche und der sandigen Brandungsküsten bis hin zu den vielfältigen Maßnahmen des modernen, technischen Küstenschutzes hat diese Insel alles zu bieten.

Die Bandbreite der Küstenforschung spiegelt sich schon beim Titel beginnend, in diesem Tagungsband wider. Das ist für die Tagungen des Arbeitskreises der Meere und Küsten durchaus gewollt, da auch die geologisch-geographische Küsten- und Meeresforschung ein großes Spektrum aufweist.

Die Kunsthalle zu Kiel unterstützte mit all ihren logistischen Möglichkeiten die 27. AMK-Jahrestagung, und die Nähe zu den Kunstobjekten gab dieser Veranstaltung ein ganz besonderes Flair. Logistische Unterstützung erfolgte auch vom IFM-GEOMAR und dem Präsidium der CAU. Die vielen freiwillig helfenden Studentinnen und Studenten, die ein großes Interesse an dieser Küstenforschung zeigen, lassen, was den wissenschaftlichen Nachwuchs angeht, hoffnungsvoll in die Zukunft blicken.

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ozean der zukunft
DIE KIELER MEERESWISSENSCHAFTEN

Vorwort des Sprechers

Die 27. Jahrestagung des Arbeitskreises „Geographie der Meere und Küsten“ (AMK) fand auf Einladung von Klaus Schwarzer und Karl Stattegger vom Institut für Geowissenschaften, Küsten- und Schelfgeologie der Christian-Albrechts-Universität zu Kiel, sowie von Kerstin Schrottke vom Exzellenzcluster „Ozean der Zukunft, AG Meeresspiegelanstieg und Küstenerosion“ in der Kunsthalle zu Kiel statt. Rund 90 Teilnehmerinnen und Teilnehmer gestalteten ein vielseitiges Programm mit 26 Vorträgen und 10 Posterbeiträgen.

An der 27. Jahrestagung des AMK waren Arbeitsgruppen geographischer und geologischer Institute der Universitätsstandorte Göttingen, Greifswald, Hamburg, Jena, Kiel, Köln, Marburg und Oldenburg sowie zahlreiche Wissenschaftler internationaler Forschungseinrichtungen beteiligt, beispielsweise aus Brasilien, Polen, Thailand und Vietnam. Besonders hervorzuheben ist die aktive Einbindung offizieller Stellen, Behörden und außeruniversitärer Forschungseinrichtungen wie zum Beispiel des Landesbetriebs für Straßen, Brücken und Gewässer in Hamburg, der Hamburg Port Authority, des Forschungsinstituts Senckenberg, des Alfred-Wegener-Instituts für Polar- und Meeresforschung, des GKSS-Forschungszentrums Geesthacht, des Leibniz-Instituts für Ostseeforschung Warnemünde sowie des Ministeriums für Landwirtschaft, Umwelt und ländliche Räume, des gleichnamigen Landesamts und des Landesbetriebs für Küstenschutz, Nationalpark und Meeresschutz des Landes Schleswig-Holstein. Diese anregende Mischung dokumentiert sowohl gelebte Interdisziplinarität innerhalb des Arbeitskreises als auch die unmittelbare Umsetzung von Forschungsergebnissen in die Praxis.

Die Vorträge der 27. Jahrestagung deckten eine Vielzahl hochaktueller Themen ab. Schwerpunkte lagen im Küstenzonen- und Küstenrisikomanagement, im Meeresmonitoring und in der Modellierung von „Ecosystem Services“. Ein weiterer Vortragsblock befasste sich mit Extremflut- und Hochwasserereignissen an Elbe und Weser und mit historischen Aufwachsraten und der Sturmgefährdung ausgewählter Halligen, insbesondere vor dem Hintergrund der globalen Klimaänderung. Es folgten Studien zum Sedimenttransport im Wattenmeer und in der Tideweser, zum Monitoring von Kolken an Offshore-Pfeilern und zur ökosystemar relevanten Temperaturverteilung in Wattsedimenten. Ein weiterer Vortragsblock thematisierte event-stratigraphische, geomorphologische und paläogeographische Studien zur Erfassung und Rekonstruktion von Tsunami-Ereignissen in Griechenland, Portugal und Thailand. Zudem wurden Modellierungsergebnisse für eine Tsunami-Risikoanalyse für die thailändische Küste vorgestellt. Für das Mekong-Delta (Vietnam) wurden neue Ergebnisse zum Deltavorbau und zum postglazialen Meeresspiegelanstieg präsentiert. Der abschließende Vortragsblock befasste sich mit der holozänen Küstenentwicklung der südlichen Ostsee und der Dynamik von Dreissena-Muschelbänken und ihrer ökologischen Bedeutung im Oderhaff. Ein Beitrag zeigte Möglichkeiten und Grenzen der Datierung von Küsten- und Meeressedimenten mittels Lumineszenzmethoden auf.

Mit diesem Buch liegt ein weiterer Band der seit 1983 durchgehenden Reihe wissenschaftlicher Veröffentlichungen zu den Jahrestagungen des AMK vor. Den Organisatoren gebührt größter Dank für die Organisation und Durchführung der Tagung in Kiel sowie für die Redaktion des Tagungsbandes in der Reihe Coastline Reports.

Andreas Vött

Sprecher des AMK

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Boulder transport by high-energy wave events at Cap Bon (NE Tunisia)

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Abstract

The Mediterranean is characterized by a considerable seismic and geodynamic activity resulting in a high tsunamigenic potential, particularly for the central and eastern Mediterranean. Within the last decades, numerous studies dealing with deposits caused by extreme events revealed recurrent tsunami events in the Mediterranean throughout the Holocene. In general, two main types of extreme wave event deposits have been described so far: (i) fine-grained allochthonous marine sediments found in near-coast geological archives and (ii) wave-emplaced block deposits along rocky shorelines. However, in many cases, there is an ongoing debate on whether these deposits were accumulated by tsunami or storm events.

This paper presents, for the first time, evidence of block accumulations from the north-eastern coasts of Tunisia induced by extreme wave events. Along the north-western coast of Cap Bon, several block fields and wave-transported boulders were detected. The blocks are partly arranged in the form of imbrication trains up to 4 m a.s.l. Many boulders show two distinct rock pool generations allowing for a relative chronological interpretation. Furthermore, the presented results point to a tsunami-induced transport of the blocks rather than to a storm-induced dislocation.

1 Introduction

The devastating December 26th, 2004 Indian Ocean tsunami dramatically changed public awareness of tsunami hazards all over the world. However, the event not only showed the tremendous and catastrophic wave-induced energy of tsunami and its potential for destruction - in particular, it demonstrates the need for intensified geoscientific research on tsunami events and on extreme wave events. A comprehensive knowledge about comparable tsunami events in the past is necessary for the estimation of tsunami hazard in a distinct area and for effective coastal protection measures. Apparently, reliable information on tsunami recurrence intervals as well as on the intensity and dimension of wave inundation are inevitable for an appropriate hazard assessment (Bondevik 2008). In this context, geo–scientific investigations, besides the analysis of historical accounts, are considered as one of the most promising approaches in palaeo-tsunami and palaeo-event research.

First sedimentary studies about tsunami imprints in geological archives were carried out in the late 1980s (Atwater 1987). Since then, two main types of extreme wave event deposits have been described: (i) fine grained allochthonous marine sediments found in near-coast geological archives, such as lagoons or coastal swamps, and (ii) wave emplaced block deposits along rocky shorelines. However, in many cases the determination of the event source remains problematic and only the marine origin and the high-energy nature of the deposit can be proved. Therefore, a vivid discussion on the distinguishability between tsunami and storm deposits in the geological record has evolved (for instance Goff et al. 2004, Kortekaas 2002, Kortekaas & Dawson 2007, Morton et al. 2007, Nott 1997, 2003a, 2003b, Robinson et al. 2006, Scheffers & Kelletat 2001; Scheffers 2005; Switzer & Burston 2010, Switzer & Jones 2008a, 2008b, Williams & Hall 2007).

In this paper, we present first evidence of block accumulations from the north-eastern coasts of Tunisia induced by extreme wave events. Chronological aspects of the block movement and possible event sources are discussed.

2 Palaeotsunami studies in the Mediterranean

Evidence for extreme wave events during the Holocene is known from a number of areas in the Mediterranean, and in most cases these events are associated to tsunami. In particular, numerous historical reports on tsunamis exist for the central and eastern Mediterranean, especially for Italy and Greece, summarized in tsunami catalogues (for instance Soloviev et al. 2000, Tinti et al. 2004). In these catalogues, additional information on event-related earthquakes, tsunami wave heights, inundated areas and other effects is recorded.

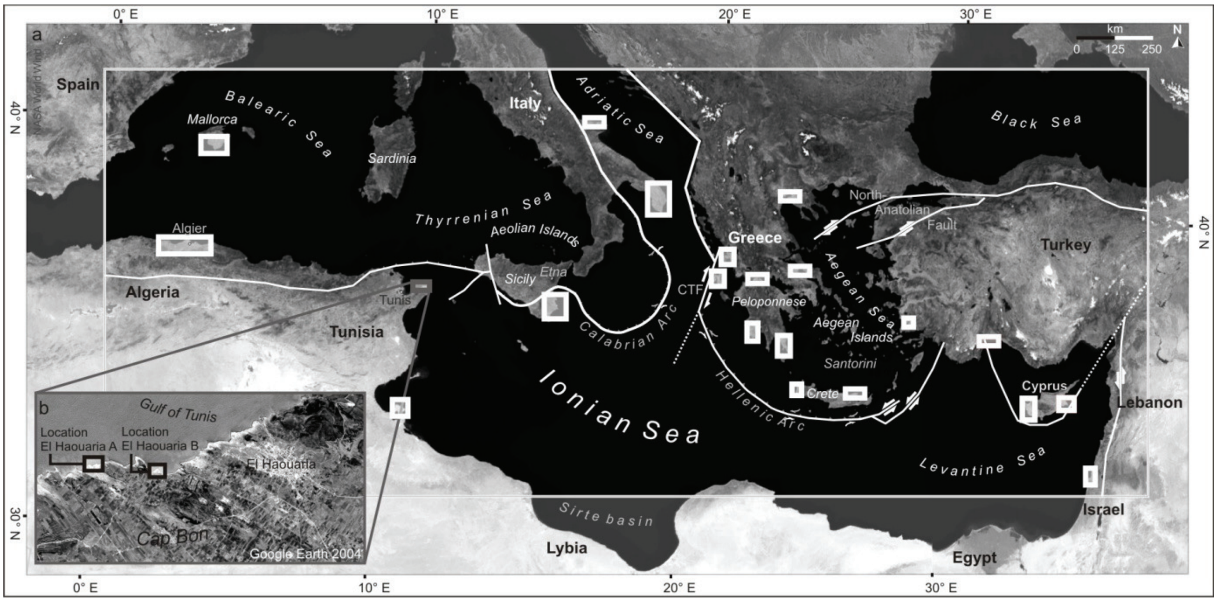

Figure 1: a) Overview of the Mediterranean with main tectonic structures (map based on Facenna et al. 2001, Wortel & Spakman 2000). White boxes mark reports on sedimentary tsunami imprints. The study area presented in this paper is marked by a grey box. b) Study area, north-western coast of Cap Bon, NE Tunisia, with presented locations of block findings. The coastal morphology shows a typical bay and headland configuration.

Sedimentary evidence for palaeotsunami events in the central Mediterranean proves the occurrence of tsunami events since the mid-Holocene. Especially the eruption of Santorini in the Bronze Age was subject to geological investigations (Bruins et al. 2008, Dominey-Howes et al. 2000a, McCoy & Heiken 2000, Minoura et al. 2000, Scheffers & Scheffers 2007). More recent events also left sedimentary signatures such as the 1956 tsunami in the southern Aegean Sea for which imbricated pebbles on the island of Astypalaea are described (Dominey-Howes et al. 2000b). Korteekaas (2002) and Kontopoulos & Avramidis (2003) gave evidence for tsunamigenic sediments in the Corinthian Gulf. Scheffers et al. (2008) found palaeotsunami imprints on the coasts of the southern and south-western Peloponnese. For northwestern Greece, Vött et al. (2006, 2007, 2008, 2009, 2010), May (2010) and May et al. (2008) presented manifold sedimentary evidence of tsunami influence on the Preveza-Lefkada coastal zone.

Several studies were also conducted on tsunami induced changes of coastal morphology such as boulder and block accumulations along rocky shorelines (Mastronuzzi & Sanso 2000, 2004; Scicchitano et al. 2007) and washover fans (Gianfreda et al. 2001) in southern Italy. Further evidence for extreme wave events was presented by Reinhardt et al. (2006) for the Israeli coast close to the ancient harbour of Cesarea, and Morhange et al. (2006) gave evidence for wave emplaced boulders at the coast of Lebanon. From the North African coast, Maouche et al. (2009) report on large boulder accumulations in northern Algeria and suggest a tsunamigenic origin and Kelletat (2005) describes wave transported boulders in southern Mallorca. Frébourg et al. (2007) describe a possible tsunami layer found within eolianites from eastern Tunisia. Block accumulations are also known from Morocco (Mhammudi et al. 2008), but may be related to event sources in the Atlantic Ocean, comparable to the 1755 earthquake and tsunami of Lisbon (Andrade 1992, Whelan & Kelletat 2005).

When considering possible source mechanisms for tsunami events in the Mediterranean, several potential triggers must be taken into account (see also figure 1). Especially the central Mediterranean exhibits a high seismic activity. Numerous strong earthquakes are reported from the subduction zone of the Hellenic Arc or major fault zones. It is well known, that vertical crustal movements of terrestrial and submarine origin have a high tsunamigenic potential in this region (for instance Benetatos et al. 2004, Pirazzoli 1986). In northwestern Greece, the Cefalonia transform fault (CF), situated west of the Ionian Islands Cefalonia and Lefkada, connects this zone of subduction with an area of continent-continent collision beginning off the coast of southern Epirus (figure 1). The CF also shows a remarkably high seismic activity and has been responsible for numerous strong earthquakes during history (Benetatos et al. 2005, Cocard et al. 1999, Louvari et al. 1999, Sachpazi et al. 2000, Papadopoulos et al. 2003). In the western Mediterranean, several tsunamigenic earthquakes are known from south-eastern Spain and North Africa (Alasset et al. 2003, Gràcia et al. 2006). Moreover, Pareschi et al. (2006) suggest that flank collapses of the Etna volcano, occurring during the middle Holocene, resulted in mega tsunami events effecting large parts of the Mediterranean. From the central Ionian Sea and the Sirte basin to the north of the African coast, several turbidite layers have been detected in the deep sea geological record. These layers suggest repeated and extensive submarine mass movements in the area that may also have produced large tsunami events in the central Mediterranean (Hieke 2000, Hieke & Werner 2000). Further potential tsunami triggers are cosmic impacts for which, however, no evidence has yet been found in the Mediterranean.

3 Study area

Field survey was carried out along the north-western coast of Cap Bon, NE Tunisia (figure 1). In general, the Geology of the low lying coastal areas at Cap Bon is dominated by Tertiary and early Pleistocene sequences, mainly consisting of marine sandstones and aeolianites (Mensching 1979). The coastal morphology is characterized by slightly elevated marine terraces, most likely of late Pleistocene origin (Jedoui et al. 1998, Morhange & Pirazzoli 2005).

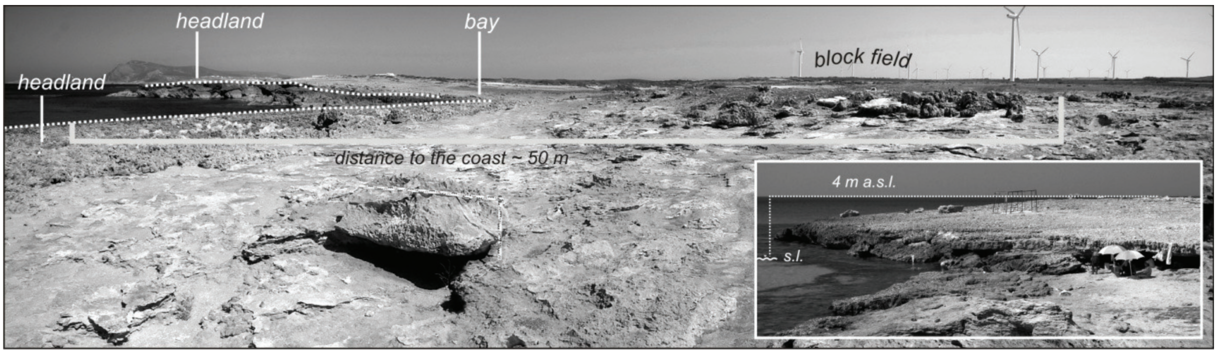

Figure 2: Cliff top platform with field of dislocated blocks, around 50 m distant from the sea. Inlay: View of Pleistocene terrace with cliff top platform reaching up to 4 m a.s.l. Elevation of cliff ~ 2 m. Note typical coastal configuration with bays and headlands.

They form, in most cases, small headlands, which are characterized by a well-developed cliff, up to 5 m high, and a cliff top platform, up to 200 m wide (figure 2). These promontories are separated from each other by small and narrow bays with, at some locations, sandy beaches. Well-defined notches document a comparatively stable relative sea level for the area for the late Holocene. The cliff top platforms are free of vegetation and characterized by intense karstification and, in the littoral and supralittoral zone, extensive rock pool formation.

4 Methods

During August 2008, a geomorphological field survey was carried out along the northern shorelines of Tunisia in order to detect geo-scientific imprints of extreme wave events. In this context, we found evidence for extreme wave emplaced blocks, up to at least ~ 5 m³ and 11 t.

Block fields detected during the geomorphological survey were documented and partly measured. The sizes of selected boulders were estimated based on measurements of the x-, y- and z-axes using a measuring tape. All the dislocated blocks and boulders were examined for rock pools on their surfaces. The number and the dimension of different rock pool generations were studied in order to get information on different phases of boulder transport. For weight calculation of the transported boulders, rock density was estimated to ~2.2 g/cm³ (Scicchitano et al. 2007). GPS points were measured for the study areas and for the sampling points.

5 Results and discussion

Location one (El Haouaria A, 37°03'9.08"N; 10°56'46.91"E, figs. 1 and 3) is situated 5.5 km west of the City of El Haouaria. Here, the cliff top platform reaches an elevation of around 4 m a.s.l. (above mean sea level) and is covered by numerous blocks and boulders, up to 3 m³ in size. The blocks are assembled in block fields and can be followed up to a distance of 50 m onshore.

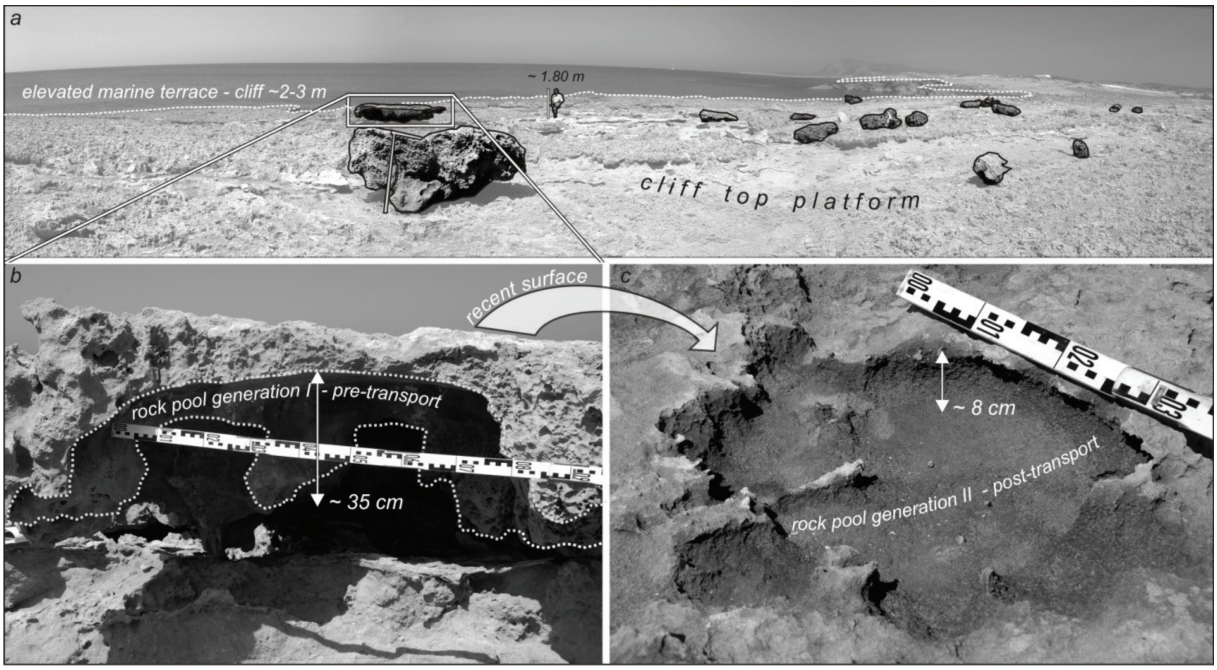

Figure 3: a) Block field at El Haouaria site A. Cliff top platform lies at around 3 m a.s.l. Note person (around 1.80 m) as scale. b) Overturned block of ca. 2.7 m³ in size with former surface (rock pool generation I) at its bottom side. c) Rock pool generation II on top of the recent surface.

Most blocks show extensive rock pools at their surface. These rock pools are usually formed by bio-erosional processes in the littoral zone (Laborel & Laborel-Deguen 1994). Found in the present constellation, they clearly prove that the blocks were transported from the littoral zone to their current position. Most probably, the rock slabs and blocks originate from the cliff front area.

Some of the dislocated blocks are overturned, with the former surface facing downwards. For the block depicted in figure 3, which is around 2.7 m³ in size and weighing approximately 6 t, this is indicated by well-developed rock pools, up to 35 cm deep and 1 m wide, found on the lower side of the block (figure 3b, rock pool generation I). A comparatively long period of rock pool formation was thus needed before the block was dislocated and transported to its recent position. Clear indications of bio-erosion by gastropods point to the formation of the rock pool in a littoral environment. Moreover, a second generation of rock pools (rock pool generation II) was observed on top of the recent surface. This rock pool generation shows a much smaller depth and width of around 8 cm and 40 cm, respectively, and must have developed subsequent to the transportation of the block (figure 3c). Thus, for this block, the period of time between the start of the formation of rock pool generation I and its displacement must have been much longer than the period of time since its transport. As not more than two rock pool generations could be observed, a displacement of the block during one singular event can be assumed.

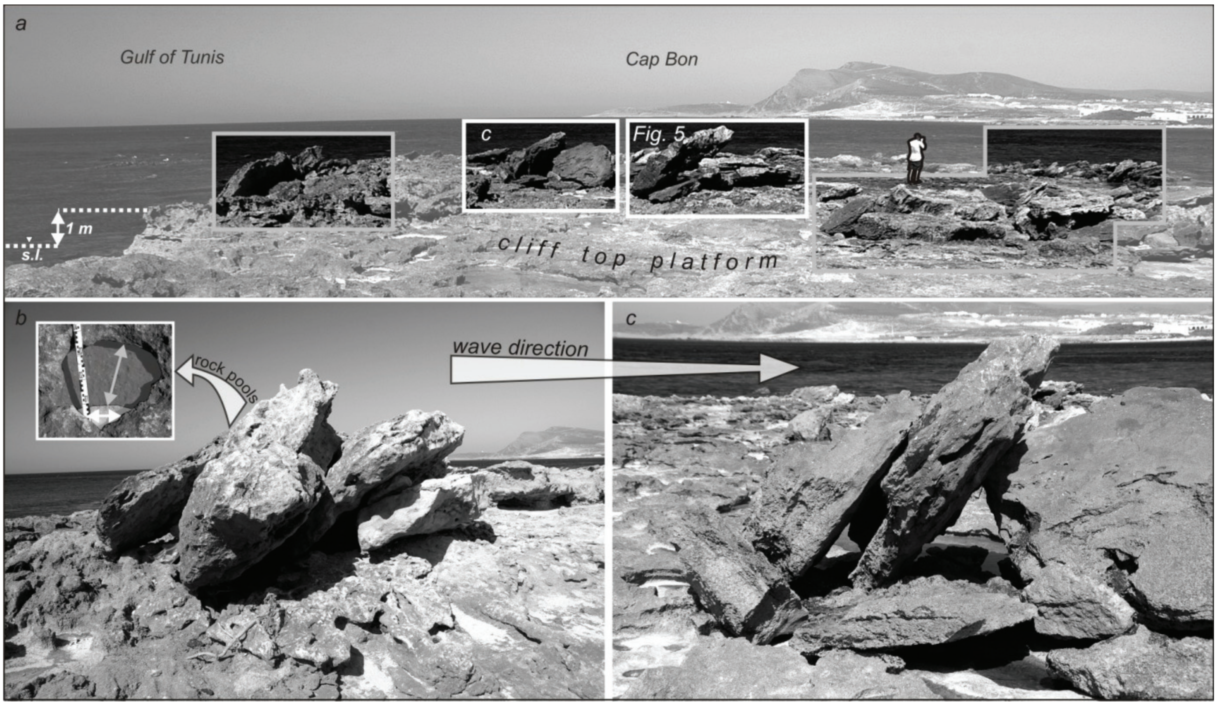

Figure 4: a) Block field at El Haouaria site B showing several imbrication trains; the cliff top platform lies at around 1 m a.s.l. Note person (around 1.80 m) as scale. b) and c) Imbrication trains – blocks are typically tilted in wave direction. Inlay in b) shows two rock pool generations found for the second block within the imbrication train (grey – rock pool generation I, white – rock pool generation II).

Location two (El Haouaria B, 37°03'5.00"N; 10°58'9.20"E, figure 1 and 4) is located around 2 km east of location one and some 3.5 km west of El Haouaria. Dislocated blocks and boulders were encountered on top of an elevated marine terrace, about 1 m a.s.l. As illustrated in figure 4, blocks and rock-slabs are abundant and are assembled in a block field, extending approximately 3000 m². Within the block field, several trains of imbricated blocks, up to 5 m^3 in size, were found, consisting of up to 6 tilted blocks or rock-slabs. The imbrication of the blocks proves their extreme wave generated displacement and deposition.

Several blocks exhibit rock pools on their surface. Comparable to the findings at location El Haouaria A, two generations of rock pool formation can be observed, regardless of the position of the hosting blocks within the imbrication train (figures 4b and 5). Rock pool generation I appears to be deeper and wider than rock pool generation II (figure 5). Thus, the period of formation of rock pool generation I must have been longer than the one of rock pool generation II. Due to these findings we suggest that (i) the imbrication trains were arranged by only a single extreme wave event, and (ii) the blocks have not been shifted or tilted and thus remained in one and the same position since the time of their dislocation.

Along the coasts of Cape Bon, we thus encountered numerous wave emplaced blocks and boulders on top of the elevated terrace platforms lying up to 5 m a.s.l. and up to 50 m distant from the sea. In both study areas, two rock pool generations were observed on the dislocated blocks. In general, rock pool generation I appears to be considerable deeper and wider than rock pool generation II. Regarding the size of the rock pools, it can be noticed that, at both locations, rock pool generation II has only about ¼ of the size of rock pool generation I. These findings indicate that, at both sites, a comparable period of time was needed for the formation of rock pool generation II. We thus conclude that the displacement of the blocks occurred during the same event.

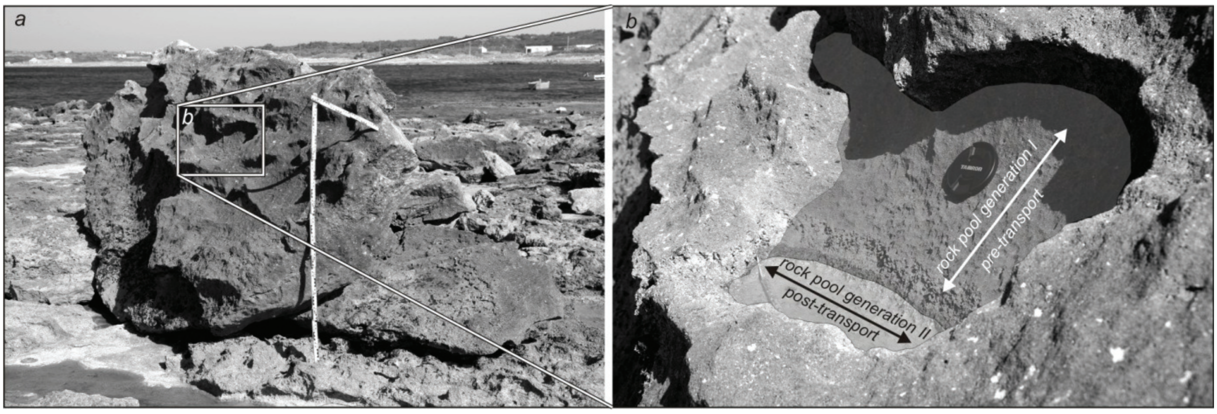

Figure 5: a) Imbricated block (~ 5.3 m³, ~ 11 t) with two rock pool generations. b) Rock pool generations I and II found on top of block shown in a).

As for the situation at El Haouaria site B shown in figure 5, due to the low lying terrace surface, it is assumed that the blocks are often flooded during usual winter storms. However, no more than two different rock pool generations were observed for all investigated blocks. These findings thus document a stable position of the blocks since their displacement and, in some cases, even since the related formation of imbrication trains. A recurrent transport, shifting or tilting of the investigated blocks during winter storms can thus be excluded.

During the last decades, several authors reported on cemented marine sediments of mid- to late Holocene age along the southern Tunisian coasts, found in elevations up to 1 m a.s.l. (for instance Jedoui et al. 1998, Morhange & Pirazzoli 2005). According to these authors, this marine sequence developed during a mid-Holocene sea level high stand. Vött et al. (2010) present findings of beachrock-type calcarenitic tsunamites from three different coastal areas in western Greece, partly associated to dislocated blocks. Within the context of the results presented in this paper, the deposition of fine-grained marine sediments above present mean sea level along the Tunisian coasts may possibly be explained by extreme wave events, rather than by a relative sea level high stand. However, further studies on these cemented marine deposits are needed to answer this question.

6 Conclusions

Block fields along rocky shorelines, consisting of rock-slabs, blocks and boulders, partly imbricated, are reported from all over the world. Their formation is linked to tsunami- or other extreme wave events, such as huge winter storm surges or hurricanes (for instance Goto et al. 2009, Kelletat & Schellmann 2001, Nott 2003a, Scheffers et al. 2005, Scicchitano et al. 2007, Switzer & Burston 2010, Williams & Hall 2007). However, it remains difficult to realize an appropriate determination of the event source, and the application of hydraulic equations dealing with the wave energy necessary for the wave induced transportation of blocks, which may be helpful to estimate the event source and intensity, still exhibits considerable uncertainties (see for instance Nott 2003a, 2003b, Switzer & Burston 2010).

This paper documents, for the first time, extreme wave emplaced blocks and boulders on the coast of northeastern Tunisia. Due to our findings, the following conclusions can be made considering the formation of the block fields:

1. At the north-western shore of Cap Bon peninsula, block dislocation and deposition occurred up to 5 m a.s.l. The emplaced blocks are assembled in fields on top of elevated marine terraces and have been transported up to 50 m inland.
2. Several blocks and slabs were overturned or tilted by wave activity. Numerous blocks exhibit two rock pool generations. At study site El Haouaria B, blocks show distinct imbrication and are arranged in imbrication trains of up to 6 tilted blocks.
3. The existence of two rock pool generations on top of numerous displaced blocks suggests one singular event responsible for displacement. Considering the dimensions of the rock pool generations, the period of time since dislocation of the blocks is considerably shorter than the period of time before their displacement when the blocks were lying in their original positions.
4. A stable position of the blocks before and since the time of movement can be assumed. Therefore annually recurring winter storm activities do not shift or move the blocks, although, due to the low lying cliff top platform, some of the blocks most likely are overflown by sea water during winter storms.
5. Due to these findings, a tsunami event rather than a storm has to be assumed for the deposition of the observed block fields. Also regarding the stable position of the blocks since their displacement, a storm-generated origin seems to be unlikely.

In general, the question of determining and localizing the event source and the ability to distinguish between tsunami and storm origin is important in palaeo-event research; further analytical studies are required to improve our understanding of the geomorphological and sedimentological fingerprints of the different kinds of extreme wave event deposits.

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Estimating tsunami hazards between Lefkada and Preveza, NW Greece, by means of computer modeling

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Abstract

The intention of this paper is to outline selected results of modeling hypothetic tsunami events for the present coastlines between Lefkada Island and the southernmost areas of Epiros, NW Greece. Modeling results are compared to geoscienctific field evidence of palaeotsunami landfall which have been found during the last years. Moreover, possible consequences of modeled extreme wave events on the shores of the Lefkada-Preveza coastal zone are discussed.

1 Introduction: Tsunami in the study area

Within the study area, several hints for former tsunami impacts were identified during previous studies (Vött et al. 2007, 2008, 2009a, May et al. 2007). Widespread wash-over fans strike at the spit between Lefkada Island and Akarnania. Numerous large blocks of up to 14 tons in weight, made up of beachrock, were obviously mobilized and dislocated, partly appearing in an imbricated assembly. In the nearby Lake Voulkaria, a layer of marine high-energy deposits was identified, sandwiched between units of limnic mud (Vött et al. 2009b). Furthermore, an evaluation of several tsunami catalogues revealed the occurrence of at least 46 tsunamis in the eastern Ionian Sea within the last 2400 years, eight of which were also observed around the study area (Soloviev et al. 2000, Vött et al. 2006).

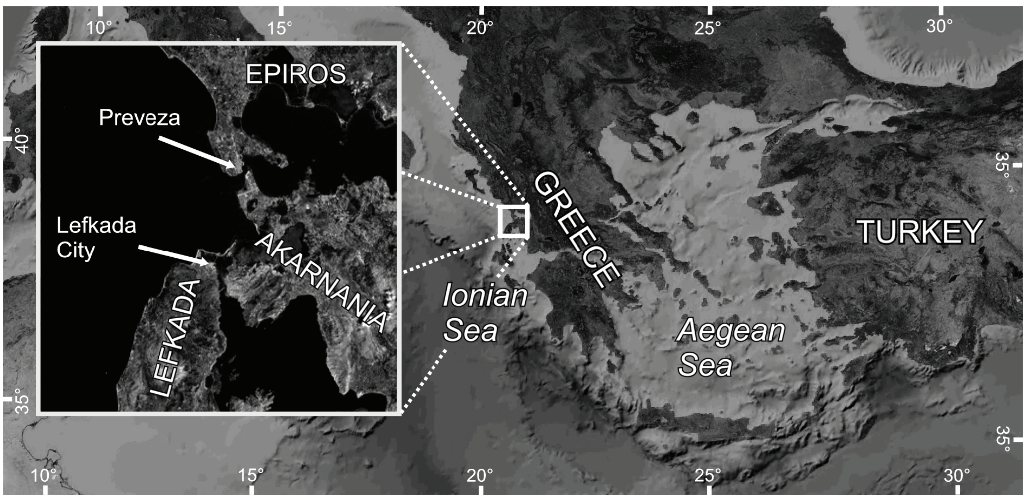

Figure 1: Situation of the study area showing the location of the towns of Lefkada City and Preveza (Source: NASA WorldWind 1.4, Landsat 7 ETM Satellite Image, modified)

2 The Model

AnuGA was developed by the Australian National University and Geoscience Australia in consequence of the tsunami-event of late December 2004 (Nielsen 2007). The focus for the simulation of tsunami affecting the coasts of the study area was on generating a sinusoidal wave train on the western boundary. The idea was to compute 15 scenarios on the base of three distinct directions of origin (WNW, W, WSW) and with five qualitative degrees of intensity, the latter corresponding to the maximum generation height of the waves at the western boundary of the studied area (2 m = slight, 5 m = moderate, 10 m = severe, 20 m = strong, 50 m = extreme; Floth 2008, Floth et al. 2009).

3 Potentially endangered objects

Within the study area, two major towns can be identified: Lefkada City, lying at the northwestern end of the Sound of Lefkada with a population of approx. 11.000 people, and Preveza, located at the entrance to the Ambrakian Gulf with approx. 20.000 inhabitants. Further villages are situated around the Sound of Lefkada, predominantly on the westernmost part of Akarnania, called Plaghia Peninsula. Those show a number of up to 1000 residents. The village Aghios Nikolaos, situated on the coast right between the cities of Lefkada and Preveza shows a population of approx. 500 people. Other objects of importance are the civil-/Nato-airport of Actio Headland with some 3000 flights per year just as the undersea tunnel connecting the Preveza Peninsula with Actio Headland (Floth 2008).

4 Case study Preveza

Like all other parts of the study area, the region of Preveza seems to be well protected from minor tsunami-events (figure 2). This is mostly due to the fact that the town is built on the shore of the inner Ambrakian Gulf and thus averted from the open sea. Our data show that only a severe or stronger event would cause damages or even fatalities in edge areas. Surprisingly, tsunamis from WSW do not show the strongest effects, although hitting the coast with an almost perpendicular direction. However, they trigger highest inundation values for the harbour area. Especially the north of Preveza seems to remain untouched by tsunami wave action, while the simulations show strongest impact to the SE quarters along the coast. (Floth et al. 2009).

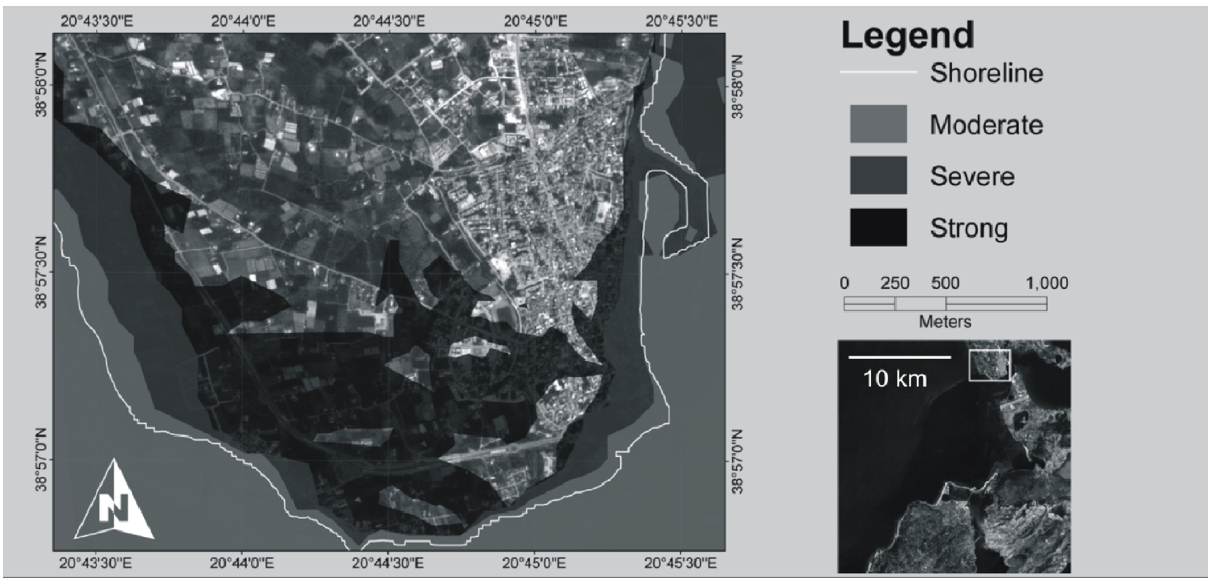

Figure 2: Potentially flooded areas of Preveza in case of tsunami from WNW (Image based on Ikonos and Landsat 7 ETM Satellite Images) for tsunami categories “moderate”, “severe” and “strong”.

Sedimentary evidence of tsunamigenic flooding was found for the entire coastal zone between the cities of Lefkada and Preveza, locally testifying to multiple tsunami landfall during the Holocene (May et al. 2007, Vött et al. 2009a). Geomorphological and geoarchaeological traces document the more or less complete inundation of Actio Headland directly opposite to city of Preveza (Vött et al. 2007). These results also imply tsunami-borne damages to modern Preveza and distal areas of the nearby Louros River delta. Geo-scientific studies to the immediate NNE of the city revealed at least one major tsunami impact during the past millennia. Compared to geo-scientific field data, our modeling results strongly corroborate the tsunami hazard for the Preveza-Lefkada coastal zone concerning both flow direction and spatial dimensions of extreme wave events (Floth et al. 2009).

5 Conclusion

Our modeling results clearly show that all locations in the study area are well secure from minor tsunami-events. This is explained by their sheltered position behind spits and beach ridges (Aghios Nikolaos, Lefkada City) or on the lee-side of a peninsula (Preveza) and by their sheer elevation (Plaghia villages) or distance from the sea (Airport facilities).

In case of major events, however, almost all inhabitated sites are endangered of peripheral to an entire flooding.

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Shallow water sediment structures in a tsunami-affected area (Pakarang Cape, Thailand)

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Abstract

The influence of tsunami on the seafloor is poorly understood. Detailed hydroacoustic surveys and sediment sampling campaigns were carried out in 2007 and 2008 offshore Pakarang Cape (Thailand) to catalogue the geomarine effects of the 2004 Indian Ocean tsunami. A major problem in determining tsunami influence in offshore deposits is the lack of pre-tsunami mappings. Starting in 15 m water depth, a system of sand ridges composed of coarse sand exists offshore Pakarang Cape. Elongated sediment transport structures on the NW-flanks of the sand ridges, slowly fading during the annual cycle, indicate the presence of a current oblique to the coastline. This current might coincide with the 2004 Indian Ocean Tsunami. A several cm-thick event layer found at the base of a sand ridge is composed of silty sediment, which could be related to the tsunami backwash or strong floods during the monsoon. These event deposits are covered by coarse sand. They might enter the geological record.

1 Introduction

Tsunamis are among the largest catastrophic events in the world. They are recorded since historical times and numerous investigations have been done about their origin, wave distribution and energy release along coastlines. On December 26th, 2004 an M 9.3 submarine earthquake was generated off the northwest coast of the Indonesian island Sumatra due to a complex tectonic activity between the Indo-Australian plate and the Sunda-Plate. This generated a giant tsunami which had an impact over many SE Asian coastlines, reaching to the East-coast of Africa (Lay et al. 2005).

Compared to the influence of the 2004 Indian Ocean Tsunami to onshore areas, the impact to the offshore environment is not well understood. Only few studies document tsunami effects offshore (e.g. Van den Bergh et al. (2003), Noda et al. (2007), Abrantes et al. (2008), Feldens et al. (2009), Paris et al. (2009), but influence and physical properties of the sediment-loaded tsunami backwash are largely unknown. Dawson & Stewart (2007) propose that offshore tsunami deposits are more common in the geological record than onshore deposits. A secure identification of offshore tsunami deposits would therefore be of great value for the recognition of paleotsunamis. A major, but common problem is the missing data about pre-tsunami conditions when working on recent tsunamigenic structures on continental shelf areas. It has to be carefully considered, if observed structures have existed before a tsunami hit the area, were created during the tsunami event or were altered by the tsunami impact. We present observations and first results of selected sedimentological and morphological features, recorded during cruises in the framework of the TUNWAT project (Tsunami deposits in near-shore- and coastal waters of Thailand; funded by the Human Research Foundation (DFG), Grant: SCHW/11-1) offshore the tsunami impacted coastline of Khao Lak, Phang Nga Province, Thailand.

2 Investigation area

The continental shelf of the Andaman Sea adjacent to the Malay Peninsula is narrow and slightly inclined; the 50 m isobaths is reached approximately 7 km offshore Phuket and about 30 km offshore Phang Nga Province located towards north. The coastal area is dominated by rocky cliffs altering with sandy lowlands and pocket beaches. From December to February the NE-monsoon dominates while the SW-monsoon is active from May to September (Khokiattiwong et al. 1991). The influence of storms and typhoons on this part of Thailand's coastline is low (Kumar et al. 2008, Jankaew et al. 2008). The tide is mixed semidiurnal, ranging between 1.1 m and 3.6 m (Thampanya et al. 2006).

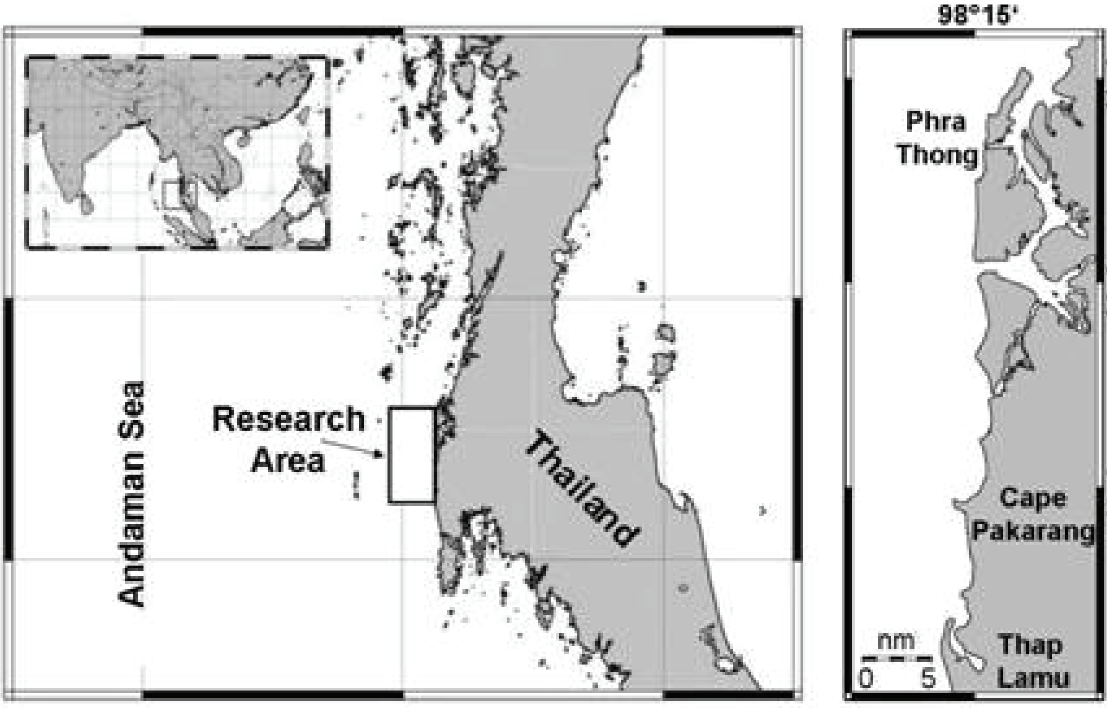

Figure 1: The research area is located in front of Khao Lak, Phang Nga province, Thailand.

The research area, between Thap Lamu and Phra Thong Island comprises of approximately 1.000 km² (figure 1). It was selected as it was hit severely by the 2004-Indian-Ocean-Tsunami (Bell et al. 2005, Tsuji et al. 2006). The wave run-up heights reached more than 15 m at Pakarang Cape (Siripong 2006) and up to 20 m at Phra Thong Island (Jankaew et al. 2008). At Pakarang Cape an area of about 12.500 m² was eroded by the tsunami (Synolakis & Kong 2006) and hundreds of reef rocks could be observed on the intertidal area after the event (Goto et al. 2007). For the investigation area the fluvial discharge is small, which increases the preservation potential of tsunamigenic features on the seafloor.

3 Methods

Two cruises have been carried out; a first one in Nov./Dec. 2007 with RV CHAKRATONG TONGYAI and a second with RV BOONLERT PASOOK in Nov./Dec. 2008. Both ships are operated by the Phuket Marine Biological Center (PMBC). Different side scan sonar systems were applied; a Klein 595 with digital data acquisition in 2007 and a Benthos 1624 digital side scan sonar system in 2008. Side scan sonar systems measure acoustical properties of the seafloor, which mainly depend on grain size distribution, seafloor roughness and the angle of the seafloor slope (Lurton 2002). Features protruding from the seafloor, e.g. boulders, but as well large ripples are easily recognized in side scan sonar images due to the acoustic shadow formed behind them. In this study, fine grained deposits appear in lighter colours, while coarse grained material is represented by darker colours. For ground-truthing of the side-scan sonar data grab samples were taken on selected positions.

A shallow water multibeam echosounder (ELAC SeaBeam 1185) was used to acquire bathymetric data. Multibeam echo sounders provide many simultaneous depth measurements over a narrow section of the seafloor. The SeaBeam 1185 system is working with a frequency of 180 kHz, which is suitable for a high resolution mapping in shallow waters. The acoustic beam of the system has a fan width of 153°, giving a theoretical swath width of 8.3 times the water depths. Calibration for tidal fluctuations was done by using the software WX-Tide32 (www.wxtide32.com), as no direct water level measurements are available in or close to the research area.

Shallow water high resolution reflections seismics (C-Boom System), in combination with the recovery of short gravity cores, was used to obtain information about the uppermost layers of the seafloor. X-radiography images of thin slabs taken from the core surface were prepared to detect sedimentary structures that cannot be seen otherwise (Jackson et al. 1996). The database of the cruises carried out in 2007 and 2008 include about 1500 nautical miles (nm) of hydroacoustic profiles, 112 Surface sediment samples and 42 short sediment cores.

4 Results

Side scan sonar images offshore Khao Lak show several different sedimentary structures in depths from 7 to 30 m (figure 2). In water depths between 7 and 15 m, extended patches of fine grained sediments are deposited. Connected to these patches is a small scale channel system starting at 10 m water depth. Here we focus on structures appearing at 15 m water-depth. Elongated SW-NE striking morphological ridges are visible in the hydroacoustic data (Figure 2). These structures are common along the whole coastline between Thap Lamu and Pakarang Cape, and up to Phra Thong Island towards north. The continuation of the ridges into deeper waters is yet unknown. The ridges, with a steep NW- and a gently dipping SE flank reach heights of about 2 m, while their length exceeds several kilometres. The distance between two ridge crests varies from several hundred meters to several kilometres. In front of the steep north-eastern side of these ridges, small channels with incision depths of approximately 1 m are sometimes cut into the seafloor. According to seismic data, the ridges are not connected to subsurface structures, but are clearly separated from the sedimentological structures below by an unconformity (figure 5).

For one ridge, a side scan sonar mosaic was draped over the bathymetry (figure 3) to correlate sedimentology and morphology. Grab samples taken around the ridge (figure 3) reveal the presence of different sediment properties in a small area: Generally, the south-western, landward flank of the ridge and the surface of the seafloor surrounding the ridge are composed of coarse sand. Bright elongated sediment structures are deposited on the seaward flank of the ridge and are composed of well sorted fine to medium sand. The patches are separated from each other by thin bands of coarser sediment. From their appearance in the side scan sonar image, the structures resemble large-scale flaser beddings. However, as the genesis of the observed features is different to flaser beddings, which are formed due to tidal activities, the term will not be used.

The sediment patches are commonly observed on the seaward, northern flank of sand ridges along the coastline. Rarely, they are found on the flat seafloor. Boulders are sometimes exposed in close vicinity (figure 3, figure 4). At the base of the ridge flank shown in figure 3, grab samples contain muddy material just a few centimetres below the seafloor.

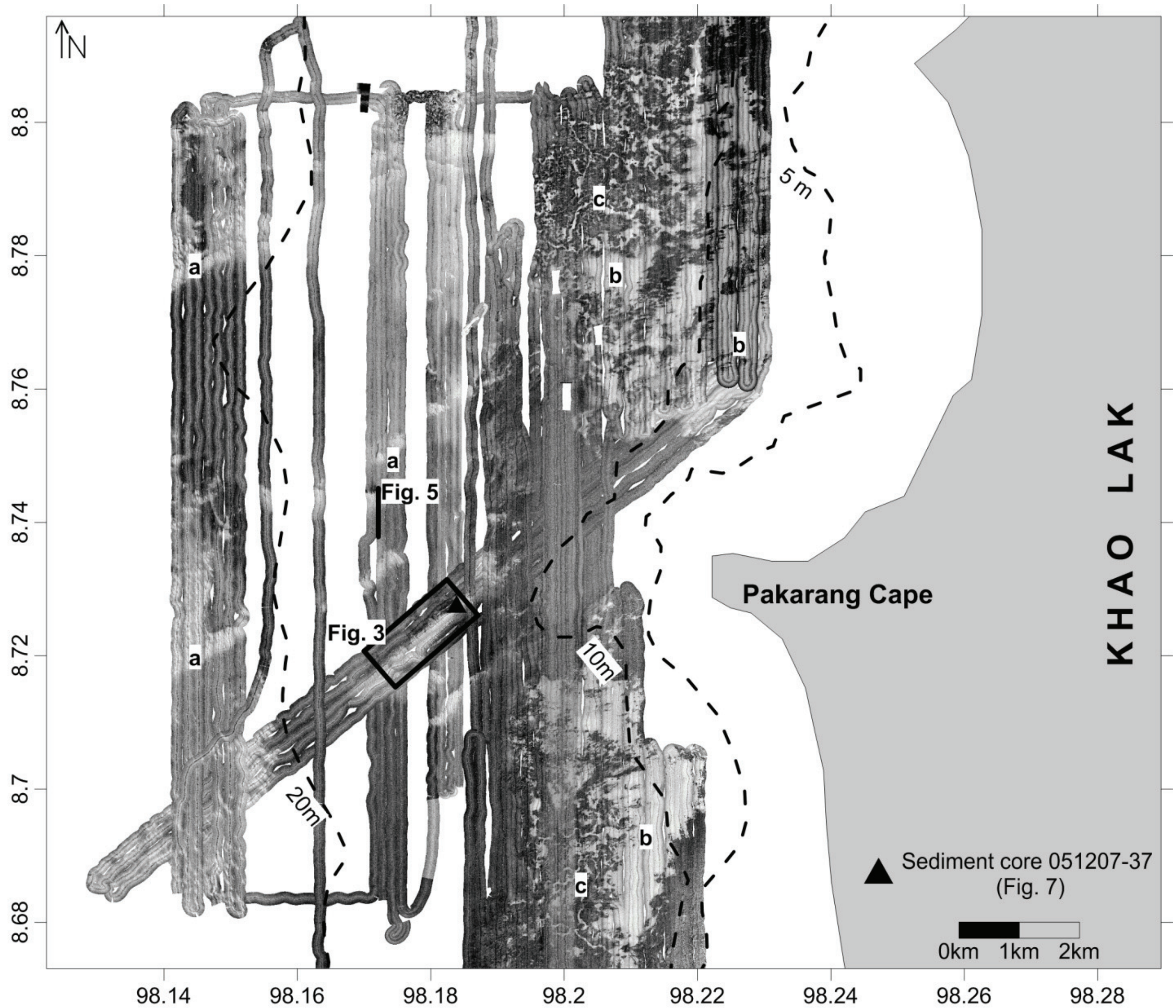

Figure 2: Side scan sonar data around Pakarang Cape. Sampling stations and the positions of fig. 3 and fig. 4 are indicated. Sediment core 051207-37 is shown in fig. 7. This article is focusing on SW-NE striking sediment structures visible as lighter-coloured bands in the side-scan sonar image (a). Closer to the coastline, extended areas of fine grained sediment (b) and a small scale channels (c) are visible.

Core 051207-37 (figure 7) is divided in four sedimentary units. Unit 1 (0-8 cm core depth) is mainly composed of brown sand, including some shell fragments. Between 8 and 11 cm, a layer composed of silt, containing no sand, is apparent (unit 2). The lower boundary of unit 2 is sharp, while its upper boundary is not well defined. Between app. 11 to 12 cm core depth, unit 3A is composed of well sorted sand. Below, unit 3B (12 to 20 cm core depth) contains higher amounts of clay and silt. Various shell fragments are abundant in unit 3B. From 20 cm to the base of the core, unit 4 is composed of sandy silt, and includes some shell fragments. Partly, layers containing higher amounts of sediments in the sand fraction are recognized in the x-ray images.

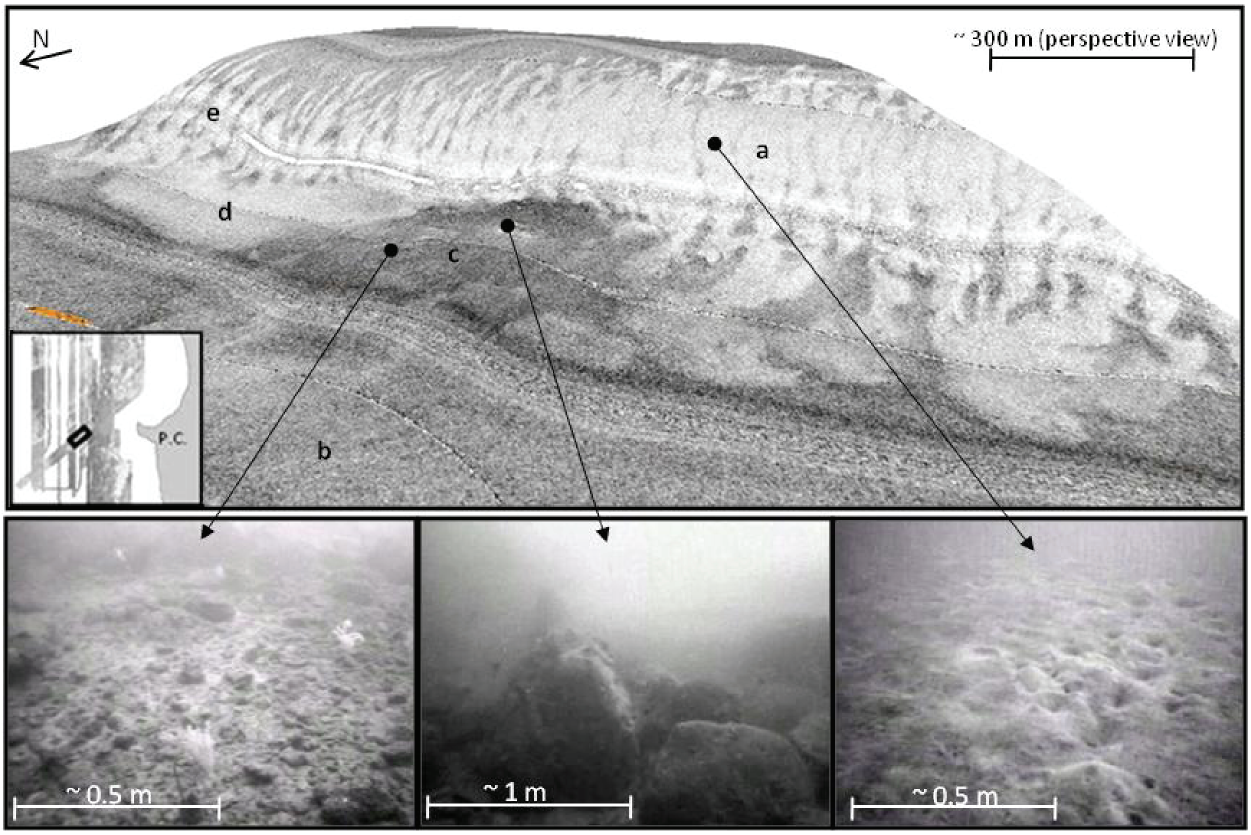

Figure 3: Side scan sonar draped over the bathymetric dataset. For position see figure 2. The length of the ridge is approx. 1500 m (perspective view). a) elongated sediment patches, consisting of fine to medium sand b) coarse sand c) carbonatic gravel and boulders (notice video image) d) sand at the surface, muddy material below e) position of short core (051207-37, fig. 7), composed of sandy material on top and a fine grained layer at 10 cm depth.

5 Discussion

Sand ridges are formed due to regular hydrodynamic processes, e.g. tidal currents in inlets, ocean currents at the shelf margin or during storms (Ernstsen et al. 2006, Flemming 1978, Holland & Elmore 2008), although moribund ridges as remnants from times with a lower sea level are known (Dyer & Huntley 1999). Goff et al. (1999) report that sand ridges on the northeast US Atlantic shelf are asymmetric, having steeper seaward flanks. Holland & Elmore (2008) report that grain sizes across sand ridges typically range from coarse to fine sand. The typical height of storm generated sand ridges is given with 3 to 12 m (van de Meene & van Rijn 2000). Commonly, sand ridges are oblique to the coastline, with the acute angle opening into the prevailing flow direction (Swift et al. 1978, Holland & Elmoore 2008). Most of these features are found in the observed ridge system. The strike direction of the ridges indicates an approximately south-north directed current which was responsible for their formation. This was not the main current direction observed during the tsunami (images of the IKONOS satellite, Goto et al. 2007). Therefore, the ridge system existed prior to the tsunami, although the definite process responsible for its formation has not yet been identified.

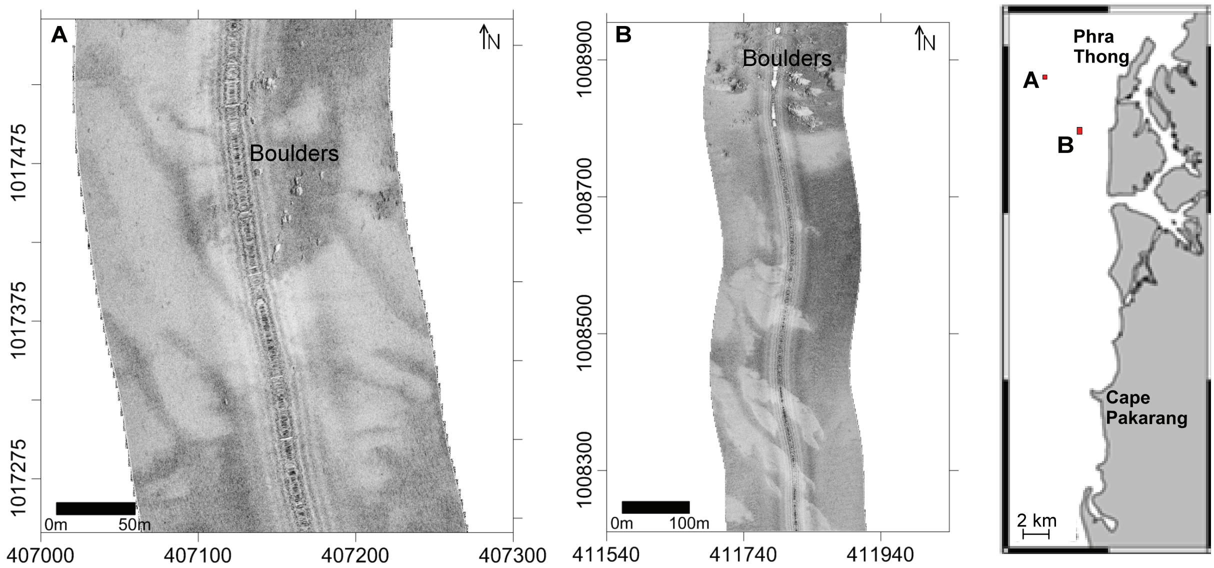

Figure 4: Elongated sedimentary structures offshore Phra Thong. Frequently, boulders are exposed in close vicinity to these structures. Water depth at A: 27 m. Water depth at B: 21 m.

Notable are elongated sediment patches commonly found on the northern flanks of the sand ridges. While finer sediment on the steeper slope of asymmetrical sand ridges is common, in front of storm dominated coasts (Holland & Elmore 2008). Here fine sediments are not visible over the entire length of the flank, but instead they are deposited in small patches separated by coarser sediment. Similar bedforms on the continental shelf offshore Brazil have been formed due to storm events (Moscon & Bastos 2010). The comparison of side scan sonar images from 2007 and 2008 (figure 6) indicates that the general shape of the patches is preserved, but smaller parts begin to fade during one annual cycle, indicating an out-of-equilibrium event based deposition and ongoing reworking of the sediment. Additionally, the existence of identical sediment structures on the flat seafloor further indicates that their formation is not connected with the formation of the sand ridges. Therefore these elongated patches of fine grained sediment have to be interpreted as bedforms created by currents along the north-east/south-west direction. The general stability of these bedforms, combined with the slow fading of delicate structures suggests that no frequently occurring event is responsible for their formation. Since strong storms are rare in the area, and none occurred between the 2004 tsunami and our measurements (based on tracks published by the Regional Specialised Meteorological Centre – Tropical Cyclones (RMSC), New Delhi), it is reasonable to assume that the observed sediment pattern was influenced by the 2004 tsunami, either during the run-up or the backwash.

It is assumed that the muddy material frequently found in grab samples at the base of the sand ridge corresponds to unit 2 in core 051207-37. Therefore, such material is present over a larger area at the base of the sand ridge, and not only locally in one core. Considering the silt separating two units of coarse sand, its deposition likely corresponds to a single event. Similar deposits in cores offshore the Eel River have been described by Crocket & Nittrouer (2004) as flood deposits, which could be generated in the research area by strong monsoon events. But also a tsunami backwash transports large amounts of fine-grained material offshore (Shi & Smith 2003). The process responsible for the formation cannot be determined with certainty. However, a deposition of this material during the monsoon is unlikely, as more regularly occurring structures would be expected. Regardless of the origin of their formation, these event deposits were preserved in the comparably sheltered environments at the base of the sand ridges. They are covered by coarse sand (unit 1), typical for this area of the shelf, indicating some sediment dynamics in the area. This agrees to the change of sedimentological boundaries observed in side scan sonar mosaics between 2007 and 2008 (figure 6). A potential deposition of the sediments beneath unit 2 during an event, indicated for instance by the marked change in sand content of unit 3A compared to unit 3B, or the abundance of shell fragments in unit 3B, is uncertain. Further analysis is needed to identify the origin and the spatial extension of these potential tsunami deposits, especially closer towards the shoreline.

Interesting are frequent observations of boulders close to the elongated patches deposited at the seaward flank of the sand ridges. Many of these boulders show no connection to structures in the subsurface, and must have been transported to their current position. Potentially, this could have happened during the tsunami, either during the run-up from source areas in deeper waters, or during the backwash (compare Paris et al. 2009)

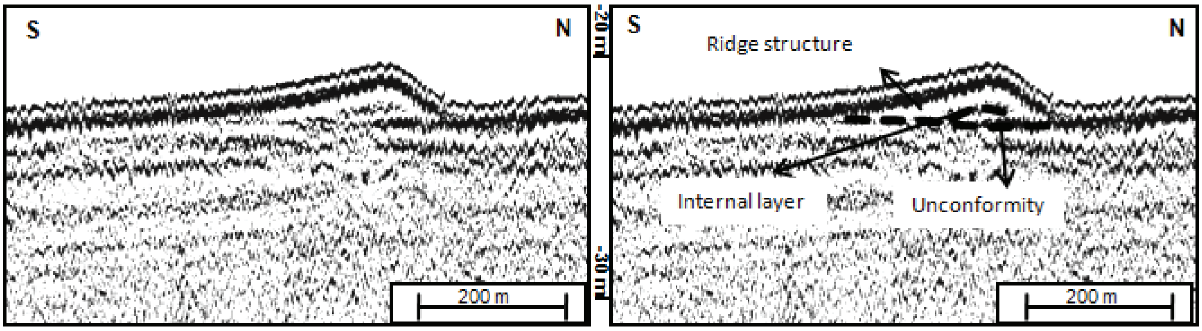

Figure 5: Seismic profile crossing a sand ridge (for position see Figure 2). Clearly visible is the asymmetric form of the ridge which is indicating a transport direction from South to North. Additionally, the ridge is separated from the older surface below by an unconformity.

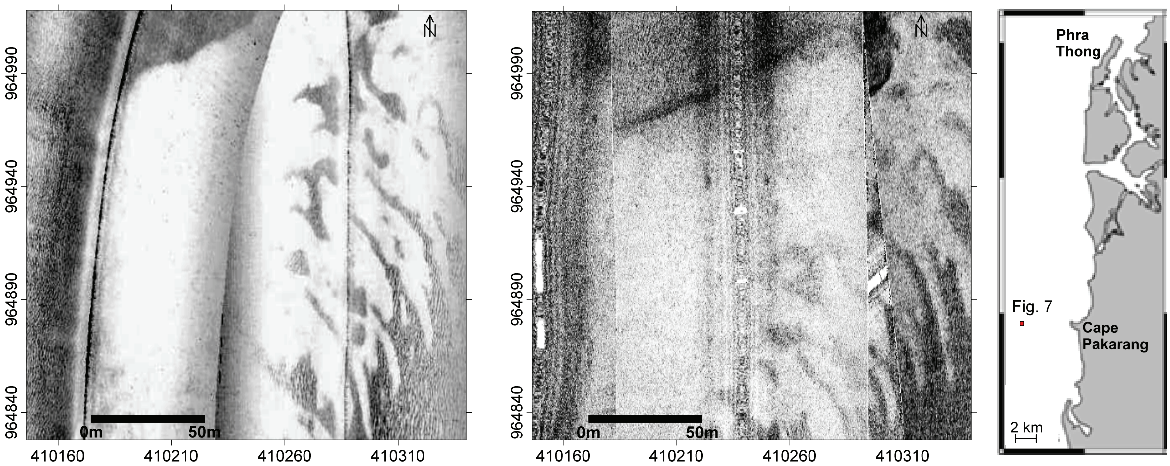

Figure 6: Two side-scan sonar images showing a comparison of a detail of the sand ridge shown in figure 3. The left image was recorded in 2007, the right image in 2008. Small differences are visible. The contours of the elongated sedimentary structures are more pronounced in 2007.

During the tsunami run-up, many boulders were transported towards the intertidal area on Pakarang Cape (Goto et al. 2007). The backwash at Pakarang Cape was modelled by Goto et al. (2007). The authors show that the current speed of the backwash was in the order of 3m/s. This is strong enough to move the observed boulders (Goto et al. 2007, Imamura et al. 2008), which have a diameter of less than 1 meter according to underwater images. Taking into account a channelized backwash (Le Roux & Vargas 2005, Fagherazzi & Du 2007), it is possible that in some areas the current speed was strong enough to transport boulders downslope from the reef platform fringing Pakarang Cape back towards the sea. However, this cannot explain the presence of boulders found several kilometers offshore (Fig. 4).

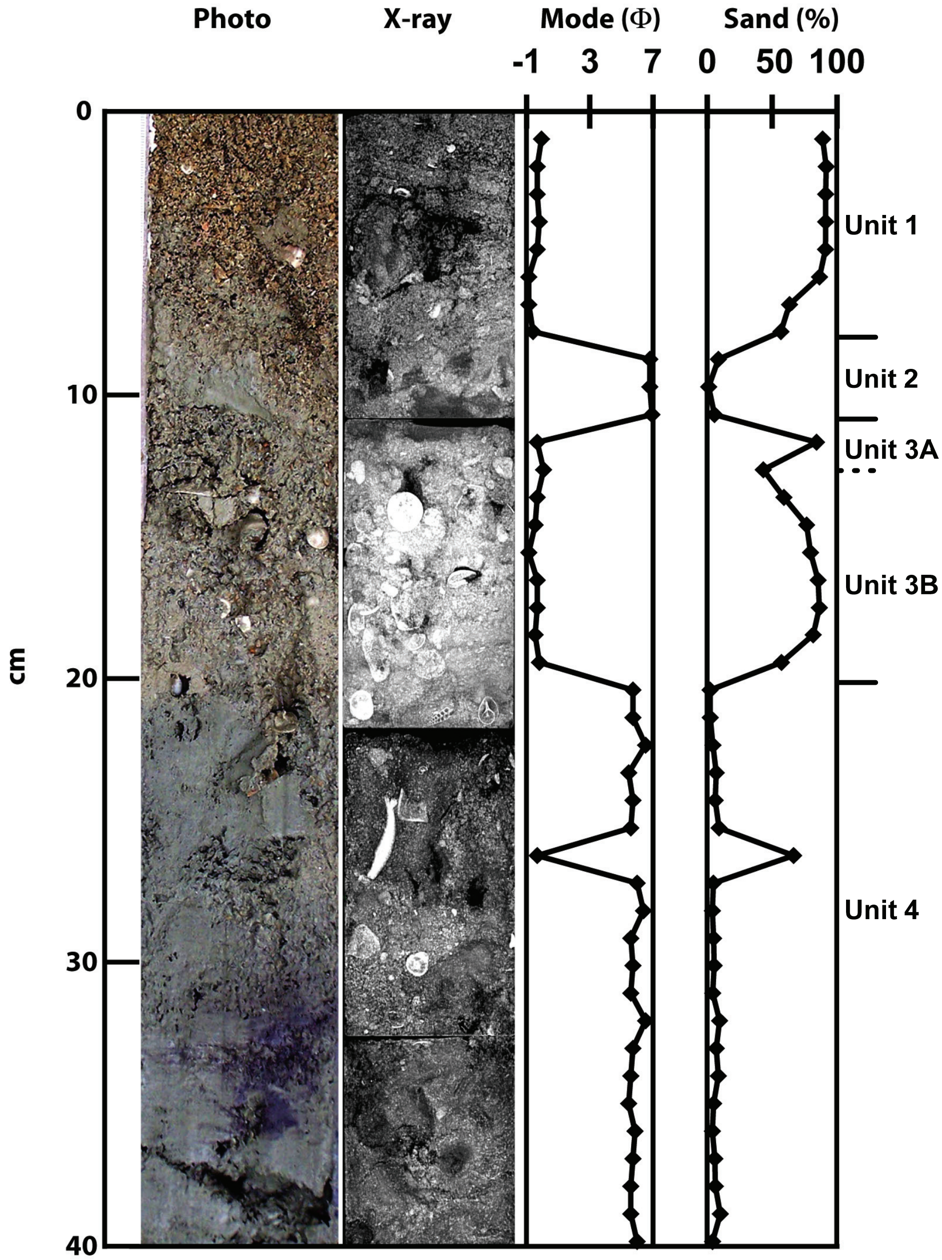

Figure 7: Properties of core 051207-37. From left to right, photo, x-ray image, first mode in phi-degrees, sand content and sedimentary units are presented. For position, refer to Fig.2.

6 Conclusion

Detailed hydroacoustic surveys have been carried out offshore Phang Nga province (Thailand) in 2007 and 2008 and sediment samples have been collected. Starting at 15 m water depth, a system of sand ridges, formed by coarse sand, was discovered. The sand ridges existed prior to the 2004 Indian Ocean Tsunami. Elongated sediment patches on the seaward flank of the sand ridges consist of fine to medium sand, and indicate a current oblique to the coastline. They fade slowly during the annual cycle, and were potentially reworked during the 2004 Indian Ocean Tsunami. An event layer found at the base of a sand ridge is composed of silty sediment, which could be related to the tsunami backwash or floods during the monsoon. These event deposits are covered by coarse sand, and might enter the geological record.

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Use of high resolution geodata for inundation modelling as part of a tsunami risk assessment in Thailand

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Abstract

The mega-tsunami of Dec. 26, 2004 strongly impacted the Andaman Sea coast of Thailand and devastated settlements, tourism resorts and coastal ecosystems. In addition to the tragic loss of many lives, the destruction or damage of life-supporting infrastructure, such as buildings, roads, or water & power supply caused high economic losses in the region.

To mitigate future tsunami impacts there is a need to assess tsunami risks in vulnerable coastal areas at the Andaman Sea coast and to develop adequate risk management strategies.

In the bilateral German-Thai research project TRAIT mechanisms, impacts and long term consequences of the 2004 tsunami are investigated in order to conduct a local risk assessment and to design a comprehensive risk analysis tool. Methods are developed for detailed hazard analysis as well as for vulnerability analysis of the socio-economic and the ecological system combining field investigations, household and company surveys, remote sensing techniques and numerical modelling. This paper deals with the hazard analysis as one part of a risk assessment.

Hazard analysis on a local scale requires detailed knowledge of the topography and the inundation flow dynamics. Thus a high resolution digital elevation model was generated based on remote sensing data. Moreover, to include the damping effect of vegetation on the tsunami waves, a field campaign was conducted to derive roughness parameters for different land use classes in the region. Based on an object-oriented land-use classification these values were transferred into a site specific roughness map. Including a deep sea and near shore bathymetry, mult-scale resolution topographic data, roughness maps and information on structural patterns like buildings, a numerical tsunami inundation simulation could be performed. A comparison of the first results shows that the resolution of the geo basis data strongly influences the accuracy of inundation simulations and the applicability of inundation maps for risk assessment and management.

1 Background and objectives

The Indian Ocean Tsunami on 26.12.2004 caused one of the most devastating natural disasters in history. Triggered by a Mw ~9.1-9.3 megathrust earthquake (Lay et al. 2006, Stein & Okal 2005) in the Sumatra subduction zone the tsunami killed about 230.000 people around the Indian Ocean and destroyed buildings, infrastructure and coastal ecosystems. Besides Banda Aceh in Indonesia the Andaman Sea coast of Thailand was the next most heavily impacted area. The tsunami most severely affected the provinces of Phang Nga and Phuket 1:45-2h after the earthquake with run-ups of up to 15 m observed near Khao Lak (Tsuji et al. 2006).

However not all regions suffered the same degree of flood impacts, some localities were hit harder than others. Thus, in order to determine the spatial distribution of risk and to manage present and future tsunami risk, there is a need to assess the tsunami hazard and vulnerability in flood prone areas at the Andaman Sea coast.

To study the complex interactions of tsunami related impacts on and offshore in the Andaman Sea Region the German-Thai Research cooperation TRIAS (Tracing Tsunami Impacts onshore and offshore in the Andaman Sea Region) was initiated, funded by the German Research Foundation

(DFG) and the National Research Council of Thailand (NRCT). This research cooperation focuses on tsunami-related issues in order to gain a better understanding of the physical impacts of tsunamis on the seafloor and on land, resulting in sediment mobility and destruction, and to develop methods and tools for tsunami risk assessment and management. Six German-Thai research projects are part of the TRIAS cooperation addressing the whole transection of the tsunami from the deep sea, across the shelf to the coast and the coastal hinterland.

The work presented here is about one work package in one of the six projects, TRAIT (Tsunami Risks, Vulnerability and Resilience in the Phang Nga and Phuket provinces, Thailand). In TRAIT a detailed, local risk assessment is conducted for the Provinces Phang Nga and Phuket.

The overall objectives of TRAIT are:

1. Providing a quantitative approach for risk assessment including the analysis of hazard mechanisms as well as an assessment of social, economic and ecological vulnerability
2. Investigating the potentials of earth observation for vulnerability assessment, resilience monitoring and as an inherent part of a tsunami risk analysis tool
3. Developing a comprehensive risk analysis tool that assists risk mitigation and management

This paper highlights the factors and data requirements for inundation modelling as part of the hazard analysis. As TRAIT is an ongoing project and work is still in progress only preliminary outcomes are presented.

2 Study areas

The area of investigation reaches from approximately 8°52’10’’N to 7°45’30”N and covers the coastal lowlands of the provinces Phang Nga and Phuket at the Adaman Sea coast in southern Thailand.

Within this region four different types of study areas have been selected in order to cover the different aspects of risk (figure 1).

Ban Nam Khem is a small community in the North of the Phang Nga province dominated by fishery and agriculture. The community was severely affected by the 2004 tsunami due to the very flat and exposed location and the poor quality of buildings. More than 1000 out of 6000 inhabitants lost their lives by the tsunami and infrastructure as well as fishing facilities were destroyed (Paphavasit et al. 2009).

Further to the south *Khao Lak* represents a young booming tourism resort which was also strongly impacted in 2004 due to two reasons: a) the largest tsunami wave heights were measured in this area and b) many tourists were on the beaches or in hotels close to the beaches as the tsunami occurred during high season. Thousands lost their lives, among them many foreign tourists. Dozens of hotels and resorts were destroyed or damaged.

Thai Muang national park located on a spit around a tidal inlet hosts large areas of intact coastal ecosystems like mangroves or beach forests. Hence this site represents a study area where the impacts of the tsunami on vegetation and coastal habitats can be investigated.

Patong Beach on Phuket island represents the most populated and urbanized community in the area of investigation. Due to the high density of large buildings the tsunami mainly damaged the first road parallel to the coast and the buildings at the beach front. Nevertheless, the water was channelled in the streets, perpendicular to the coast and spread further into the hinterland. Due to the dense infrastructure of shops, hotels, and restaurants, the economic damage was estimated to be about 217 million €.

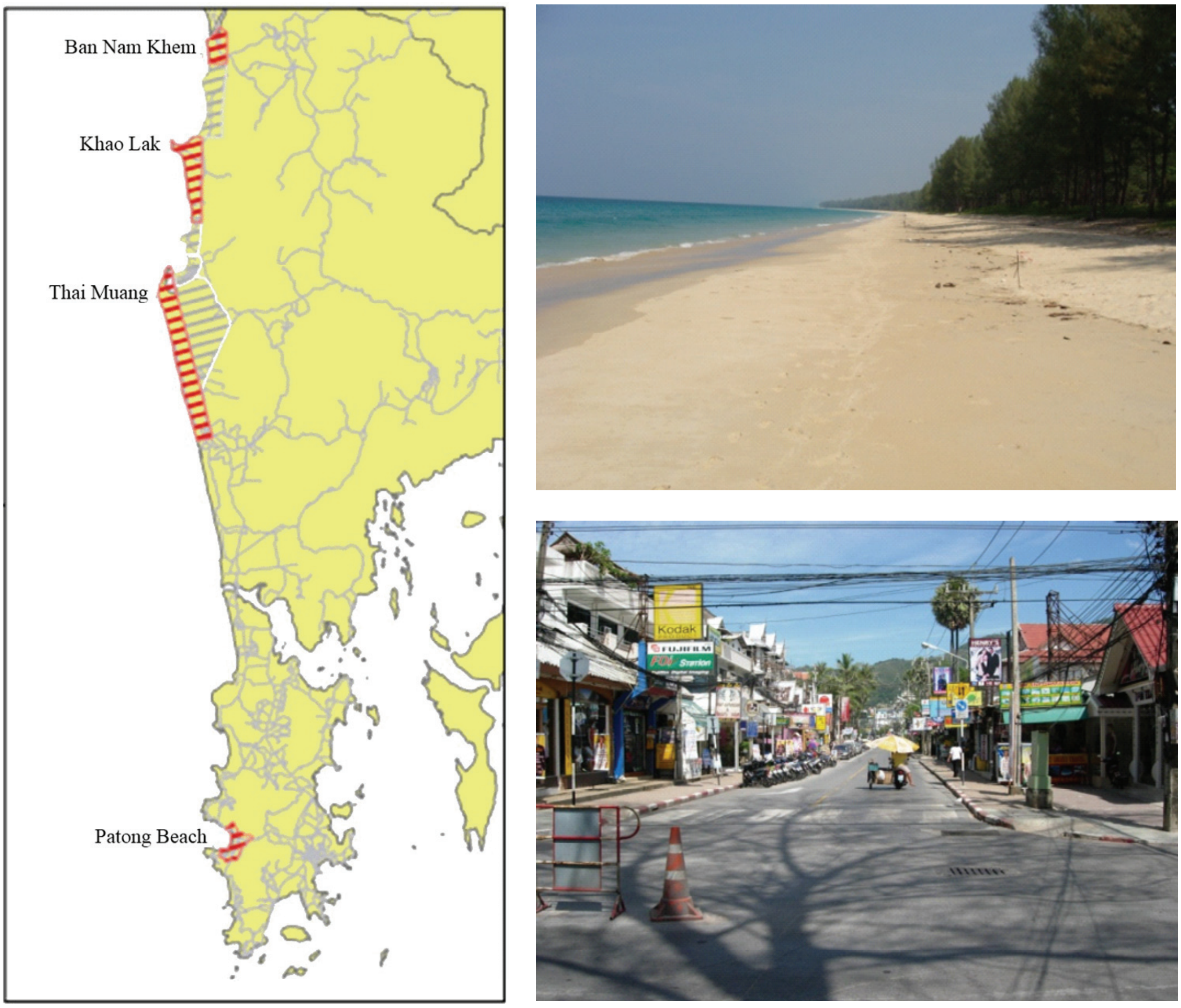

Figure 1: The study areas Ban Nam Khem, Khao Lak, Thai Muang national park (upper right) and Patong Beach (lower right) at the Andaman Sea coast of Thailand

3 Methodology

Risk assessment and the development of a risk analysis tool carried out in TRAIT are based on a common concept of risk, hazard and vulnerability widely applied in natural hazards research (amongst others Wisner et al. 2004, UNDP 2004), flood risk management (Schanze et al. 2006), and environmental science (Turner et al. 2003).

Tsunami hazard analysis in this study includes the geophysical sources of an earthquake, the modelling of the generation and propagation of waves to the coast and its landward inundation characteristics including small scale landforms like coastal forests, buildings, rivers, tidal inlets and ponds.

Vulnerability analysis is conducted by assessing the exposure of the elements at risk of the social, economic and ecological coastal system, their susceptibility to be harmed by the tsunami and their resilience, i.e. their ability to cope and recover.

This means that the tsunami impacts are a function of various risk parameters which vary with time and space.

In TRAIT an integrated approach is applied including extensive field investigations, numerical modelling, household and company surveys as well as GIS and earth observation. Special focus is given to the application of remote sensing techniques, not only for quick assessment of damages caused by the tsunami but also for monitoring processes. A time-series of multi-scale remote sensing data (i.e. SRTM, ASTER, IKONOS, MFC) is used to derive digital surface and elevation models, to assess damages to buildings, to detect beach erosion or uprooting of vegetation, and to gain information on how the recovery process has proceeded until today (e.g. recovery of coastal forests, restoration of tidal inlets).

As the Asian Tsunami of 2004 and its impacts are documented very well, a detailed analysis of mechanisms and consequences of this event is conducted. From this detailed analysis key parameters of tsunami risk will be derived to allow for comprehensive, quantitative risk assessment. The combination of the numerical modelling and a GIS database with quantitative vulnerability criteria provides a comprehensive GIS-based tsunami risk analysis tool.

Hazard analysis

The tsunami hazard analysis, as part of the overall risk assessment, comprises modelling of the tsunami generation, propagation and inundation including the interaction of the tsunami with vegetation or buildings (figure 2). The analysis is performed for the 2004 event as well as for different scenarios for the study areas Patong Beach, Khao Lak, Thai Muang national park and Ban Nam Khem. Special consideration is given to the inundation simulation as inundation depth, velocity, and expansion are crucial for risk analysis, risk management and evacuation planning.

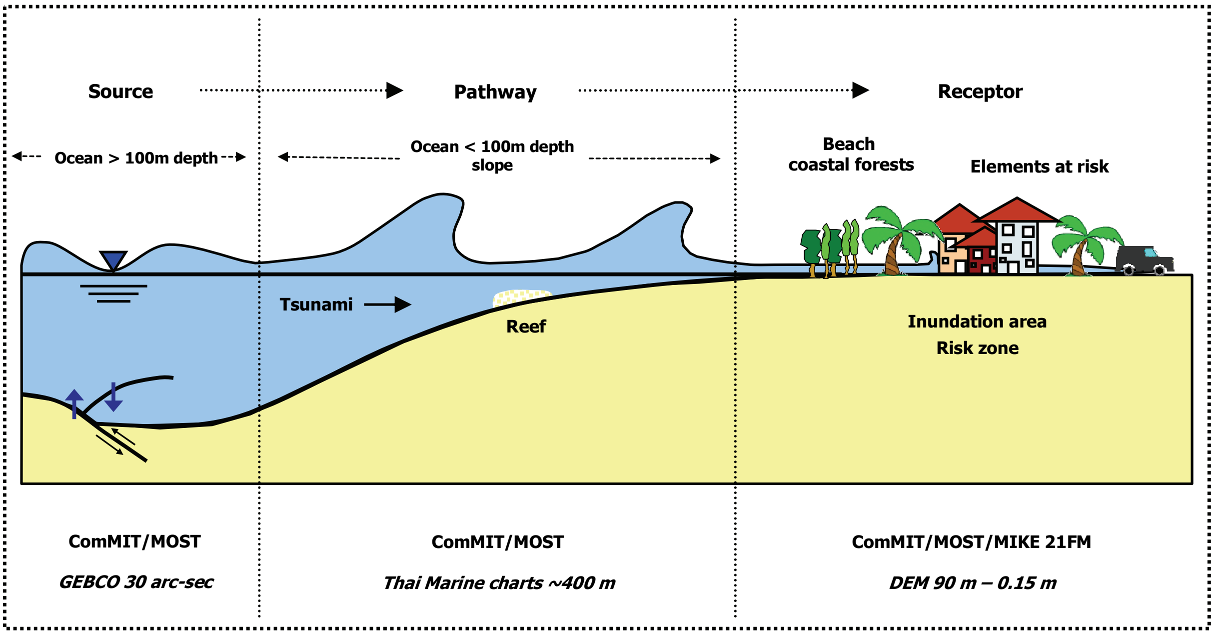

Figure 2: Tsunami risk model

As the quality of the model results strongly depends on the detail and the resolution of the input data, we check how different data sets on different scales influence the results of the tsunami modelling. The key data sets are bathymetry, topography and a roughness maps, representing bottom friction caused by land cover.

Land use classification

A detailed land use map is an important basis for hazard and vulnerability assessment as it provides information on the spatial characteristics of land cover in the area of investigation. The land use information was derived from high-resolution satellite images (IKONOS) with a horizontal resolution of 4 m in the multispectral channels. With a rule-based object-oriented classification scheme (Definiens Developer 7.0 software) land use information could be extracted very accurately from the multispectral image.

The preliminary step of the object oriented classification is to segment a raster image into image objects or segments which fulfil a user defined homogeneity criteria (Blaschke & Strobl 2001). The multi-resolution segmentation, which is a patented segmentation algorithm of Definiens AG, was realized by using two hierarchical segment levels. Subsequently the image objects could be assigned to a respective land use class by analyzing the spectral, shape-specific, textural and neighbourhood-specific characteristics of the segments. For this, a complex system of rules (rule set) was created which incorporates both crisp and fuzzy rule definitions. Finally the quality and robustness of the developed rule set was evaluated by transferring the rule set to a different IKONOS scene.

The final classification map for the coastal zone between Ban Nam Khem and Thai Muang city includes 42 different land use classes which are organized in the following nine super-classes:

- Agriculture and Aquaculture: includes plantations, orchards and aquaculture
- Barren land: sandy beaches, sand mining, mudflats etc.
- Buildings and infrastructure
- Grassland and Herbaceous vegetation: dense and sparse grassland with scattered trees
- Scrubland: predominance of scrubs
- Semi-open landscapes: mixture of woodland, scrubland and grassland, comparable to savannahs
- Water: water surfaces like ponds, rivers, bays
- Woodland: different types of natural forests, e.g. Mangroves, Casuarina forest, Primary Rain forest
- Other: clouds, shadows and no data values.

In connection with the hazard analysis, the land use map contributed to generating digital elevation models and to provide the spatial distribution of roughness values.

Hydrological roughness

Coastal forests like mangroves or beach forests are assumed to have a damping effect on the tsunami wave (Dahdouh-Guebas et al. 2005, Wolanski 2007, Danielsen et al. 2005). To prove this for the study areas, IKONOS data from 2003 and 2005 were compared with change detection techniques to identify areas with damaged vegetation and to gain rough information on the protective function of vegetation during the 2004 tsunami. To include the effect of wave attenuation in the inundation simulation a method was developed to calculate the appropriate Mannings roughness coefficients for each land use class in the study areas.

To use this aforementioned method seven vegetation classes, defined as coastal habitats, were investigated in the field, which included three types of plantations with a large extent in the study areas: coconut plantations, oil palm plantations and rubber plantations as well as natural habitats: mangrove forest, beach forest (outer beach forest fringing the sandy beach and inner beach forest adjacent to the outer area), and a temporary swamp forest (Melaleuca area). For these habitats tree parameters like the “diameter at breast height” or “vegetation density” were measured and transferred into Manning values according to Petryk & Bosmajian (1975).

For the remaining habitats in the study areas Manning values were estimated according to the “Guide for selecting Manning’s roughness coefficients for natural channels and flood plains” by Arcement and Schneider (1989) to avoid gaps in the final maps.

Additionally an estimation of the influence of the drag coefficient was performed following the approach of Tanaka et al. (2009). Eventually a roughness map with Manning values was generated and implemented in the modelling (figure 3).

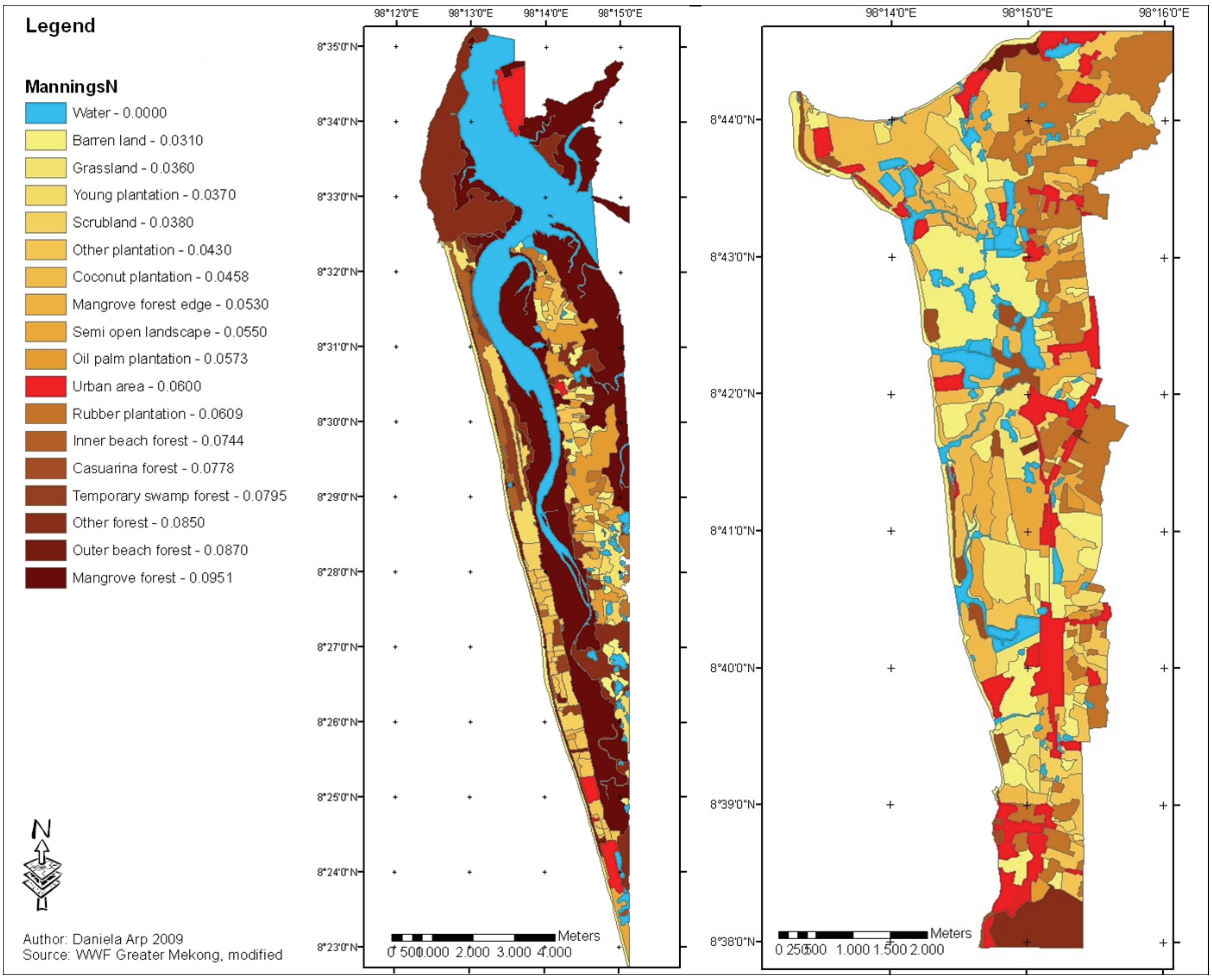

Figure 3: Land use classification with Manning values for each land use class, left: Thai Muang, right: Khao Lak

Generation of digital elevation models

Two different elevation models were generated, processed, and applied to investigate the effect of the resolution of the topography on inundation simulations: (1) Data from the Shuttle Radar Topography Mission (SRTM) with 90 m resolution and (2) a 0.15 m surface model derived from an airborne flight campaign conducted in the study areas with the multi- functional camera MFC-3, which contains an array of three RGB-Charge-Coupled-Device (CCD)-lines-modules (Börner et al. 2008).

The SRTM is a digital surface model, including vegetation and buildings in its surface description. Hence the height information in each raster cell is a function of land surface characteristics. Thus in forest-covered areas SRTM C-band interferometric SAR measures heights within the tree canopy generating height differences of up to 20 m in the study areas due to patches of tropical forest. As this caused problems in using SRTM data for inundation modelling the surface model had to be corrected to a real ground model. Information on the vegetation structure was measured in the field to gain surface heights of typical land use classes. The mean height values of every land use class and the ground coverage were then added to the land use classification which was converted into a raster, resampled and eventually subtracted from the SRTM data using GIS techniques. Finally a filter was applied to smooth the results, and rivers, ponds and tidal inlets were corrected with additional vector files. The results were validated with GPS elevation measurements gained in the field. Although this methodology generated good results in homogenous land use classes, some restrictions became obvious: The vegetation heights to be subtracted as well as the SRTM raster cell information represent mean values leading to inaccuracies. Moreover the land use classification is based on 2003 imagery, while SRTM data were collected in 2000, when land use may have been different.

To get a more detailed elevation model including buildings, river mouths and small scale changes in the topography, which influence tsunami flow patterns, a MFC surface model with 0.15 m resolution was generated from the aforementioned airborne flight campaign (figure 4). In this model vegetation was removed by filtering. However, in densely urban areas (e.g. Patong Beach) buildings were not removed from the surface model, as resistant buildings are supposed to influence flow dynamics.

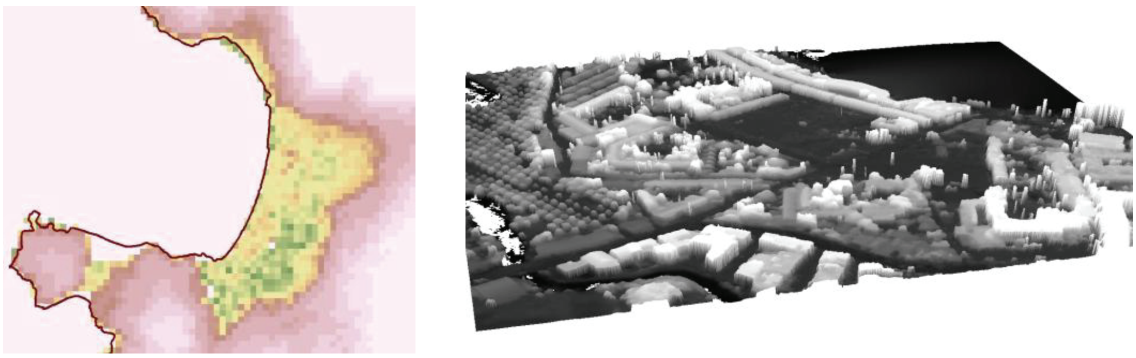

Figure 4: Digital surface models of Patong Beach with SRTM/90 m (left) and MFC DSM/0.15 m (right) resolution

Inundation maps

Based on the GEBCO 30 arc-second bathymetry combined with digitized marine charts in the near shore zone (resolution ~ 400 m), the topography and roughness maps, nested grids were generated with different resolution to model tsunami inundation in the study areas.

For the tsunami modeling two numerical models are being applied, which are boths based on the non-linear shallow water equations including bottom friction using Manning values. The MOST/ComMIT model (Method of Splitting Tsunami, (Titov & Gonzalez 1997)) uses a seismic deformation model to compute wave propagation and run-up over a set of three nested rectangular computational grids. Here, ComMIT is used for tsunami generation and propagation of the tsunami over the ocean. The model is connected to the MIKE 21 HD FM model (DHI) for inundation modelling. MIKE 21, which is based on an unstructured mesh, allows the inclusion of a detailed roughness map in the inundation simulations. To validate the model results, computed values are compared with measured tsunami heights provided by several research groups (e.g. Tsuji et al. 2006, Thailand Group 2005).

Various inundation maps have been produced based on different elevation models and for different roughness. Analysis of the first results has shown that a correction and filtering of digital surface models is inevitable for inundation modelling in densely vegetated areas. The SRTM elevation data are a useful source as they are available for most areas in the world. Nevertheless, for risk management the resolution turned out to be too coarse as small scale changes in topography, fluvial structures, or buildings can not be differentiated. For an analysis of the flow dynamics including barriers like buildings and different roughness within urban areas high resolution data are required. An analysis of the effect of buildings shows that including buildings as height information in the model generates a much more realistic indundation according to the measured inundation in the field.

Figure 5 examplifies this in a difference image for the inundation depth with and without buildings, showing that the inundation extent increases significantly without including buildings in the model. At the same time backwater effects occur when including buildings as height values.

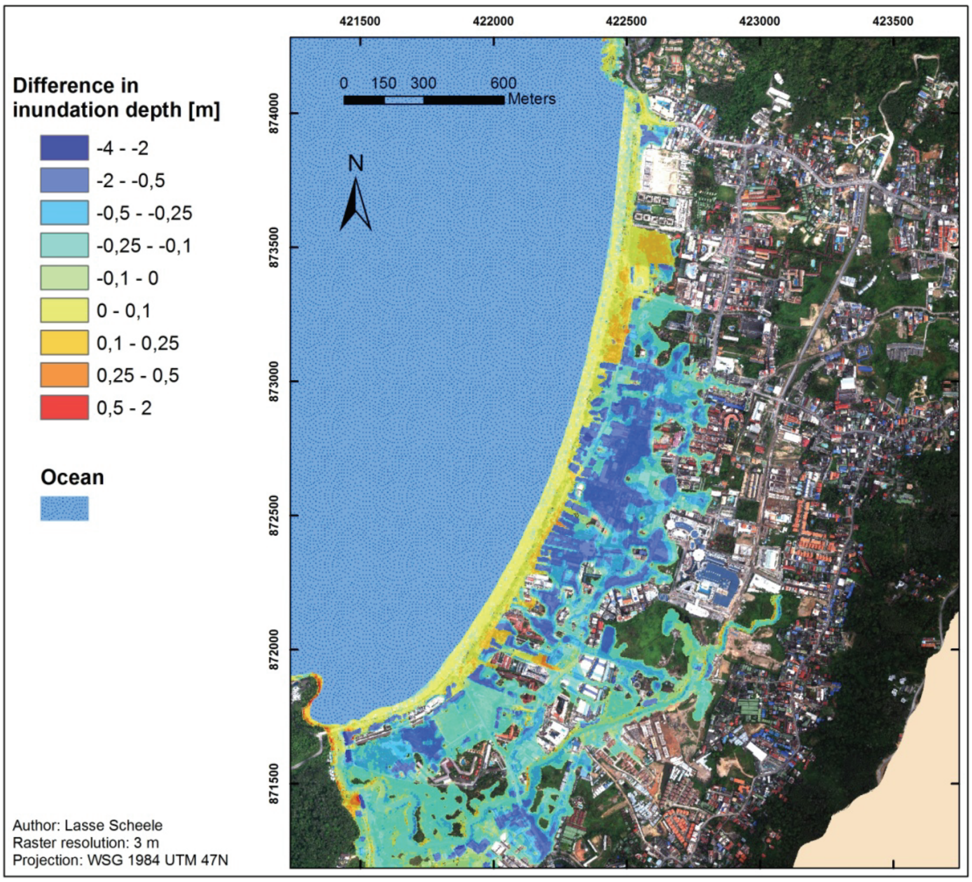

Figure 5: Inundation depth in Patong Beach showing the difference of an inundation simulation including buildings as height values and a simulation without buildings in the model grid, based on MFC data (resampled to 3 m)

4 Conclusions and outlook

In the German-Thai research project TRAIT research is performed on local tsunami risk assessment at the Andaman Sea coast of Thailand including a hazard analysis and a vulnerability analysis.

The tsunami inundation modeling provides hazard maps including the inundation depths, the maximum inundation area and flow dynamics. They build a basis for a detailed analysis of the 2004 tsunami impacts, for risk assessment and management at the Andaman Sea coast of Thailand. First outcomes of this study show that the accuracy and the resolution of the geodata used as input for the hazard analysis are crucial not only to understand the small scale mechanisms of tsunami impacts but also to provide inundation maps as a reliable basis for risk assessment, evacuation planning and risk management.

Since this paper presents work in progress further analysis will be conducted on multi-scale topography, the influence of detailed roughness information, inundation flow dynamics in urban and rural areas as well as inundation mapping.

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Zoning instruments for "Coastal and Marine Protected Areas of Multiple Use" – An Example in Southern Chile

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Abstract

Chile is a threshold country whose economic development is primarily based on the exploitation of natural resources. Within that context, the fishery sector and its products play a major role. In the course of application for membership into the Organisation for Economic Co-operation and Development (OECD), Chile has to commit to put 10 % of its total territory including its marine areas under protection. However, until today, a very small fraction of its territory has been reserved. The percentage of marine areas is extremely low compared to the percentage of terrestrial areas. In order to increase the percentage of marine areas, the instrument of "Coastal and Marine Protected Areas of Multiple Use" was established. The aim of this instrument is to combine resource protection, sustainable use, and economic development. However, previous implementation approaches regarding the declaration of these areas were not very successful. There exists not only a lack of financial means and of acceptance regarding the necessity of conservation and protection of natural resources, especially marine ones, but also a lack of scientific experience in this field. This paper examines the existing categories of zoning instruments in Chile and compares them to respective international categories. The result is a proposal of a re-categorisation of these instruments in order to provide policy makers in the Chilean government with a useful concept for future planning and implementation of "Coastal and Marine Protected Areas of Multiple Use".

1 Background and motivation

In order to become a member of the Organisation for Economic Co-operation and Development (OECD), Chile has to achieve the aim of reserving 10 % of its territory for environmental protection, including the surrounding marine areas. Additionally, the National Coastal Politic (SubSecMar 1995) demanded the zoning of the coastal strip along the entire country by the end of March 2009. However, the politic did not provide the necessary tools which are needed to obtain this target. Therefore, up to this point this aim has not yet been accomplished in Chile due to limited financial resources and because of insufficient technical knowledge of the executing authorities.

The Coastal and Marine Protected Areas of Multiple Use constitute one instrument for the Chilean Government to obtain OECD membership. Their purpose is to combine the protection of natural resources with a sustainable use of the same and with economic development (SubSecMar 1995).

2 Objectives

The first and most important objective is to elaborate an approach of zoning instruments for the Chilean coasts. However, some aspects must be considered previously in order to understand the approach. A zoning is necessary and reasonable to integrate multiple uses in practice. But for the process of developing a zoning, a suitable concept or instrument is advisable, i.e. to be able in the first place to integrate different uses of resources. It is precisely the presence of such an instrument that is currently lacking in Chile.

The second objective is to apply the elaborated approach accordingly in a preliminary zoning proposal for the pilot region Fresia, a commune in the Llanquihue Province in South Chile.

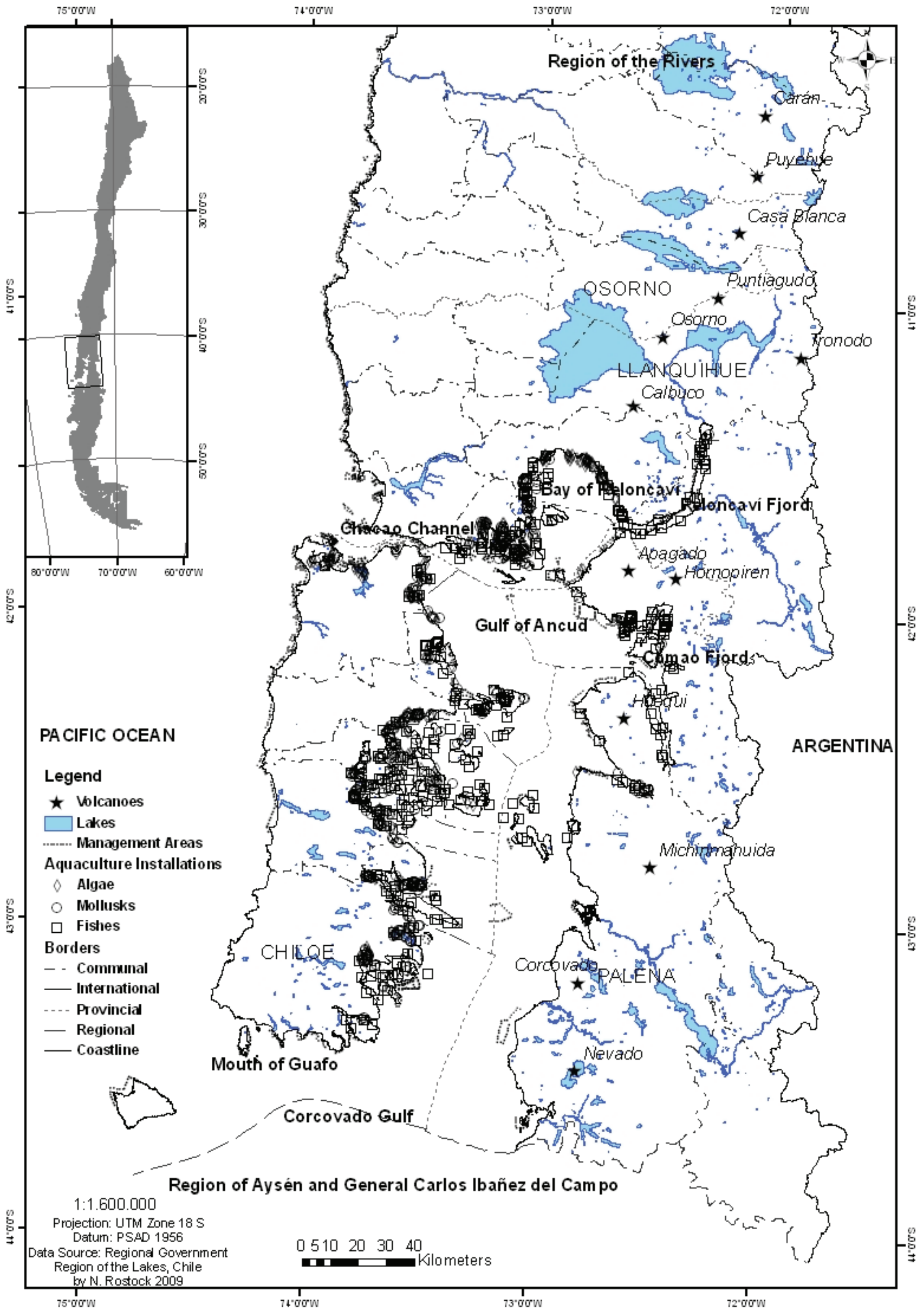

Figure 1: The Los Lagos Region in South Chile: overview and spatial distribution of main economic activities in coastal waters. The circle indicates the location of the pilot region Fresia (Data Source: Regional Government of the Los Lagos Region; modified by the Author)

3 Regional setting

The study area is located in the southern part of Chile approximately around 41°S latitude in the Los Lagos Region. This region is influenced by the west wind drift with high precipitation rates of around 2,000 mm/year and relatively low differences in temperature between the seasons (Jan. 14.4°C; July 6.6°C) (Mühr 2000). The adjacent marine areas are strongly influenced by the Humboldt-Current-System and the Cape Horn Current. These currents are shifting in accordance to changes in the overlying atmospheric pressure systems: the subtropical high-pressure area and the subpolar low-pressure area. In winter (July), the region is dominated by the Cape Horn current because both pressure systems are moved towards North. During summer (Jan.) it is dominated by the Humboldt Current because of the southward movement of the pressure systems which leads to seasonal upwelling events near the coast (Thiel et al. 2007). The mountains of the Andes at this latitude are characterised by a chain of glacial lakes and active volcanoes (figure 1).

The coasts of the Los Lagos Region can be divided into two distinct sub regions with respect to location, morphology and origin. The open Pacific coast is a rugged rocky shore characterised by cliffs and small bays (figure 2). It is a high energy environment where the swell and waves reach the coast nearly without previous energy dissipation. The beach material consists mainly of gravel and boulders. Few smaller sandy stretches exist only in the vicinity of river mouths or in calm and small cliff protected embayments.

Figure 2: The Pacific coast in the Los Lagos Region, South Chile (Photo: N. Rostock, May 31st 2008)

The second sub region is the Inner Sea, east of the Big Island of Chiloé. It is an enclosed part of the sea consisting of the Gulfs of Reloncaví, Ancud and Corcovado (figure 3). It was formed under the influence of the Pleistocene glaciations as observed in the fjords at the eastern rim of the Inner Sea. It comprises many small islands grouped into archipelagos which are divided by channels. The same characteristics continue to the south. The beaches are often sandy with a relatively low energy environment. Locally the formation of marshlands is in progress.

Fishing and aquaculture are the main economic activities in the coastal and marine areas. These include small-scale coastal and offshore industrial fisheries as well as the cultivation of fishes, mussels and algae (figure 1). In official Management Areas (Spanish: Areas de Manejo y Explotación de Recursos Bentónicos) near the shore all kinds of benthic resources are allowed to be extracted from their natural environment. Each Management Area comprises a strip of sea of approximately half a nautic mile in width and varying extension up to kilometres alongshore. Onshore economic sectors are agriculture, forestry and tourism.

Figure 3: The coast of the Inner Sea in the Los Lagos Region, South Chile (Photo: N. Rostock, June 7th 2008)

4 Methods

The basic assumption for this method was that every activity is a use and therefore can be defined as a use category. It is a necessary prerequisite so that in the process of zoning each zone can be defined by a use category. At the end, the zoning integrates all different kinds of uses. In this approach the instruments for zoning are the suggested use categories (table 1).

The basic procedure was a category assessment which was followed by analysis of the usefulness of these categories for the purpose of zoning.

At first, an assessment and analysis of the legislative framework in Chile regarding marine and coastal areas was conducted. The most important law is the Fishing and Aquaculture Act (FAA) from 1991. This law defines and regulates nearly all permitted activities carried out in Chilean waters: fishing and aquaculture, the extraction of benthic resources in the Management Areas (see above) as well as environmental protection in Marine Parks and Reserves. Subsequent regulations and changes of the law are set in additional declarations such as Supreme Decrees.

The second step was an assessment and analysis of international categories such as the United Nations Biosphere Reserves Programme and the Management Categories of the International Union for Conservation (IUCN). These were compared with the Chilean categories. If necessary, they were used to complete use categories which were not yet represented in the current Chilean legislation.

Additional possible uses which have not been taken into account by all these previous categories but seemed reasonable were considered. Their usefulness was analysed and if proven worthy an additional use category was defined.

Finally, all worked out categories were evaluated and integrated into one common approach of re-categorisation. This re-categorisation relates especially to the contents of these categories. The categories themselves might have existed before but not necessarily in this form or context, respectively. So, only their contents and possible meanings were re-defined.

5 Results

An approach for zoning instruments

The categories presented here constitute an approach for zoning instruments (table 1). However, they should be considered as a concept and not as a rigid instrument. These categories are use categories which can be assigned to an area or a site inside the area to be be zoned. Then, this area is bound to a specific use according to the use category. In this way, a zoning can be obtained for the whole area needed. Thus, all multiple uses can be integrated.

According to the FAA, the first category, fishery, is divided into three subcategories: small-scale coastal fishery within the five-nautic-mile-zone; industrial fishery in the exclusive economic zone (EEZ) which in exceptional cases only are allowed to operate within the five-nautic-mile-zone, but never further onshore than one nautic mile; and last but not least the sports fishery.

A similar subdivision is applied to the aquaculture activities and the extraction of benthic resources in Management Areas reported in the FAA. These last two categories are divided according to the species cultivated or extracted, respectively.

Tourism is not specified in the FAA. Nevertheless, it plays an important role for coastal areas all over the world, including Chile. Therefore, it will be considered and given a separate category. This category will also be divided into two subcategories according to the activities carried out. It is already an attractive activity to watch Blue Whales and Humpback Whales in the Inner Sea, but also sea lions, dolphins and a variety of sea birds can be seen. Regarding the rich benthic flora and fauna, they could be considered as possible basis for participative activities such as diving.

Besides all that, the protection of these natural environments must be taken into consideration. For this category the basic concepts of preservation and conservation (table 1) were provided by the FAA in terms of Marine Parks and Marine Reserves, respectively. Both concepts form the basis for a further division into subcategories. However, a buffer area and an area with restricted access are still missing. The buffer area concept originates in the UN-Biosphere Reserves but until now it does not exist in Chile. The areas with restricted access originated from the IUCN categories and their conditions of protection degrees – another aspect which has not been considered in Chilean legislation.

The next main category is transportation. After all the consideration of possible activities carried out in the coastal and marine areas in Chile, the transportation as the main supporting action has not been taken into account. However, without marine transport none of these activities can be realised. In order to perform them there will be subcategories for each transaction, basically to conduct the associated operations and to prevent misuses of the according traffic routes. As a result, routes will be designated for tourism such as animal watching, for productive activities such as fishery, and finally for surveillance in order to monitor all activities and to assure their correct use plus scientific monitoring.

Last but not least, a category for infrastructure installations at onshore sites of such Coastal and Marine Protected Areas of Multiple Use will be included. They are also subdivided into the following subcategories: quays or other anchoring and landing places in order to alleviate the access to the coast and to transfer the catch; processing centres for subsequent treatment of the catch like storage, drying and slaughtering; and finally, buildings and other installations for scientific and administrative purposes.

Proposal for a preliminary zoning in the pilot region Fresia

Fresia is a coastal municipality in the Llanquihue province, located northwest of Puerto Montt. The access to the coast is relatively difficult. The single road has only one lane, it is unpaved and might temporarily be intrafficable. It leads to the southern end of Fresia, the mouth of the Llico River. The northern parts can only be reached by boat, on horseback or by foot. However, all these ways take various hours and might be impassable during bad weather conditions.

The economy of this municipality is characterised by agriculture and forestry as well as small-scale coastal fishery and the extraction of benthic resources in Management Areas (figure 2). However, no official infrastructure installations of any kind are constructed onshore.

Table 1: Suggested use categories for coastal and marine areas according to the new approach

Main category	Subcategory	Application and/or purpose to CMPA-MU Authorized individuals and/or users
Fishery	Artisanal Industrial Sport	Artisanal fishermen Industrial fishermen Person with licence for sports fishing
Aquaculture	Fishes Mussels Algae	If not already present, they will not be allowed to develop, due to high potential environmental impact and alterations of the environment itself; if already present they might continue, but under conditions of ecological keeping (best practices)
Benthic Resources	Mussels Crustaceans Algae	Permission to extract resources in a sustainable way, consequently the permissions will be granted temporarily for each economically important species, not effecting the non-commercial species
Tourism	Whale and Bird Watching Participative Activities	Such as marine mammals and sea birds with certified and/ or licensed guides only Showing the practice of extracting benthic resources such as Loco and Algae for demonstration purposes only
Ecosystem and Habitat Protection	Conservation Preservation Restricted Areas Buffer	Keep the present state and avoid destructive or wasteful use; through management the conservation shall be granted Keep safe from harm, destruction or decay; provide access for scientific purposes only “No take zone”: neither access nor extraction is allowed in order to protect the ecosystems itself including all living species; such areas could be spawning grounds or nurseries A transitional area between the protection area and the other uses to obtain a spatial separation allowing access for scientific purposes only
Transportation and Transit Traffic Routes	Tourism Productive Surveillance	The routes for animal watching to get to the linger places The routes for vessels of industrial fishery to get passed the five-nautic-mile-zone, between their allowed fishing grounds and the harbour; The routes for artisanal fishermen to go to their fishing grounds, that lie within the five-nautic-mile-zone, they may be allowed to pass that zone further offshore to get there The routes for authorities to supervise and monitor the activities, included are passages for scientific reasons
Buildings and Infrastructure (coastal-productive and coastal-scientific)	Quays Processing centres Observation facilities	Anchor places for local fishermen and to unload the catch Catch to be processed (storage, drying and slaughtering) Buildings and installations for scientific and administrative purposes

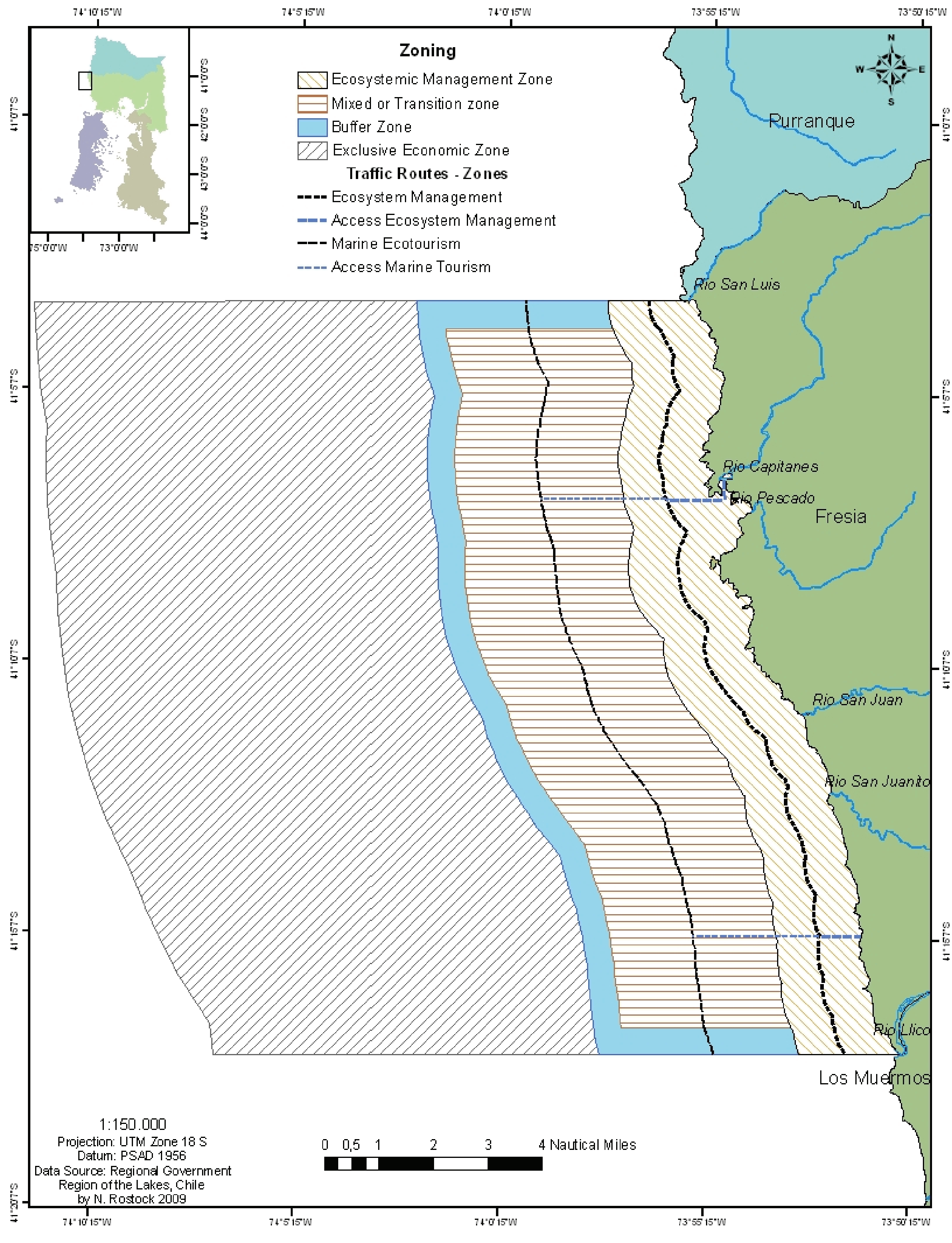

Figure 4: Suggested zoning in the pilot region Fresia according to the new approach (Data Source: Regional Government of the Region of the Lakes; modified by the Author)

Hopefully, this will change with the implementation of a Coastal and Marine Protected Area of Multiple Use in this municipality. The preliminary zoning (figure 4) proposes a minimum area of a width of five nautic miles. This minimum area will not be negotiable. The adjoining seven-nautic-mile-zone shall be negotiable with the responsible authorities (e.g. the Regional Coastal

Commissions). At best, this future Coastal and Marine Protected Area of Multiple Use will comprise a total of 12 nautic miles along the entire coastline of Fresia. If possible the parts now belonging to the Management Areas (figure 4) will be included as well.

The five-nautic-mile-zone shall include a buffer zone of half a nautic mile in width that surrounds the Transition or Mixed Zone in the North, East and South. In the Mixed zone, several uses of the suggested use categories shall be integrated such as small-scale fishery and tourism. The next zone toward shore is an Ecosystem Management Zone. In this proposal a width of about one and a half nautic mile is suggested. This zone shall integrate the protection of coastal habitats and the sustainable extraction of benthic nearshore resources. Both zones, the Mixed Zone and Ecosystem Management Zone, need further subdivision according to the use categories. Unfortunately, the data available for this municipality are not sufficient to develop a more detailed zoning. Especially, specific data about ecology and the impacts of extracting benthic resources are lacking.

6 Discussion and conclusion

These categories are suggested to be used by policy makers in coastal and marine affairs in Chile. They shall provide a new concept or even instrument to conduct zoning at the Chilean coasts. During the process of zoning all desired uses can be combined, and undesirable uses can be excluded for certain reasons. However, final decision has to be made by persons which are competent or executing authorities. For this reason all possible uses were included in the present approach.

Until now this re-categorisation has been used to elaborate the zoning of the coastal strip of Fresia by the Non-Governmental Organisation CODESOSUR-SINERGIAS as it was demanded by the National Coastal Commission. Together with the preliminary zoning presented in this paper, both proposed zonings constitute an attempt of Integrated Coastal Zone Management in Chile for the first time.

It is clear that this approach still needs to prove its value in practice. But due to the lack of feasible nearshore zoning in Chile up to now, it is a step forward toward future Integrated Coastal Zone Management.

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Estimation of Presídio's Barrier Island (Guamaré-NE/Brazil) Migration by Means of GIS and Remote Sensing.

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Abstract

Coastal zone occupation has been increasing in the last decades, which has caused an expressive rise in the density of coastal zone population. A relative rising in mean sea level has provided a diminution on the coastal zone land area. Barrier islands have been used for habitation and entertainment purposes, and they also represent a natural protection to the coast acting as a shelter for the coastline against wave and tide action.

In this sense a spatio-temporal triennial analysis, using satellite images, was done for NE Brazil. The images were obtained from CBERS, satellite dated from 14/08/2004, 13/08/2005 and 09/03/2006. They main goal of this study is to quantify the progradation of Presidio's barrier island (Guamare-RN, NE Brazil) during the period from 2004 - 2006. Approximately 200m/year was the progradation observed for the referred island, pointing out high morphodynamic process for this region. Attached to the progradation, a shoreline retreat was observed at the area adjacent to the West extremity of the island. The total retreat measured was around 130m.

1 Introduction and objectives

During the last decades coastal erosion has been observed along many coasts around the world. In some cases this occurrence is linked with rise in sea level. However, in the case of the NE-Brazilian coast the erosion is due to the sedimentary budget (Dominguez & Bittencourt 1996). Low sediment availability is attributed to tectonic activities in this region (Bezerra et al. 1998, Vital et al. 2003, Vital et al. 2006). This statement is supported by data from sea level curves which were reconstructed fort this region indicating that around 5000 years B.P. sea level was a few meters above the actual level (and showing a general falling trend during the last 5000 years B.P (Caldas et al. 2006, Bezerra et al. 2003, Peltier 1998).

There are a number of techniques used to measure coastal erosion or coastline retreat and satellite images turned to be very popular during the past decade. This work will focus on the use of this technique on the measurement of the coastal erosion occurring on the N coast of the RN state (NE-Brazil) between 2004 and 2006 by using three images form the satellite CBERS. The images were acquired from INPE (Instituto Brasileiro de Pesquisas Espaciais).

2 Geographical and geological settings

The study area is located close to the city of Guamaré (Brazil-NE) which is approximately 170 km NW of Natal (figure 1), the capital of the State Rio Grande do Norte. The area is inserted on the domains of the Potiguar Basin (Bertani et al. 1990). It is subjected to a semi-diurnal mesotidal regime (Araújo et al. 2004).

Presidio's barrier island is elongated in E-W direction. It is composed of quaternary sediments deposited due to a wave and tide dominated environment.

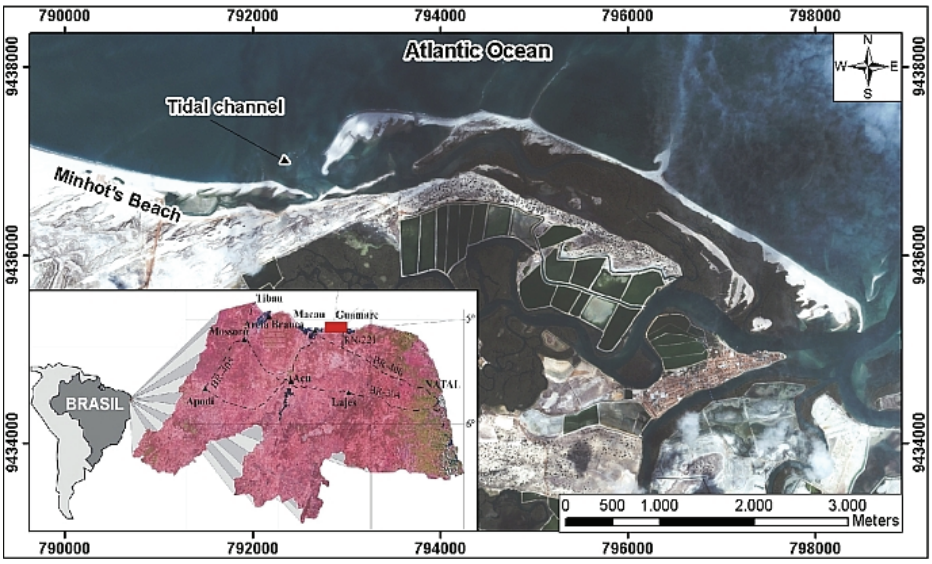

Figure 1: Geographical setting of the study area.

3 Methods

In order to estimate the progradation of the western part of the island, three images (14/08/2004, 13/08/2005 and 09/03/2006) obtained from the satellite CBERS which has 20m spatial resolution were used. Image processing was done using the software ErMapper 6.0 and the spatio-temporal analysis using ArcGIS.

4 Results

From 2004 to 2006 a fast progradation of the West extremity of the island was observed reaching approximately 670 m which results in an average of approximately 423 m/year (figure 2), however, the rate of progradation was not the same along this whole period as between 2004 and 2005 the progradation observed was higher than between 2005 and 2006.

The progradation of the island triggered an intensive coastline retreat on the Minhoto's which was approximately 130 m during this period. This resulted in a rate of retreat of approximately 82 m/year (figure 2).

5 Conclusion and discussions

The sediment from Presídio's barrier island beach is reworked by waves and transported by longshore current and deposited on the westernmost part of Presidio's Barrier Island causing its progradation. In addition during ebb phase the complex of tidal channels placed eastward of the area act as conduits transporting sediment toward the continental shelf. These sediments may also be caught by the longshore current, transported and deposited on the western part of Presidio's barrier island.

The progradation of the island triggered an intense coastline retreat at Minhoto's beach which is located adjacent to the western extremity of the island (figure 1). On this part the water exchange of the back barrier lagoon is done through the tidal channel which separates Presídio's Barrier Island from Minhoto's Beach (figure 1). The narrowing of the tidal channel mouth (caused by the island progradation) increased the hydrodynamic conditions on this place in order to maintain the balance of sea water going in and coming out of the back barrier lagoon during flood and ebb phases. Therefore, the erosion observed on Minhoto's beach is the result of the new hydrodynamic conditions of the tidal channel mouth.

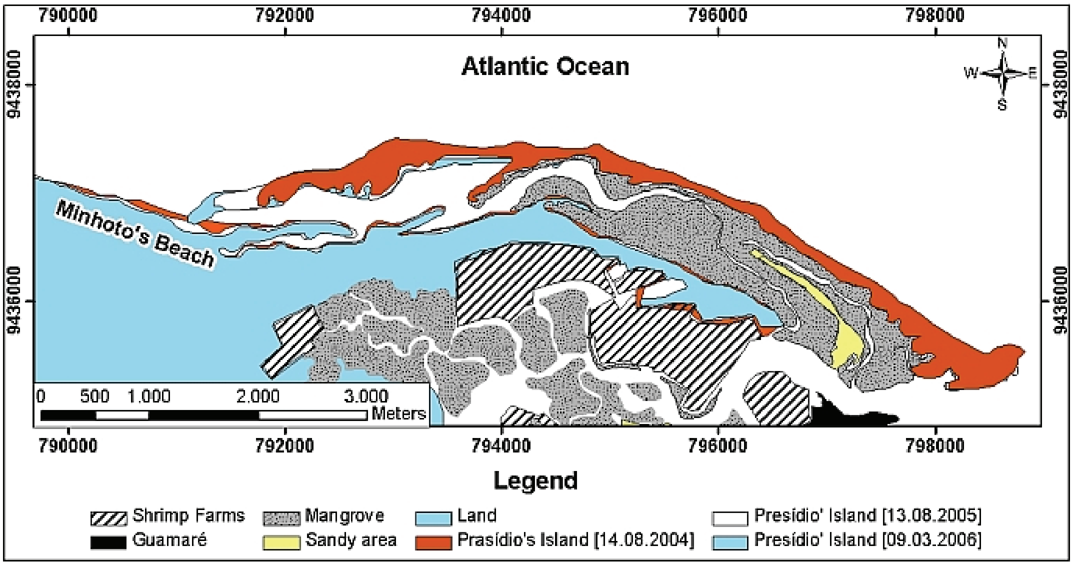

Figure 2: Progradation of the west extremity Presídio's Barrier Island and the resultant coast line retreat on Minhoto's Beach.

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Dynamics of mussel beds in the Szczecin Lagoon

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Abstract

Mussel beds play an important role as secondary hard substrate both in the North Sea and in the Baltic Sea. Many species live on them, stabilise the sediment and foster bentho-pelagic coupling. In the very eutrophic Szczecin Lagoon at the German-Polish border, zebra mussels (*Dreissena polymorpha*) might help to restore more natural conditions by filtering and thus cleaning the water. In preparation for a pilot project for biological restoration methods using zebra mussels we wanted to evaluate the mussels' status quo. We therefore mapped the current distribution of zebra mussels in the Szczecin Lagoon in summer 2007, using underwater video imaging, a scientific SCUBA-diving team and benthos samples taken with Van Veen grabs and box corers.
Apparently the mussel beds have strongly decreased in size over the last 14 years. This could be due to the high trophic state in combination with global warming, causing temporal oxygen deficiencies. Other reasons may be strong predatory pressure or methodical differences in preceding studies. We plan to continue investigating the dynamics of mussel beds in a German-Polish interdisciplinary project.

1 Background

Mussels such as blue mussels (*Mytilus edulis*) or zebra mussels (*Dreissena polymorpha*) are known as "habitat engineers" (Jones et al. 1994) because they live in clumps or bigger aggregations ("beds") that offer many niches and hard substrate for a wide variety of other species dwelling on the mussels. Mussel beds are therefore often islands of high biodiversity, especially in areas with muddy sediments where only few species can live. By enhancing interspecific facilitation, a high biodiversity can thus lead to more effective resource consumption and better ecosystem functioning (Cardinale et al. 2002).

Recently many mussel beds in Germany and North America have decreased in size and biomass (Smith et al. 2006, Büttger et al. 2008), raising the question of the causes.

In the Wadden Sea, the *Mytilus* decrease is attributed to 1) mild winters causing low recruitment and 2) the invasion of the Pacific oyster *Crassostrea gigas,* a neozoon which is a competitor for food and space. In North America, a strong winter (1979/80) caused a massive reduction in density and biomass of mussels (*Mytilus spp*.), caused by ice scour (Cousson& Bourget 2005). The recent decline of mussel bed community diversity (about 60 % from 1960/70 to 2002) is attributed to climate warming (Smith et al. 2006).

Besides providing hard substrate for many other species, mussels have another important function: they filter the water. This capacity can be used for bioremediation (restoration of a less eutrophic state of a water body) (Reeders & Bij de Vaate 1990). In order to calculate the necessary amount of mussels to allow for a better water quality, it is essential to know the status quo of the existing mussel population.

2 Objective

The aim of the present study was to map the existing mussel beds of *Dreissena polymorpha* in the German part of the Szczecin Lagoon (Kleines Haff). The distribution and population composition are prerequisites to estimate their active filtration potential. The results are a basis for calculating the number and biomass of mussels necessary to ameliorate the water quality. We plan an interdisciplinary German-Polish project to test biological restoration methods, especially aiding the existing *Dreissena* mussels to increase water clarity and enable remesotrophication.

3 Location and Methods

The study was carried out in June and July 2007 (4.6.-5.7.2007) in the German part of the Szczecin Lagoon, called Kleines Haff, which is situated at the German-Polish border. June was chosen because it has the highest visibility in summer according to long-term monitoring data (LUNG MV unpubl. data) and water temperatures that enable long diving periods. We used the research vessel "Bornhöft" of Greifswald University and a rubber boat. Sediment samples were taken with Van-Veen grabs (0.1 m²) and Günther box corers (0.06 m² surface, penetration depth: about 20 cm).

A total of 701 stations were checked for *Dreissena* mussels. Investigations took place along a grid with sampling points every 0.5 nautical miles. The very deep and muddy areas were only sampled randomly because they do not offer suitable substrate for mussel attachment. At sites with mussels, divers measured the exact sizes of the mussel beds, using GPS, a compass and van Veen grab samples. As the visibility was very low, they often had to rely on haptic instead of optic evidence.

On board and in the laboratory, the lengths of the shells were measured with digital callipers. The samples were sieved (0.5 mm mesh size) and preserved with 10 % formalin. Species were determined with a stereomicroscope in the lab after watering the samples overnight and thoroughly rinsing with tap water. Additionally, the Secchi depth and oxygen saturation was measured. Water samples were taken for the analysis of nutrients, seston, BOD5, and chlorophyll content (methods and results in Fenske et al. (in prep.)).

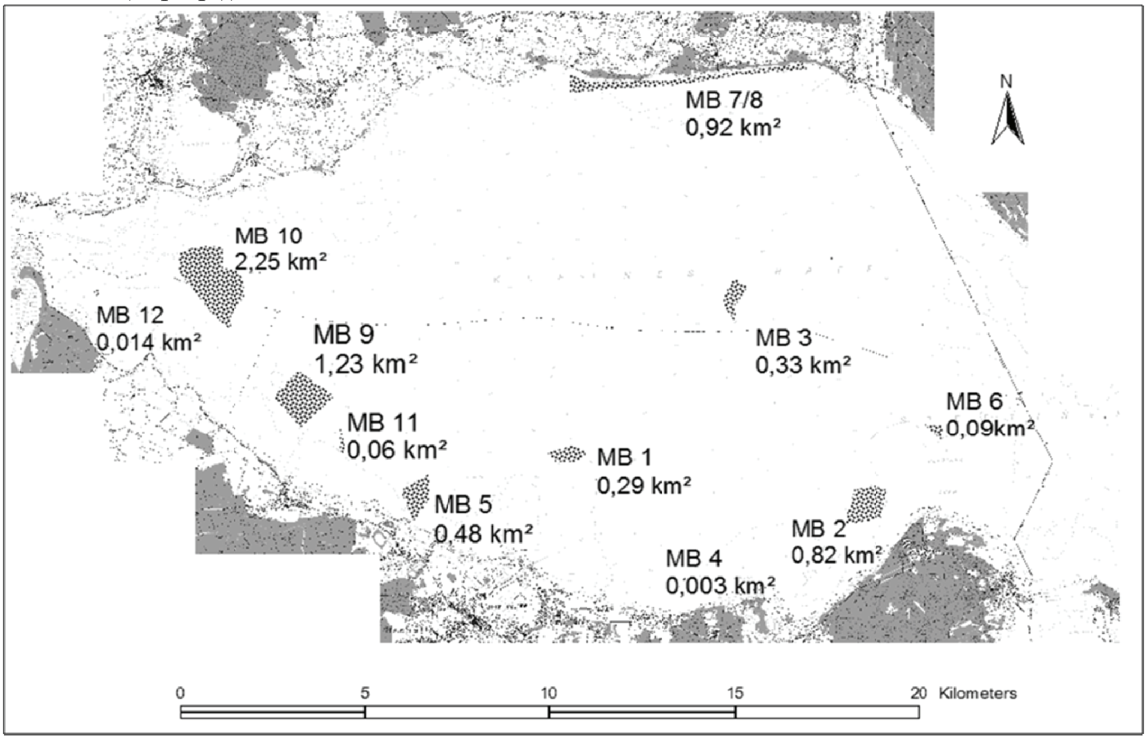

Figure 1: Mussel beds in the Kleines Haff, summer 2007. The total area covered by zebra mussels is 6.56 km² (=2.4%).

4 Results

Twelve mussel beds were found in the “Kleines Haff”, covering a total area of 6.56 km² (656 ha) which corresponds to 2.4 % of the area. Most of the mussel beds were found in sandy areas in 2.0-3.5 m water-depth, surrounding the lagoon like a belt (figure 1). One exception is the central mussel bed (MB 3), which lies on a prelitorine elevation.

The macrozoobenthos comprised 40 taxa. The average abundances of the most dominant taxa are shown in table 1. The zebra mussels (3,951 inds/m²) had a calculated total biomass of 8812.65 t (for calculation see Fenske 2003). The total average abundance of macrozoobenthic species on 7 mussel beds (26 samples) was 14,554 individuals/m².

Table 1: Average abundances of the most dominant taxa on mussel beds in the Kleines Haff

Taxon	Average abundance (individuals/m²)
Dreissena polymorpha (Mollusca, Bivalvia)	3951
Oligochaeta (Tubificidae)	4543
Chironomidae (Diptera)	2647
Helobdella stagnalis (Annelida, Hirudinea)	486
Bithynia tentaculata (Mollusca, Gastropoda)	237

5 Discussion

Mussel beds can persist over years or even decades, but they depend on many factors:

1. offspring and recruitment success (how many larvae develop successfully into adult mussels?)
2. underground (in general, hard substrate is necessary for attachment)
3. currents (too strong currents hinder settlement; low to medium current velocity secures food supply and higher chances of sufficient oxygen conditions compared to a stagnant water body)
4. temperature (if too high, mussels die)
5. oxygen supply
6. predators
7. parasites, pathogens
8. pollutants
9. intraspecific competition (within the same species)
10. interspecific competition (between different species)

No reports exist from the beginning of the 20th century about the mussel bed cover or total biomass of mussels in Szczecin Lagoon. Brandt (1894) investigated the eastern part of the lagoon and found *Dreissena polymorpha* in typical places (about 2 m depth, in areas not too exposed). However, there are no quantitative results.

In the North Sea (Wadden Sea area near Sylt), mussel beds clearly increased in size during the 20th century (Reise & Lackschewitz 1998). This may be due to positive effects of eutrophication providing more food (phytoplankton) for suspension feeders. Recently, eutrophication has been considered as a negative factor, one reason being the potential oxygen deficiency which it can entail.

Blue mussels (especially *Mytilus edulis* living in the eulitoral) can suffer from ice scour and strong winds. These reasons accounted for a strong decrease in the St. Lawrence River during the winter 1979/80 and for high mortalities in the Sylt Wadden Sea area (Nehls et al. 1998).

However, *Dreissena polymorpha* only lives in areas which are permanently submerged and most of them in depths of at least 2 m, so that in general, even strong winters should not cause them to die off completely.

On the other hand, very mild winters may also affect the mussels: It has been reported that recruitment success after mild winters is particularly low (Büttger et al. 2008). However, for several bivalve species in the North Sea, post-settlement processes decide reproductive success (Straßer et al. 2001).

While we found a total area of 6.56 km² of *Dreissena* mussel beds (= 2.4 % of the area of the Kleines Haff), a former mapping describes 19.2 km² (= 6.9. %) (figure 2, Andres 1993). The methods used were similar (scientific divers, underwater video camera recording, van Veen grab samples), but the former study was carried out over 2 weeks in August 1993 while our investigation took place for a 5 weeks period in June/July. At this time of the year, far fewer juveniles can be expected. However, this does not affect the area of the existing mussel beds. Estimates based on sediment samples taken on grid points of 1 nautical mile across the Kleines Haff in 1993 and 1994 gave a total area of *Dreissena* beds of 57.0 km² (20.6 % of the area) (Günther 1998). In these last investigations, the size may have been overestimated, as the rim of the mussel beds were not confirmed by divers.

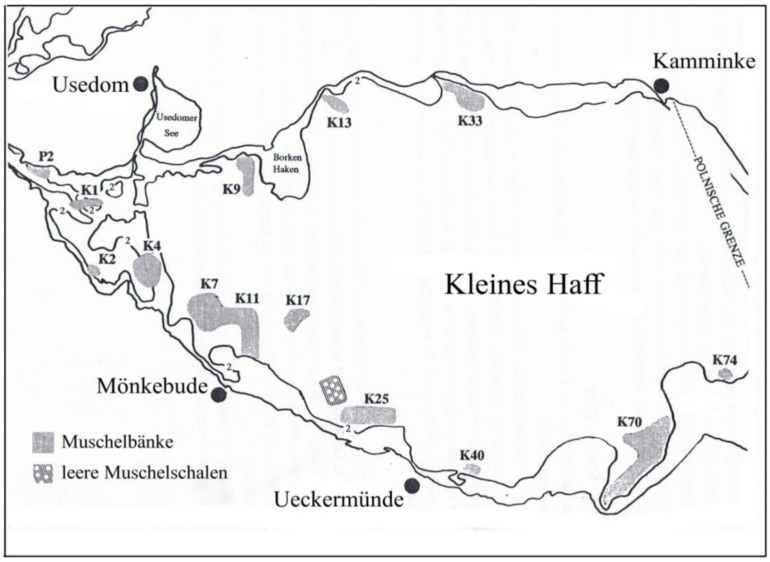

Figure 2: Mussel beds mapped by Andres (1993). The total area in 1993 was 19.2 km², about 3 times the size of mussel beds in 2007.

The "rise and fall" of mussel beds

At least one living mussel bed had vanished between 1998 and 2009. It was the one in the middle of the German-Polish border which was present (and repeatedly sampled) in 1998 (Fenske 2003), while in 2007, only dead shells but no living mussels could be found (this study). At the recorded GPS positions divers searched intensively, but there was no living mussel bed anymore. A similar fate may have occurred to the field of empty mussel shells off the south shore between Ueckermünde and Mönkebude (near K25, figure 2).

Some mussel beds discovered by Andres (1993) had vanished as well, e.g. K9 and K13 at the north-western end. K70 on the south-east side had clearly decreased in size.

On the other hand, at least two mussel beds found in our study (MB1 and MB3) are not mentioned by Andres (1993). They may not have searched intensively enough in the central part (which is mostly muddy and therefore an unlikely settling ground for *Dreissena* mussels). Still, the differences in size of the total mussel beds recorded are so large that we can assume a strong decrease in mussel beds over the last decade.

Some *Dreissena* mussel populations have been reported to vary strongly. In Lake Mikolajskie (Mazurian Lakes, Poland) abundances ranged from 100 mussels/m² to 2200 mussels/m² over the time span of 31 years (1959-1989) with abrupt changes in density (Stańczykowska & Lewandowski 1993).

A strong decrease was also observed by Wolnomiejski and Woźniczka (2008) for the Skoszewska Cove, a sheltered bay in the east of Szczecin Lagoon. Comparing the years 2001/2002 and 2005, the mussel bed area in Skoszewska Cove remained the same (10.70 km² = 51.6 % of the bay), but the average abundance (2172 mussels/m²) went down to half the number before (4691 mussels/m²). Biomass was reduced to little more than 10 % of the previous value (192 g freshweight/m², compared to 1760 g/m²). Even the high values of 2001/2002 are one order of magnitude below those from the 1950s: Wiktor (1969) describes maximum densities of 114000 mussels/m² and a maximum biomass of 20 kg/m²!

Does this imply an internal cycle of rising and falling of mussel beds? Do they reproduce and recruit so successfully that after some years they start to cause their own (intraspecific) competition? Phytoplankton production in the Szczecin Lagoon is still very high (polytrophic conditions) and competitors such as *Anodonta anatina* or *Unio pictorum* occur in comparably low numbers (about 2/m² in our investigation). Despite their larger filtration capacity, their total impact is much lower than that of zebra mussels. In a semi-enclosed bay like Skoszewska Cove, it is possible that the stagnant water is filtered several times by the mussels so that in the end not enough food is left. However high densities of one single species (monoculture!) also favour parasites and illnesses. These factors have not been checked in Skoszewska Cove.

In Lake Zürich, internal cycles of *Dreissena polymorpha* abundances were positively correlated to predator densities (birds). From 1976 to 1988 no total gain or loss of *Dreissena* was observed (Burla & Ribi 1998).

One reason for a decrease or break-down of mussel populations could be oxygen deficiency caused by eutrophication in combination with warmer water temperatures. Compared to the long-term average (1975-2000), average water temperatures between 2002 and 2006 were 0.8°C higher (LUNG Gewässergütebericht 2006). Once a mussel bed has disappeared, it may take several years to re-establish, as pelagic larvae might not be drawn to that particular place. Even though larvae might be ingested by adult mussels, as suggested by Mörtl & Rothhaupt (2003), the normal settling size (200-300 µm) is above the preferred size of food particles of adult mussels (15-40 µm, Ten Winkel & Davids 1982). This suggests that the filtering activity of adult mussels should attract larvae and help them settle in suitable places.

For Lake Zürich, Burla & Ribi (1998) found a positive correlation between the number of adult mussels and the number of larvae. With a small current mussel population in the Szczecin Lagoon, it might therefore take several years before the total population and size of mussel bed regains its potential size and filtering capacity.

6 Conclusion

Mussel beds in the Szczecin Lagoon decreased in size, average abundance and biomass between 1993 and 2007. Whether this was caused by single factors (e.g. food shortage, oxygen deficiency, mild winters and little recruitment) or whether this represents a long-term cycle remains an open question. We intend to investigate some of the influential parameters, such as predation impact and population dynamics in a joint German-Polish project on biological restoration methods.

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Coarse-grained sediment distribution in shallow water of the south-western Baltic Sea (Germany)

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Abstract

Coarse-grained sediments like cobbles, stones and boulders commonly occur in the south-western Baltic Sea, mainly on submarine abrasion platforms in front of retreating soft-rock cliff coasts. These residual sediments seem to be an important source for the development of coarse-grained beach ridges, which play an essential role as shore protection element of the adjacent coastal lowlands. A new small-scaled, high frequency side-scan sonar (SSS) is used, to analyse large-scaled distribution pattern and characteristics of residual sediments in near-shore zones of the south-western Baltic Sea. Ground-truthing is done by scientific scuba divers. For the first time, detailed mapping of sediment distribution from the water line down to 8 m water depth were done in 2009, reflecting a broad spatial distribution of different residual sediments and sand bar systems.

1 Introduction and objectives

Cliff-coasts composed of morainic material are widespread along the south-western Baltic Sea. They alternate with coastal lowlands. At many sites, wind-induced wave impact causes cliff retreat and abrasion of the adjacent seafloor (e.g. Gurwell 1991, Schrottke 2006). Under erosion, sediment with grain-sizes ranging from clay to boulder size is supplied. Healy & Wefer (1980) assumed that residual sediments are relatively stable in position. Schrottke et al. (2006) showed that coarse-grained sediments are regularly moved on submarine abrasion platforms of the Baltic Sea, mainly in landward direction with a long-shore component. These findings match with other studies, although reflecting tidal conditions (e.g. Osborne 2005, Curtiss et al. 2009). It has been postulated, that residual sediments seem to play an important role as sediment source for the development and stability of coarse-grained beach ridges of coastal lowland (Schrottke et al. 2006). Detailed information on source to sink pathways and transport rates under different hydrodynamic conditions is still lacking, but is needed especially with respect to climate-related sea-level rise and coastal erosion. Information on spatial distribution of residual sediments in the near-shore zone is retrieved in a first step of new studies to fill these gaps.

2 Regional setting

The sites are located at the German south-western Baltic Sea coast, near the villages Schönhagen and Heiligenhafen (figure 1a-c). Each site comprises an active cliff-coast section with adjacent coastal lowlands. They are differently exposed to the main wind-wave direction with diverging fetch lengths. Tidal effects are negligible. Measurements cover areas from the water-line to about 8 m water depth.

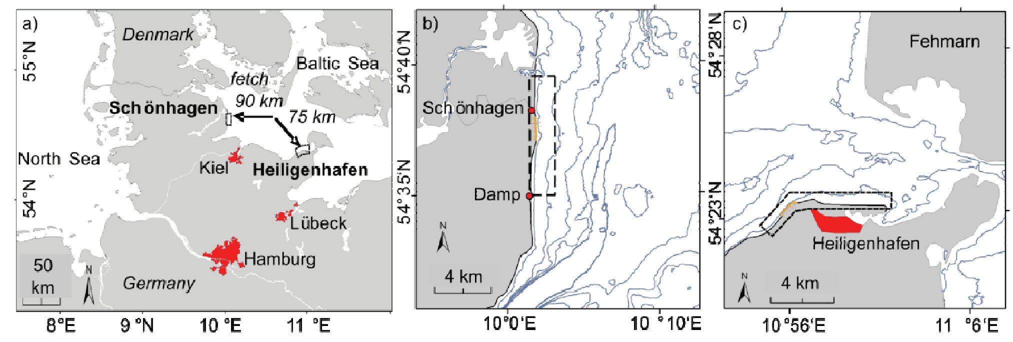

Figure 1a-c: a) Location of the study sites along the German south-western Baltic Sea, near b) Schönhagen and c) Heiligenhafen.

3 Methods

A small-scaled, dual channel, triple-frequency (260, 330, 770 kHz) SSS (Yellow Fin, Imagenex™) is used to measure even in very shallow water (< 1 m) by deployment in a fixed position from a rubber boat. The system has an across-track range resolution of 0.01 m. High frequency is used with a range of 20 m in water depths < 5 m and 40 m in water depth > 5 m. Geographical locations are given by Differential Global Positioning. A grid resolution of 10 cm is used for mosaicing (Triton IlicsTM). Ground-truthing is done by scientific scuba divers.

4 Results

Figure 2a exemplarily shows an SSS mosaic from the seafloor close to Schönhagen. The area bounded by dashed lines consists of a nearshore bar identifiable by wave-induced, cross-shore ripples. The distance between ripple crests decrease towards onshore from 95 to 10 cm. Smaller ripples appear as relatively light areas (figure 2a).

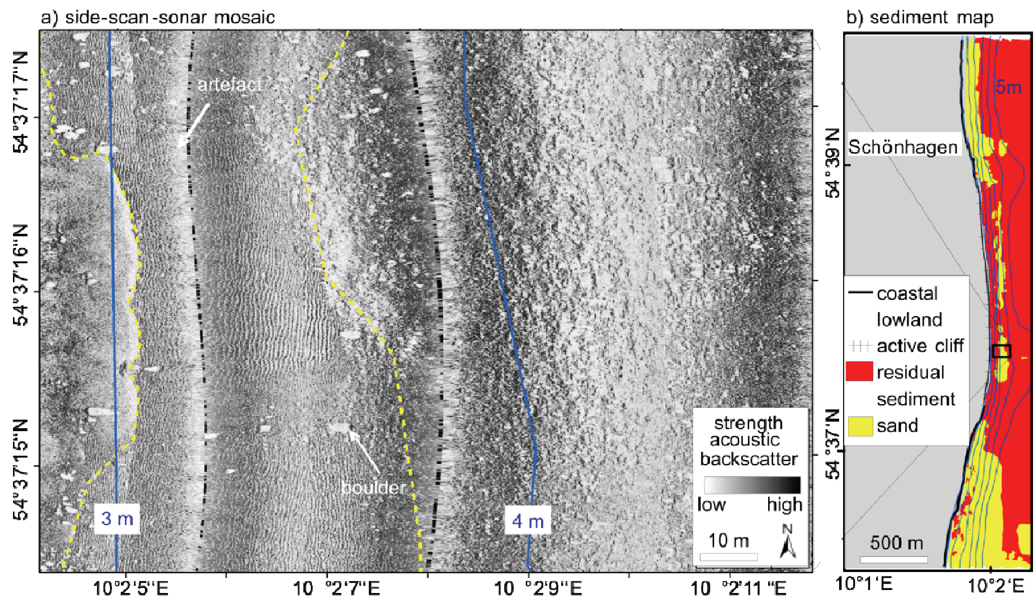

Figure 2a-b: a) Side-scan sonar mosaic from the near-shore zone of Schönhagen mapped on 23 April 2009. b) Sediment map based on SSS data.

The nearshore bar is bordered by heterogeneous sediments varying from gravel to boulder size. Boulders, which are not used as settling ground by macrophyto- and macrozoobenthos, are clearly detectable by dark spots with white acoustic shadows (figure 2a). Large areas of high backscatter indicate cobble coverage, as found eastwards of the nearshore bar. The black lines, which are surrounded by low backscatter, are allocated to device-specific artefacts. However, boulders still can be identified in these zones (figure 2a). The sediment map (figure 2b) reflects a broad, spatial distribution of residual sediments. They are particularly dominant in shallow waters in front of the cliffs and in water depths > 4m. Sandy deposits are widespread in the nearshore zones of the coastal lowlands. The nearshore bar in front of the cliff is almost rudimentary, covering residual sediments.

5 Discussion and conclusion

So far, spatial information on sediment distribution patterns in near-shore zones has been mostly based on aerial or satellite images and sediment sampling in rigid grids. Single cobbles of 10 cm in diameter could not be identified, as possible in the SSS mosaics of this new measuring device. Data of the new SSS now clearly reflect the option of detecting coarse-grained sediments and distribution patterns with high spatial coverage, especially in very shallow water, which has not been done before. In a next step, resurveys are now used to analyse coarse-grained sediment transport, combined by high resolution tracer experiments.

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Coarsening of tidal flat sediments - long-term mud depletion in a tidal bay in the northern Wadden Sea (SE North Sea)

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Abstract

The Wadden Sea is a highly dynamic system characterised by unconsolidated sediments and continuous changes which are mainly driven by hydrodynamics. The grain size composition of the tidal flats reflects information on the prevailing hydrodynamic conditions. The long-term development of the grain size composition of tidal flat surface sediments was surveyed in a shallow semi-enclosed bay in the northern Wadden Sea in order to gain information on changing hydrodynamic forces. Surface sediments were sampled during low tide from November 2004 to December 2006. The outcome was a general spatial distribution pattern of sediment types which was compared to earlier surveys conducted in 1932 - 1933, 1981 and 1989. A significant general coarsening of the surface sediments can be observed over the last 70 years. It is suggested that changing hydrodynamic conditions, that accompany ongoing climate change, are primarily responsible for the mud depletion. The coarsening of sediments is furthermore supported by rigid coastal protection measures, which increase energy levels in the bay, and a reduced areal extent of intertidal seagrass and mussel beds which means a reduction of sheltered areas.

1 Introduction

The shallow sedimentary coastal zone of the south-eastern North Sea is called the Wadden Sea. It is a highly dynamic system characterised by unconsolidated sediments and continuous changes which are driven by waves, currents, tides (hydrodynamics) and wind. The Wadden Sea's most remarkable features are the tidal flats which are exposed during low tide. The grain size composition of tidal flat sediments reflects information on the prevailing hydrodynamics. The aim of this study is to gain information on long-term changes in the grain size composition of these sediments in order to reveal possible relation to a shift in the hydrodynamic regime that might accompany ongoing climate change.

2 Study area and methods

The study area is Königshafen (55° 02' N, 8° 25' E), a sheltered tidal bay at the island of Sylt located in the northern Wadden Sea (figure 1). The tides are semidiurnal with a mean tidal range of 1.8 -2 m. The current velocities vary from 0.6 m s-1 in a tidal channel near the opening of the bay to 0.1 m s-1 in the inner Königshafen (Backhaus et al. 1989). The tidal flats are primarily sandy but muddy and mixed sediments occur in sheltered locations (figure 2, 2004 - 2006).

Surface sediment samples of 129 equally distributed stations in the Königshafen were collected during low tide in 15 sampling campaigns at regular intervals from November 2004 to December 2006. The averaged sediment data were georeferenced with a Geographic Information System (GIS) and area-wide maps calculated. The outcome was a general spatial distribution pattern of sediment types. This pattern was compared to earlier surveys conducted in 1932 - 1933, 1981 and 1989.

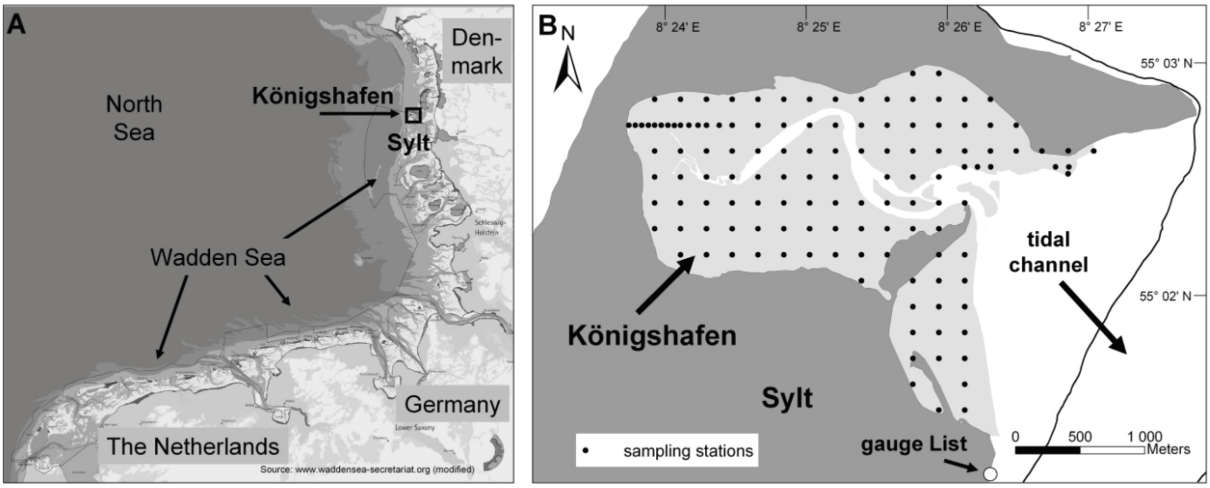

Figure 1: The sampling stations on the tidal flats of the study area Königshafen (B) at the northern top of the island of Sylt, located in the Wadden Sea (A)

3 Results

The current sediment distribution pattern reveals that finest sediments occur in the inner part while coarser sediments occur in the eastern half of Königshafen (figure 2, 2004 - 2006).

From 1932 - 1933 to 2004 - 2006, the intertidal mud cover decreased from 21 % to 2 % while sand cover increased from 68 % to 90 % (figure 2). The increasing sand dominance results from a loss of mud flats. The decrease of mud flats occurred primarily in the more exposed eastern half of Königshafen near the opening which is bordered by a major tidal channel (figure 1).

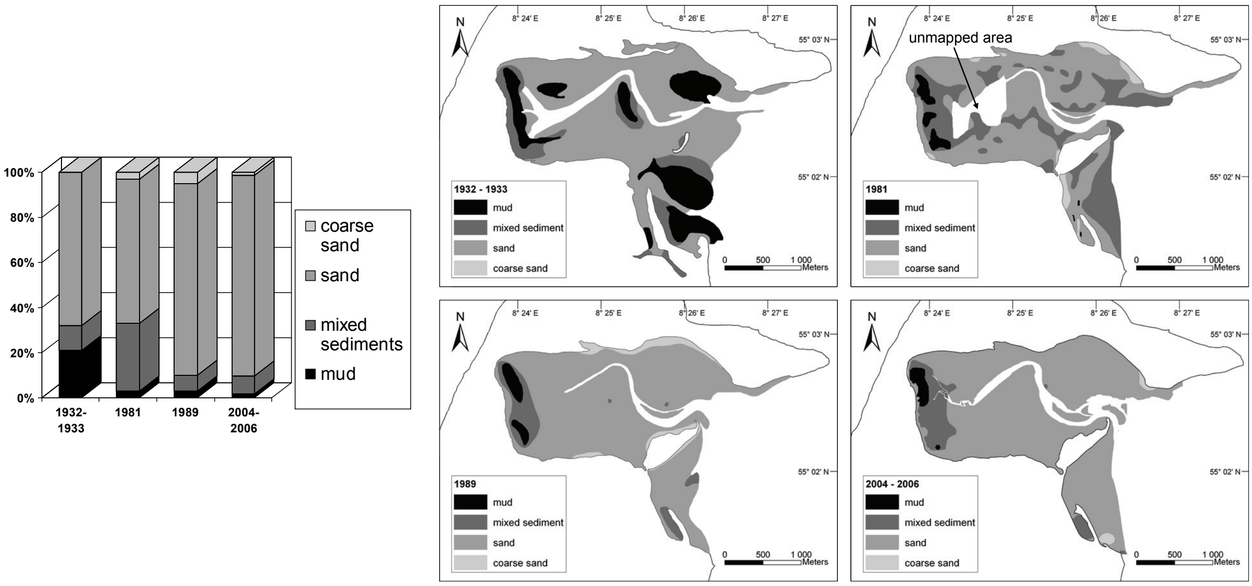

Figure 2: Sediment distribution in Königshafen in 1932 – 1933 (Wohlenberg 1937), 1981 (by Felix), 1989 (by Austen) and 2004 - 2006 (own data)

4 Discussion and conclusions

It is suggested that changing hydrodynamic conditions that accompany ongoing climate change are primarily responsible for the mud depletion. Long-term records from the gauge List show that the mean low tide level remained relatively stable at 402.9 cm (1936 – 2005), while the mean high tide level rose from 567.81 cm (1936 – 1945) to 585.23 cm (1996 – 2005). This results not only in an increased high tide level but also in an increased tidal range. Both phenomena are associated with stronger currents. The increased hydrodynamic conditions cause selective removal of fine-grained sediments and hamper mud deposition. As the opening of Königshafen is located in vicinity to a major tidal channel, the eastern half is more exposed and a decline of mud flats is predominant here.

Increased hydrodynamics are also caused by a reduction of the tidal catchment area which leads to higher energy levels within a bay (Flemming & Nyandwi 1994). Considerable embankment took place in Königshafen and the associated List tidal basin over the past 500 years, resulting in a loss of 1/3 of the tidal flat area (Reise 1998).

Mud depletion is furthermore supported by a severe decline in seagrass bed and mussel bed area (with algae cover): from 31 % (1936) to 9 % (2005) referring to the tidal flat area of Königshafen (own data). Both structures provide shelter from stronger currents and the decline of seagrass and mussel beds means fewer areas where mud flats can establish or remain.

However, coarsening of sediments is not just a local phenomenon but is reported from the entire Wadden Sea, e.g. the Dutch Wadden Sea, the East Frisian Islands and from the Hörnum tidal basin south of the island of Sylt (Flemming & Bartholomä 1997, Mai & Bartholomä 2000, Zwarts 2003, Van Bernem, pers. comm.). The change in sediment composition does not only reveal changed hydrodynamic conditions but surely has also an impact on the benthic fauna.

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Studies on the Development of Wind set-up in the River Elbe

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Abstract

Storm surges are often the reason for crevasses, flooding, damages and if it comes to the worst fatal casualities. To minimize damages the construction of stable and high dikes is one of the necessities. Another important issue is to understand the physical processes causing storm surges and the application of this knowledge to forecast water levels. These forecasts can save life and protect areas like ports or lower laying areas where portable flood protection measures can be installed. In Hamburg an approach to forecast water levels of storm surges exists already.
Within a research project the main objective is to improve the forecasting water levels along the tidal River Elbe. Additionally Hamburg Port Authority deals with the analysis of physical processes contained by empirical and statistical research especially on storm surges, while partners in the project generate numerical models to forecast water levels induced by tides. The validation for storm surges is also based on statistical interpretation.

1 Background and Motivation

Hamburg Port is the most important port of Germany and one of the most important ports in Europe. Bulk cargo and containers reach Hamburg by vessel via the River Elbe. Increasing economy during the last centuries resulted in growing length and width of vessels and of course deeper draughts. As the River Elbe is subjected to the tide it is necessary to forecast the water levels of all gauges along the fairway as exactly as possible.

To improve the prognoses for storm surges, Hamburg Port Authority (HPA) is a member of the research project OPTEL – Wind set-up Studies and Development of an Operational Model of the tidal River Elbe – funded by the Federal Ministry of Education and Research. The main intention of this project is the development of an operational numerical model which supplies continous information on water levels and currents of the River Elbe. OPTEL receives scientific support by the German Coastal Engineering Research Council.

The Federal Maritime and Hydrographic Agency (BSH) and the Federal Waterways Engineering and Research Institute (BAW) generate the models for the forecasts (OPTEL – A & C), the German weather Forecast Agency "Deutscher Wetterdienst" (DWD) handles wind data for the models (OPTEL – B) and the HPA assumes the collection and preparation of all required data and focuses on storm surges, their causes and characteristics (OPTEL – D).

In this article first studies and results on the main topic of HPA - the storm surges are presented.

2 Objectives

In 1962 a storm surge caused many crevasses and more than 300 casualities. Since then HPA is working on the research of storm surges. During this storm tide the water level reached a value which was never recorded before. After 1962 the research on storm surges headed to the establishment of the Hamburger Sturmflutwarndienst (WADI). This service alerts the port and the citizens of Hamburg in case of a storm surge. An empirical and statistical approach provides forecasts of the water level in Hamburg. In most of the cases these forecasts are precise, but there are of course some storm surges, where forecasted and measured water levels differ more than 20 cm. Results of OPTEL – D hopefully lead to further improvement of that approach to reduce such rough results.

Storm surges are mainly caused by wind. In detail the aim of OPTEL – D is to define more precisely the influence of wind in the German Bight and the Waddensea. Are there similarities between wind directions, constancy of the wind and duration of wind velocities? Where is the major influence on the water levels by the wind: from the mouth of the River Elbe up to Hamburg, in the German Bight or further offshore in the North Sea? The analysis of the development of the rising water levels from the North Sea to Hamburg is another important component of OPTEL – D.

Another topic is the analysis of the upstream water discharge of the River Elbe, measured in Neu Darchau upstream of the weir of Geesthacht. The standardization of the water levels can show the influence of discharge on storm surge water levels.

3 Location and Approaches

The first step by the project team was to agree on the main gauges to analyse the water levels, the wind recording stations to investigate the wind set-ups and to define other important data necessary for the studies besides the upstream water discharge.

The collected data for OPTEL and its storm surges refers to the period from 1980 to 2008. In addition to this period the storm surges, defined in OPTEL, needed to have the following characteristics:

- the water level in Cuxhaven exceeds more than 2.0 m above high water (mean high water in Cuxhaven: + 1.5 m NN) and
- the water level in Hamburg – St. Pauli is higher than + 4.0 m NN.

Both characteristics are independent of the phase of the tide. These basic principles lead to approximately 150 storm surges.

In the proposal of OPTEL the names of different gauges of the River Elbe which are the basic for the research, are mentioned:

Table 1: Gauges of the River Elbe considered in OPTEL

Gauge	Short	River Elbe Station [km]
Cuxhaven	CUX	724
Brunsbüttel	BRU	697
Brokdorf	BRO	684
Glückstadt	GLÜ	674
Grauerort	GRA	661
Schulau	SCH	641
Hamburg – St. Pauli	STP	623
Bunthaus	BUN	610
Zollenspieker	ZOL	598
Geesthacht (weir)	GST	586

To analyse the wind blowing from the North Sea to Hamburg the project team agreed to use the following wind recording stations: Borkum (located north of the Ems Estuary, border between Germany and the Netherlands), Scharhörn and Neuwerk (located outside of the mouth of the Elbe Estuary) and Cuxhaven, Brunsbüttel, Ruthenstrom and Finkenwerder all along the River Elbe.

Figure 1 gives an overview of all relevant gauges and wind recording stations.

Figure 1: Review of the River Elbe, position of the gauges, wind recording stations and upstream water discharge (www.google.de)

Wind set-up is defined as the difference between an expected and an actually reached water level. This difference is mainly produced by wind and leads to higher water levels. To estimate the difference the astronomical or the mean tide is required. The astronomical tide has been calculated by the BSH for the period from 1980 to 2008. The mean tide is calculated from the averaged water levels over five years. The discrepancy of the results will be analysed for both wind set-up graphs.

To identify the causes for wind set-up is the main aim of the analysis in OPTEL – D, especially to improve the forecasts. To survey a status quo for analysis of storm surges three different statistical and empirical approaches were used. All of them exclusively consider the peak values in Cuxhaven and Hamburg – St. Pauli at high water time.

The first approach is a comparison between the forecasted water level and the measured water level for Hamburg – St. Pauli by WADI and its empirical statistical method at the moment of high tide in Cuxhaven. This comparison gives information about the accuracy of the forecast by this method.

The difference between low water tide and the following high water tide is the second approach. This difference, called tidal rise, from Cuxhaven and Hamburg will be set in contrast with each other in a scatter diagram.

To obtain a relation between the wind set-up during high tide (independent of high water time) of Cuxhaven and Hamburg is the third approach.

Figure 2 shows two outlines to explain the calculation of the wind set-up and the tidal rise.

The relation for wind set-up and tidal rise between Cuxhaven and Hamburg is presented in scatter diagrams in figure 3. The values of Cuxhaven are shown on the x-axis while on the y-axis the values of Hamburg – St. Pauli are presented. The first diagram displays the results of the wind set-up. The second diagram shows the result of tidal rise comparison as well as the linear regression.

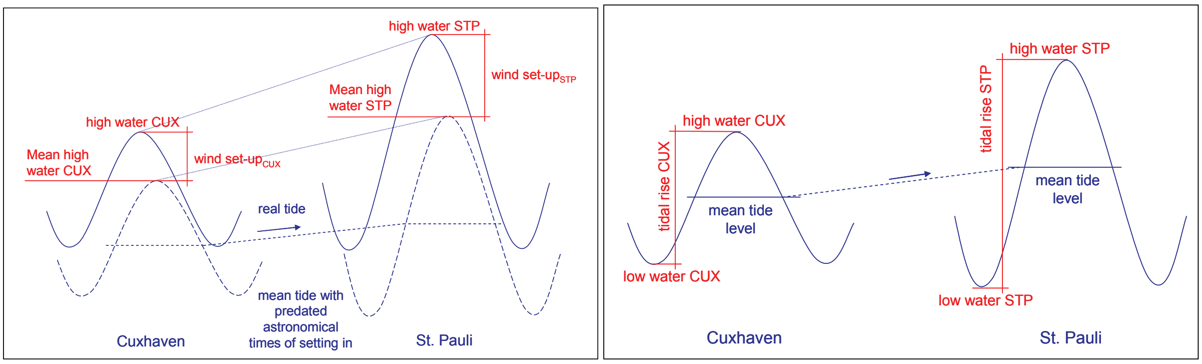

Figure 2: Outlines for the explanation of wind set-up (left) and tidal rise (right)

At first glance the results of the tidal rise look much better than the results of the wind set-up comparison. However, the different scaling of the axis and the standard error of these two approaches indicates that the wind set-up comparison provides better results.

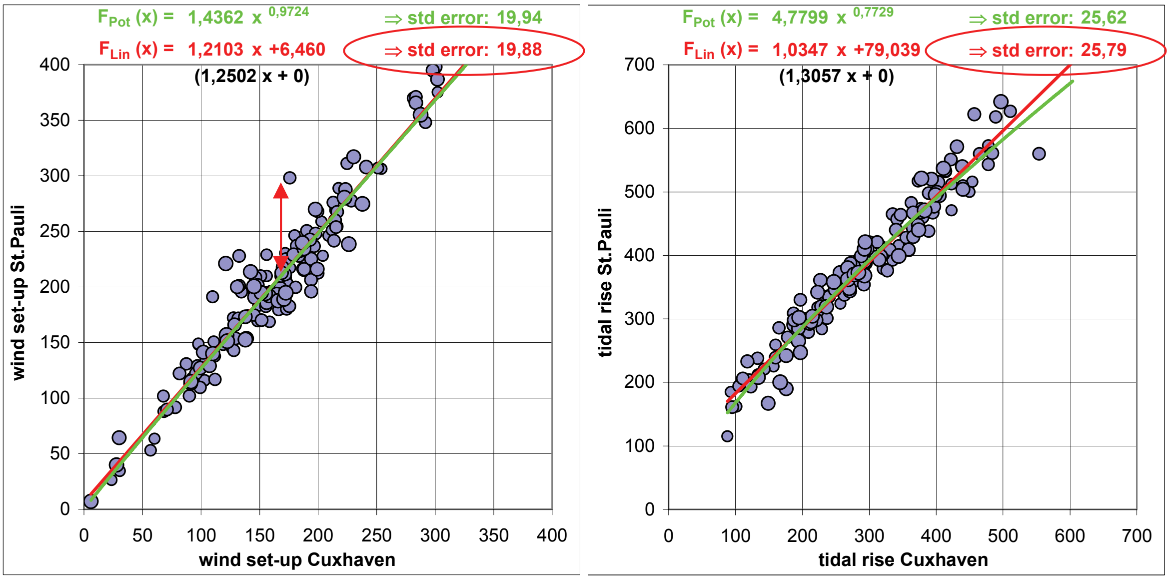

Figure 3: Scatter diagrams for wind set-up s (left) and tidal rise (right)

Another form of presentation for these scatter diagrams is a chronological order of the storm surges and their results of wind set-up / tidal rise. The difference between function value and regression line is labelled by the pink scatters in figure 4 – only shown for the wind set-up approach.

Additionally it is possible to show the correction of the upstream water discharge in this figure. By means of a multiple regression the effect of the upstream water discharge can be described. The white scatters show the dimension of the effect. The mean deviation for wind set-up averages here about ± 7.6 cm / 1000 m^3. For the tidal rise approach the discharge shows an influence of ± 16 cm / 1000 m^3.

It can be seen that the influence of the discharge in case of storm surges is not critical. The means are less than 20 cm which is the boundary value. This boundary value results of the WADI – approach. The forecast error should be less than 20 cm for storm surges.

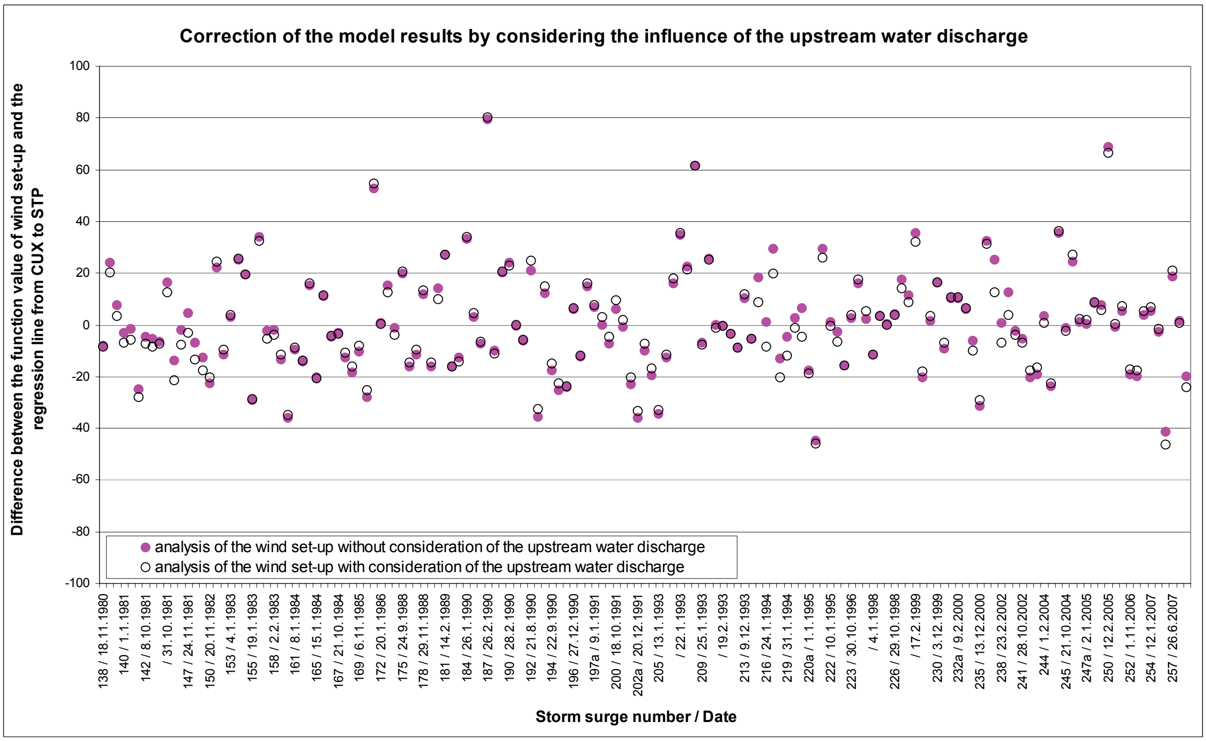

Figure 4: Difference between the function value of wind set-up and the regression line as well as the influence of the upstream water discharge

The same form of presentation demonstrates the results of all three approaches (wind set-up, tidal rise and the WADI – approach) for every storm surge in figure 5. Wind set-up and tidal rise are available for every event; unfortunately the results of the WADI – approach are incomplete. Due to the enlargement of the lists of events there is no WADI – data for every storm surge. If there has not been made a forecast by WADI, no data have been stored and it is very complex to reproduce the missing data. Therefore some gaps in data appear which will be filled contemporary.

None the less one tendency is obvious. Since 1993 – the last optimisation after the beginning of the development in 1978 – the WADI-approach supplies very good results, except a few. The continuous advancement of this approach shows that many influencing factors are already considered in this empirical and statistical procedure.

The spreading of the tidal rise approach and the wind set-up approach are clearly larger than the spreading for WADI. Especially the values of the tidal rise seem to be very discontinuous, but the standard error is nearly the same as that of the WADI – approach. The standard error of the wind set-up is a bit lower. To conclude, the wind set-up between Cuxhaven and Hamburg appears to be the best approach for further analysis.

The next step was a research along all gauges of the River Elbe to show the development of the tidal wave in the estuary. The two different approaches, tidal rise and wind set-up, were used to analyse this effect. The tidal wave runs from Cuxhaven along Brunsbüttel, Brokdorf, Glückstadt, Grauerort and Schulau to Hamburg – St. Pauli. Figure 6 shows the relation of the wind set-up between every gauge to Hamburg – St. Pauli exemplarily for both approaches.

Red circled black values give information about the forecast error. From Cuxhaven and Brunsbüttel to St. Pauli the forecast errors are about 25 and 14 cm. Upstream Brokdorf the errors are less than 10 cm, which is a very good result. Therefore the progression of the storm surges from Brokdorf to Hamburg along the inner estuary can be described quite well as linear.

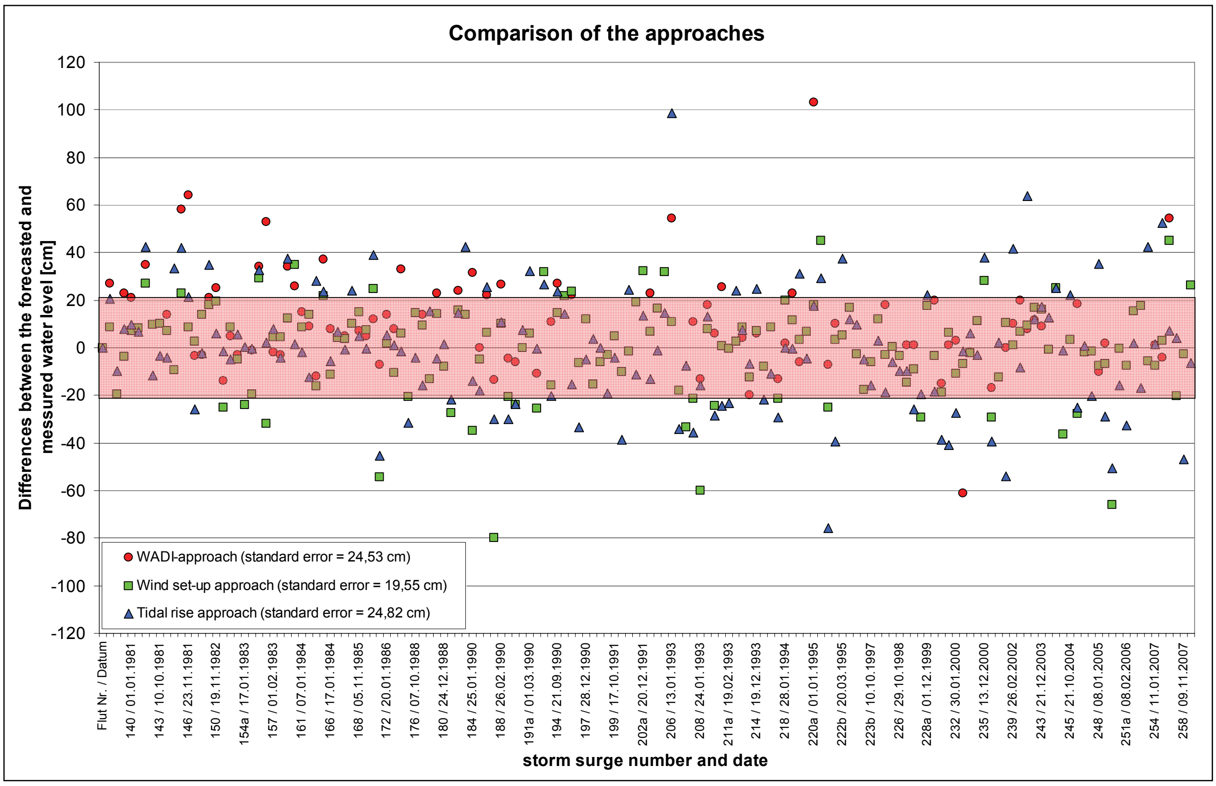

Figure 5: Comparison of the three analysing approaches and their standard error

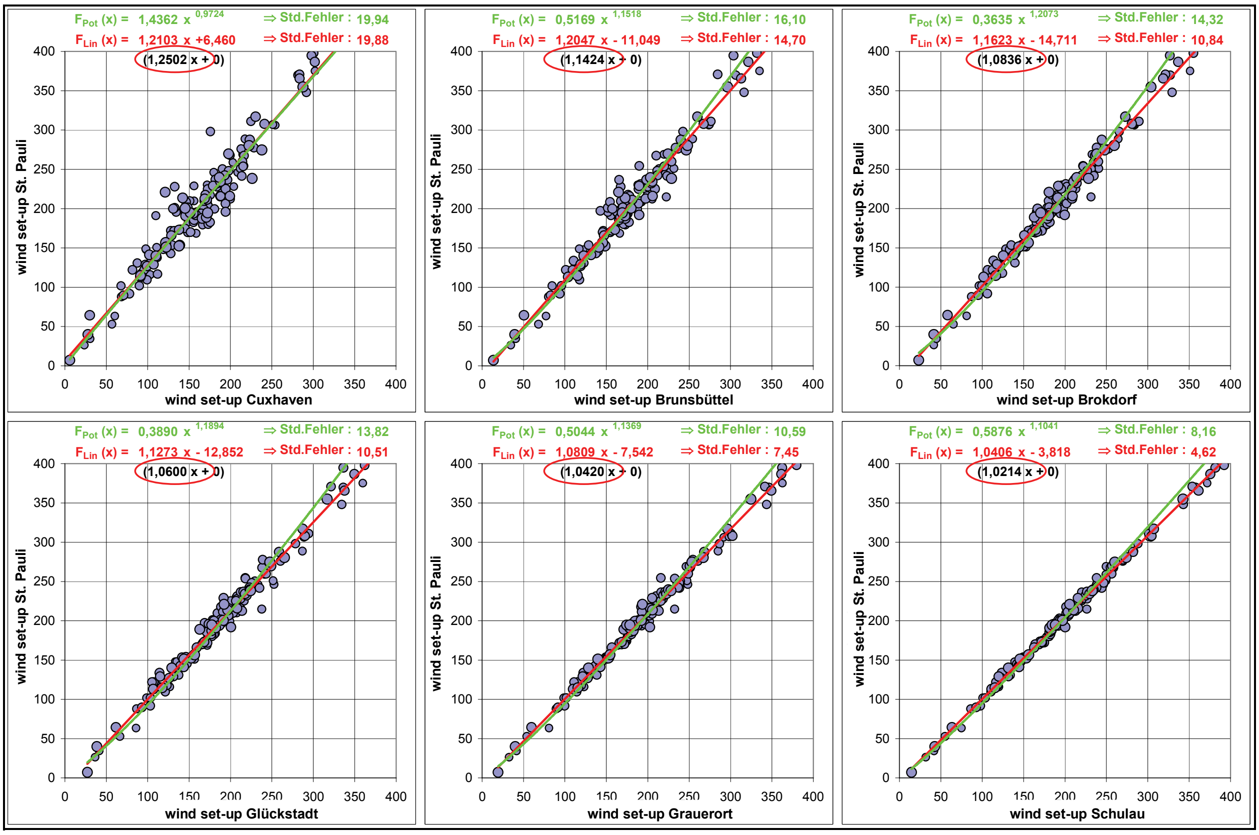

Figure 6: The run of the tidal wave from the mouth of the River Elbe to Hamburg – St. Pauli for the tidal rise approach

The results of this effect are a very important result. This implicates that the influences on the water levels are located outside the mouth of the River Elbe. Certainly this fact is just a little help for the forecasts. The tidal wave needs about 2-3 hours from Cuxhaven to St. Pauli and it would be too late for an alert. But this knowledge can be used for a specification of the forecasts and about ceasing the handling of cargo or not.

The wind is probably the most important influence on water levels, because it causes the wind set-up. Therefore it is necessary to research the main factors on that. There are three important parameters: wind direction, wind speed and the difference of wind set-up between Cuxhaven and Brokdorf. The aim is to find the main wind set-up causing direction and period of time. Is there a time period before high tide in Cuxhaven that has a great influence on the wind set-up heights and would the consideration of this result lead to better forecasts? Research of this fact is still at the beginning. Wind data from Scharhörn are currently used but probably there will be a concentration on the wind data of Cuxhaven and Brunsbüttel too.

4 Results

At the beginning data collection, controlling and validation were the main part of OPTEL - D. The following data are collected: water level, wind speed and direction, degree of salinity, flow velocity and direction, water temperature, upstream water discharge, mean and astronomical tide.

The water level data were used for the analysis of three different approaches. The evaluation of the approaches showed, that the wind set-up approach gives the best results. But to minimise the standard errors the understanding of the physical effects causing the increasing water levels is necessary.

The factor of the upstream water discharge is not responsible for high variations between expected and measured water level. There is an influence but it is not essential. Another factor is the linear describable movement of the tidal wave from Brokdorf through the estuary up to Hamburg - St. Pauli. There is evidence to imply, that all influences causing the wind set-up are located in the German Bight and the mouth of the River Elbe. The wind along the River Elbe is not that important for the water levels, which are reached in Hamburg - St. Pauli. This increase is created by the narrowing shape of the River Elbe.

At least the wind outside the estuary is the main cause for the height of the wind set-ups. But it is very difficult to apportion the different elements of the wind as direction, speed, duration and produced wind set-up height. Therefore - as a next step - all storm surges are needed to be analysed individually.

5 Discussion and conclusion

Further analyses for improved statistical and empirical models for storm surges are still necessary. Other appendages for the research in OPTEL - D are for example the variation of the gradient of the individual tide or the filling degree of the estuary, when a storm surges is expected.

The co-partners of OPTEL are dealing with other components.

OPTEL - A establishes a model of the River Elbe based on BSHcmod and designed by BSH. BAW also works on a model, but based on UnTRIM. This part is OPTEL - C. Both partners need to calibrate and validate their models. They also need to accomplish an interface to transfer hydrodynamic parameters like water levels, flow and degree of salinity from the model of the North Sea to the model of the River Elbe.

DWD computes the roughness of the surface and the topography along the River Elbe up to the weir Geesthacht. Additionally the production of coefficients for the correction of wind speed dependent on the direction is required. The coefficients are part of the meteorological models COSMO-DE and COSMO-EU.

The work proceeds very well. DWD has almost finished. BSH and BAW are arranging the parameters for each model to get comparable results. In the near future the first test runs will start. The validation and calibration of the models will proceed with six scenarios of different hydrological situations of the River Elbe. For example: outstanding low water levels caused by longer lasting southeast wind, two storm surges with different wind set-up curves and a period with high upstream water discharge.

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Total volume concentration and size distribution of suspended matter at sites affected by water injection dredging of subaqueous dunes in the German Weser Estuary

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Abstract

A laser based in-situ particle sizer (LISST) was used to analyse spatial and temporal variability of total volume concentration (TVC) and particle-size distribution (PSD) of suspended particulate matter (SPM) during water-injection dredging (WID) of subaqueous dunes in the German Weser estuary. Ground-truthing was done by water sampling. Investigated WID sites are located in the brackish and freshwater zone, respectively. Measurements were conducted in June 2008, during neap tides and low river-discharge. TVC of SPM is tidal controlled. Site-specific differences of SPM amount and sizes are recognisable, but dredging impact is hardly visible in the data.

1 Background and Motivation

Migrating subaqueous dunes are well known features of estuarine systems. Consequently, cost-intensive sediment dredging is frequently ongoing in estuarine navigation channels to guarantee save ship access. Interest is given to dredging techniques, which reduce maintenance costs such as water-injection dredging (WID), which was introduced in the eighties. Since then, worldwide operation has widely been increased (Meyer-Nehls et al. 2000). During WID, huge amounts of water are pumped from the river surface to a dredging sledge, equipped with jets injecting water into the sediment surface. Pumping capacity and water pressure can mostly be adapted to bed characteristics. Cost-intensive sediment transfer to dumping sites is redundant. Efficiency of WID has been proven for muddy (Aster 1993, Woltering 1996) and sandy deposits (Clausner 1993, Nasner 1992). It has been frequently used in harbours (Spencer et al. 2006) and in navigation channels (Stengel 2006). So far, only few studies deal with dredging-induced dispersal and behaviour of SPM. Investigations in Hamburg and Emden harbor (Germany) have shown, that dredging induced increase of suspended sediment concentrations (SSC) only occurred over a distance of 100 m (Meyer-Nehls et al. 2000) and 200 m (Aster 1993), respectively. Vertical intrusion did not exceed 1-2 m in height above the riverbed, as found in Hamburg harbor (Meyer-Nehls et al. 2000). So far, WID-induced changes in PSD of estuarine SPM are not known. Mikkelsen & Pejrup (2000) reported on dredging-related changes of PSD in the Scandinavian, non-tidal Øresund. Due to particle flocculation, size spectra changed from fine, poorly sorted to coarse, moderately sorted particles with increasing distance from the dredging device.

2 Objectives

This study focuses on potential changes of TVC and PSD during WID of subaqueous dunes in the navigation channel of the Weser estuary to assess spatial and temporal related dredging impact on estuarine suspended sediment dynamics. Two sites are chosen to verify differences linked to brackish or freshwater conditions.

3 Study area

The meso- to macro-tidal Weser estuary is located at the German North Sea coast (figure 1).

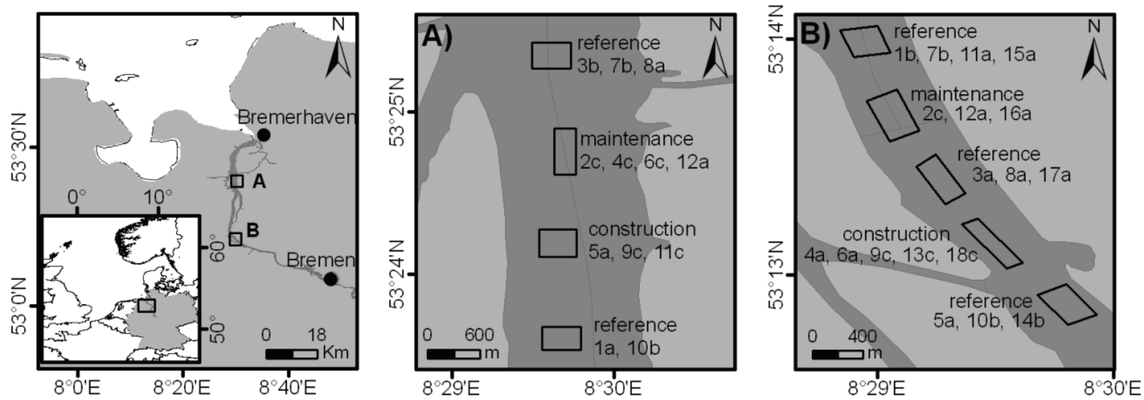

Figure 1: Left: Overview of the Weser estuary with markings of the two sites A and B. Centre and right: study sites in detail with subsections.

Site A was located at the southern end of the brackish reach and of the turbidity maximum zone (TMZ) during the experiments (figure 1). Depending on tidal phase, meteorological conditions and freshwater discharge, this zone can be shifted further up or down-stream (Grabemann & Krause 2001). The water column is well mixed due to tidal flow velocities of 1-1.3 m/s on average. SSC can reach values of up to 1.5 g/l in the water column of the TMZ (Grabemann & Krause 1989, 2001) with increasing values in the near-bed zone (Schrottke et al. 2006). Spatial distribution of SSC strongly depends on the tides. Whereas SPM is well distributed during ebb and flood phases, particle settling starts with decreasing tidal flow. Large particle aggregates of > 100 µm are formed (Wellershaus 1981).

Site B represents the freshwater reach (figure 1). Tidal currents, which amount to 1 m/s, are slightly lower (Schuchardt et al. 1993). SSC is mainly controlled by riverine input. Generally, SSC values do not exceed 0.05 g/l in the tidal dominated freshwater zone (Grabemann & Krause 2001, Schuchardt et al. 1993). Tidal induced SSC variation is less pronounced.

Riverbed morphology in the channel sections of both sites is characterised by subaqueous dunes of up to 6 m in height and of up to 150 m in length (Schrottke et al. 2006). The dunes are mainly two- or three-dimensional, lateral orientated to the main flow direction in the navigation channel and reflect ebb dominance (Schrottke et al. 2006). Dunes are mainly consist of medium-sized sands (Stengel 2006). Dune morphology and grain-size composition are frequently impact by dredging.

4 Material and Methods

In-situ PSD is detected by laser diffraction with a 'Laser In-Situ Scattering & Transmissometry' system LISST-100x (type-C, Sequoia® Scientific Inc.). A collimated laser beam is scattered at small particles in the water column and processed at a multi-ring detector. PSD is displayed in 32 logarithmically-spaced size classes, ranging from 2.5 to 500 µm (8.6 to 1.0 Phi). Particles beyond the measuring range are assigned either to the finest or largest size class, respectively (Agrawal & Pottsmith 2000). This can cause rising tails at the boundaries. There is no option for differentiation between particles and air bubbles. PSD is presented as volume concentration (VC) of each size class, summed-up to TVC. This is related to optical transmission (τ) detected with a photodiode. Multiple scattering can appear at $\tau < 0.3$, which leads to an overestimation of small particles (Agrawal & Pottsmith 2000). A path reduction module (50 %) was installed to reduce the optical path length and thus the sample volume. Checking the overall health of the instrument and in order to correct for optical attenuation by water and microscopic imperfections on the optical surfaces, a background scattering was acquired in the morning of each measuring day. A full technical description of the LISST is done by Agrawal and Pottsmith (2000) and Agrawal et al. (2008). The LISST was applied from a drifting vessel in profiling mode down to the near riverbed. Minimum distance between dredging and research vessel amounted to ~30 m.

TVC calibration was done by horizontal water sampling (2.2 litre, Hydro Bios©), at two different water depth. In the laboratory, an aliquot of defined volume was vacuum-filtered (glass-fibre filters, 1.2 µ). The filters were dried at 60°C for 12 hours. SSC was calculated by dry mass per unit sample volume.

Measurements were done on 10 June 2008 at site A and on 24 June 2008 at site B under low river discharge (180 m³/s, Water & Shipping Authority Bremen, pers. comm.) and neap tides. Both sites were subdivided in 4-5 subsections, representing the type of dredging impact such as maintenance or constructional work or unaffected subsections (reference), displayed in figure 1. All subsections exhibited comparable hydrodynamics and sedimentology. Profile indexes indicate relation of measuring position to WID: a) luv-site, b) lee-site c) on-site.

5 Results

TVC and τ significantly correlate, as found at both sites with R^2=0.89 (figure 2). Overall, τ did not exceed 0.6, more often it decreased below 0.3, as found for 80 % and 15 % of all measurements, carried out at site A and B, respectively (table 1).

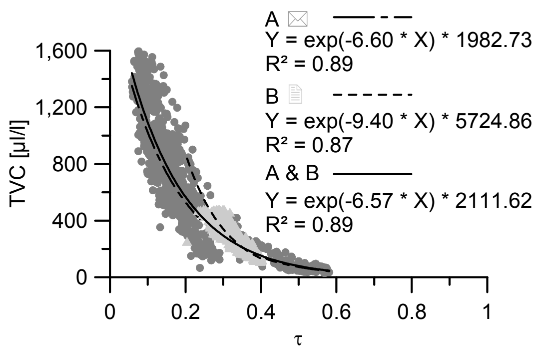

Figure 2: Correlation of optical transmission (τ) and TVC for site A and B

PSD changed within seconds from unimodal curves to the ones with rising tails at the coarse end of the size spectra. Depth-related changes of PSD and VC at site A are displayed in figure 3. Mean particles sizes range from 2.0 to 4.9 Phi (table 1) with a downward particle coarsening of 0.6 Phi on average as well as a slight increase of VC for size spectra > 8 Phi. A distinct development in mean particle size between the profiles is not obvious. Several times, water turbidity was announced to be too high before reaching the ground at subsections b and c without specific changes of TVC or particle sizes, as found by comparing measurements 7b and 8a in figure 3. At site B, mean particle-size range with 1.9 to 3.3 Phi (table 1) was slightly smaller, but again with no depth-related change (figure 4). Mean particle size only varied among the subsections.

Highest TVC at site A amounted to ~1,600 µl/l during slack-water ebb (figure 3: 7c, 8a) and ~470 µl/l for site B around slack-water flood (figure 4: 1b - 3a, 15a -18c). SSC values ranged from 22 to 320 mg/l and 26 to 128 mg/l at site A and B, respectively.

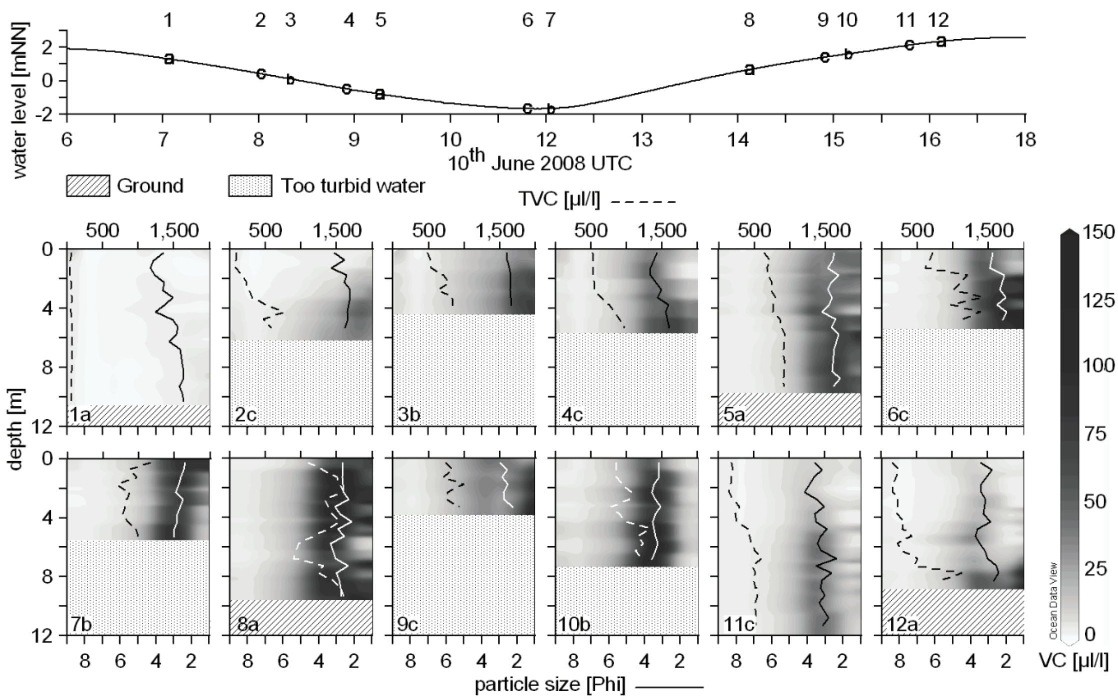

Figure 3: Depth-related VC and PSD at site A (brackish water zone). Solid curves represent mean particle size; dashed lines visualise TVC.

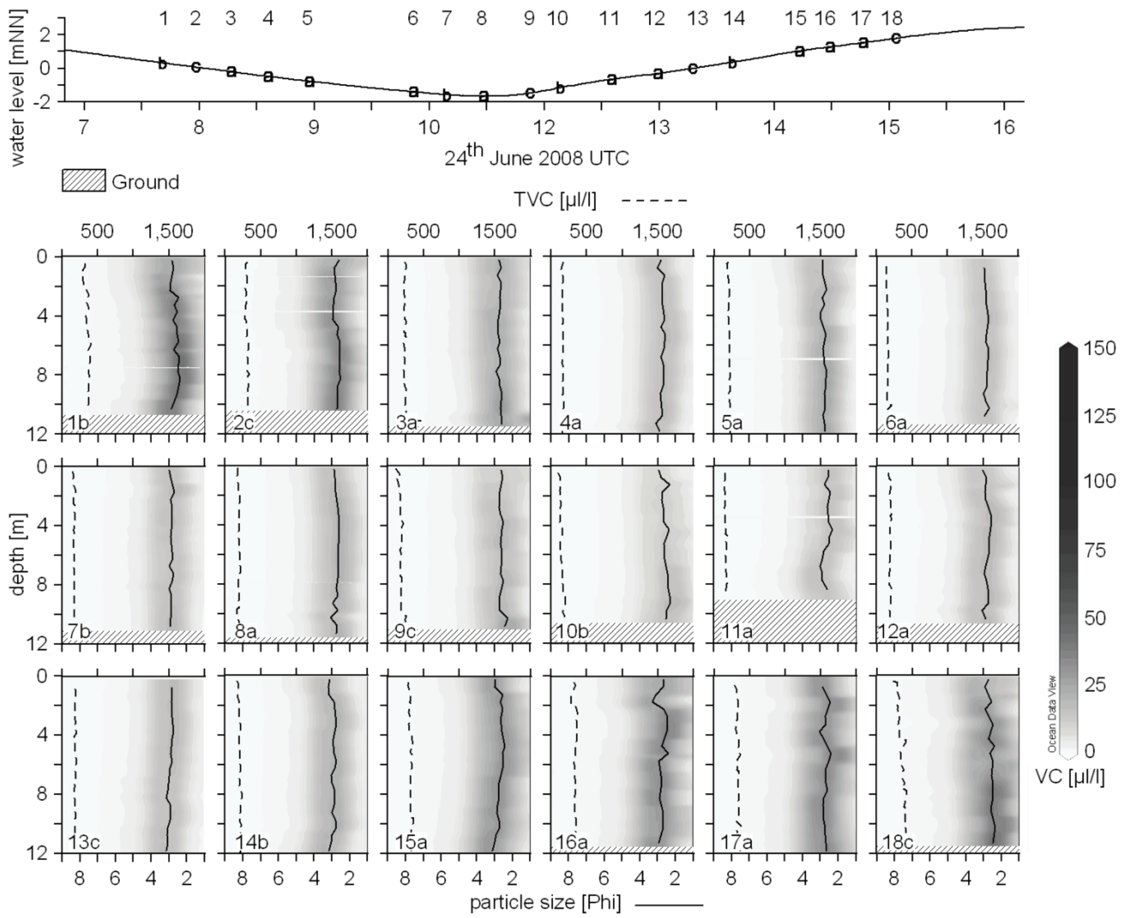

Figure 4: Depth-related VC and PSD at site B (freshwater zone). Solid curves represent mean particle size; dashed lines visualise TVC.

Table 1: Measured parameter at site A and B.

site	A				B			
	Ø size [Phi]	TVC [µl/l]	τ	SSC [mg/l]	Ø size [Phi]	TVC [µl/l]	τ	SSC [mg/l]
min	2.0	29.9	0.06	22	1.9	103.7	0.2	26
max	4.9	1598.4	0.58	320	3.3	469.4	0.4	128
Ø	2.9	650.2	0.22	113	2.8	239.2	0.3	47
τ < 0.3			80%				15%	

6 Discussion and conclusion

In the Weser estuary, suspended sediment dynamics are mainly controlled by tides and river-discharge. This is clearly reflected in data sets of TVC, PSD and SSC, especially at site A, which was located in the brackish zone, at the southern end of the TMZ. Whereas no clear indication of WID impact is given at site B, some dredging induced effects can be derived from data-sets of site A. It is assumed that WID induces temporary increase of near-bed suspended particles (Meyer-Nehls et al. 2000, Stengel 2006). Based on that, TVC must consequently increase. This might have caused repeated near-bed interruption of LISST measurements at site A during WID, where background TVC, SSC and mean particle size are side-specifically higher (brackish zone) as found at site B (freshwater reach). SSC did not rise simultaneously. This seems to be reasonable, taking into account that τ can also be considerably reduced by only few large particles or air bubbles (Mikkelsen & Pejrup 2000). Large particle-aggregates can enhance TVC without affecting mass concentration. Indeed, measured PSD indicated rising tails at the coarse particle-size spectra, repeatedly. Overall, it can be concluded that WID does not seem to have a significant impact on suspended sediment dynamics at the sites investigated with these methods.

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Das Risiko von Extremsturmfluten in Ästuaren angesichts globalen Klimawandels

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Abstract

Climate Change will cause a rise of the sea level and probably more frequent and more violent storm surges. This has serious consequences for the safety of people as well as for their values and assets behind the dikes. It is therefore inevitable to first assess how sea level rise and an extreme storm surge event designes. In a second step it is possible to determine the risk for specific locations and develop strategies.
The joint research project XtremRisk – Extreme storm surges at open coasts and estuarine areas: Risk assessment and mitigation under climate change aspects, funded by the German Federal Government will help answering these questions. The „Source-Pathway-Receptor“ concept will be used as a basis for risk analysis and development of new strategies.
The project offers methods to assess the development of extreme events under the conditions of today. Building on this foundation it tries to design extreme events under conditions reflecting the climate change.

1 Einleitung

Neben dem Anstieg des mittleren Meeresspiegels gehören häufigere und verstärkte Sturmfluten zu den unausweichlichen Folgen des Klimawandels in Küsten- und Ästuargebieten (IPCC 2007). Angesichts des langsamen Meeresspiegel-Anstiegs und der besseren Möglichkeiten zur Anpassung besteht die erste Aufgabe darin, die Folgen der Zunahme extremer Sturmfluten hinsichtlich der Häufigkeit, Intensität und Verweildauer für den Insel-, Küsten- und Hochwasserschutz abzuschätzen, um mögliche Katastrophen abzuwenden. Die Dringlichkeit, den lokalen Folgen des globalen Klimawandels in Form von veränderten Sturmflutverhältnissen vorausschauend und präventiv zu begegnen, ergibt sich unmittelbar daraus, dass Küsten- und Ästuargebiete weltweit bevorzugte Siedlungs- und Wirtschaftsräume sowie Räume wertvollster Ökosysteme unseres Planeten darstellen und daher als vorrangig gefährdet gelten.

Die Ausarbeitung verlässlicher Handlungsempfehlungen und konkreter Gegenmaßnahmen im Sinne einer nachhaltigen Anpassung stößt noch auf folgende Wissenslücken und Schwierigkeiten:

1. Zu große Unsicherheiten bei den langfristigen Prognosen der lokalen Auswirkungen des globalen Klimawandels, insbesondere hinsichtlich der meteorologisch bedingten Komponenten der Risikoquelle "Sturmflut" (Windstau und Seegang). Dies ist vor allem auf das Fehlen verlässlicher lokaler Klimamodelle mit der entsprechenden Auflösung sowie auf das Fehlen geeigneter Modelle zur Sturmflut- und Seegangsvorhersage unter langfristig veränderten küstenmorphologischen (Bathymetrie) und sozio-ökonomischen Bedingungen (Landnutzung) zurückzuführen.
2. Das Fehlen von prozessorientierten, wissenschaftlich fundierten Modellen für die Vorhersage langfristiger und großräumiger morphologischer Veränderungen im Küstenraum, die nicht nur alle Komponenten der Sturmflut - und somit die Bemessungswasserstände -, sondern auch den Bemessungsseegang maßgeblich beeinflussen. Insbesondere werden die Bemessungswellenhöhen im Küstenbereich vorwiegend durch die Wassertiefe und die Sohlneigung bestimmt

(Brechkriterien), so dass große Unsicherheiten auch bei der Vorhersage des Bemessungsseegangs unvermeidlich sind.

3. Das Fehlen grundlegender Kenntnisse darüber, wie der Sturmflutverlauf und Seegang in einer bislang von der Natur noch nicht ausgespielten Kombination zu (Sturmflut-) Szenarien zusammengeführt werden können, bei denen es zu inakzeptablen gesamtwirtschaftlichen Schäden kommt ("Perfekte Sturmflut").

Das Schließen der o.g. Wissenslücken und die Schaffung der erforderlichen grundlegenden Kenntnisse und Methoden, die es ermöglichen, wissenschaftlich fundierte Vorhersagemodelle zu entwickeln und die damit verbundenen Unsicherheiten verlässlich abzuschätzen, werden wahrscheinlich mehr als zehn Jahre in Anspruch nehmen (Oumeraci 2004).

Seit dem 1. Oktober 2008 wird daher ein vom Bundesministerium für Bildung und Forschung (BMBF) finanziertes Verbundprojekt durchgeführt, in dem Wissenschaftler der Universitäten Siegen, Braunschweig, Hamburg - Harburg sowie des Landesbetriebs für Straßen, Brücken und Gewässer Hamburg unter der Leitung von Prof. Dr.-Ing. Hocine Oumeraci des Leichtweiß-Instituts für Wasserbau der TU Braunschweig das Auftreten und die Auswirkungen extremer Sturmfluten analysieren.

Aufgrund der hohen Variabilität der Einflussparameter, der Stochastik der verschiedenen Prozesse und deren Wechselwirkungen sowie der o.g. Modell-Unsicherheiten werden neben den Unsicherheitsanalysen (z.B. Monte-Carlo-Simulation, Latin-Hypercube-Sampling) auch systematische Sensitivitätsanalysen für die Untersuchung der relativen Bedeutung der Einflussparameter sowie der praktischen Implikationen für die abzuleitenden Handlungsempfehlungen durchgeführt.

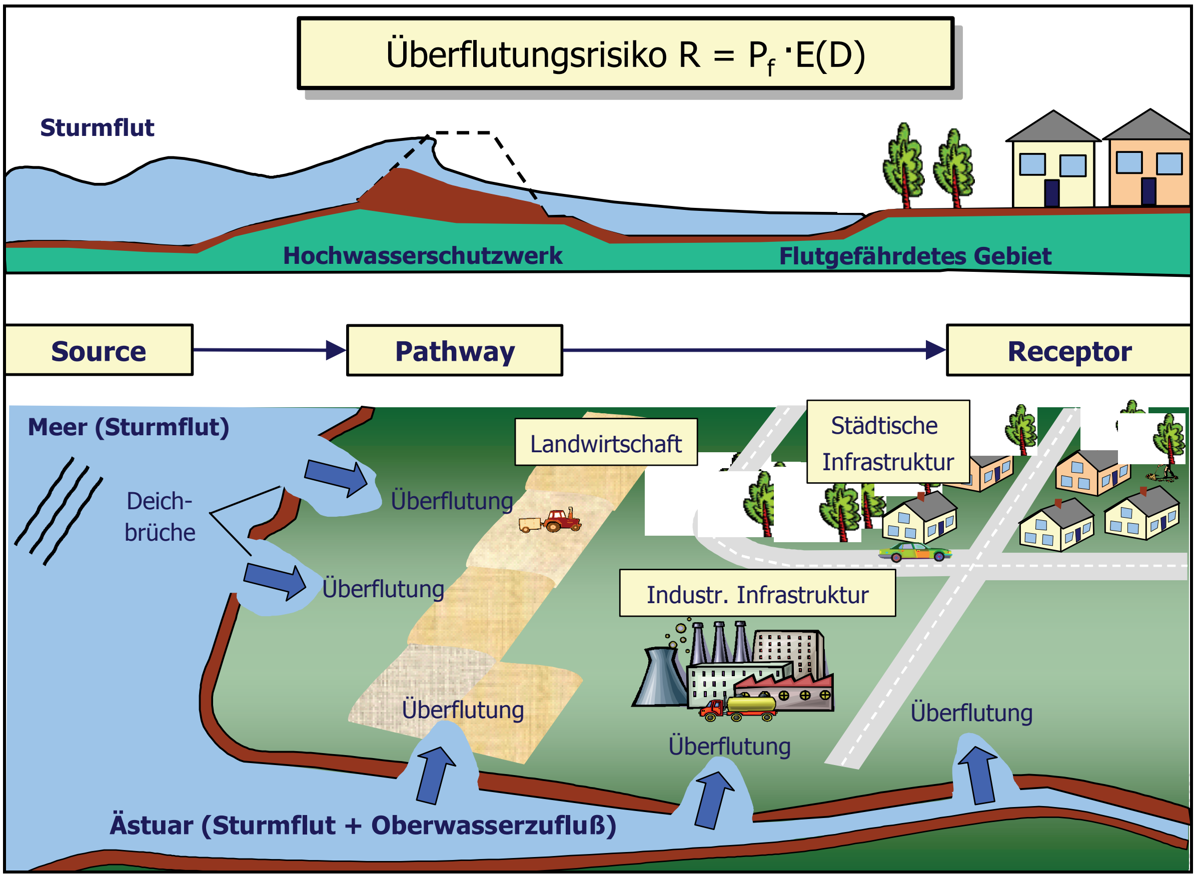

Abb. 1: “Source-Pathway-Receptor” Konzept (Oumerci 2009)

Zu diesem Zweck wird das "Source-Pathway-Receptor"-Konzept (Abb. 1) als Grundlage für ein integriertes Vorgehen für die Risikoanalyse und das Risikomanagement offener Küsten und eines Ästuargebietes, die durch Extremsturmfluten im Klimawandel gefährdet sind, herangezogen. Das gesamtheitliche Vorgehen erfordert vier Teilprojekte, die sich jeweils mit der Risikoquelle, den Risikowegen, den Risikoempfängern sowie deren Integration befassen.

Für die Implementierung der vier Teilprojekte werden zwei Untersuchungsgebiete, die Insel Sylt und die Stadt Hamburg, ausgewählt.

Grundlage der Untersuchung ist die Risikoquelle, d.h. die Sturmflut in ihrer möglichen Höhe und ihrem möglichen Verlauf. Im Folgenden werden am Beispiel für Hamburg die Vorgehensweise zur Ermittlung eines extremen Sturmflutverlaufes und die hierzu wichtigen Faktoren aufgezeigt. Für die emprische Analyse muss für Hamburg der Pegel Cuxhaven verwendet werden. Für die Charakterisierung von Sturmfluten ist es essentiell wichtig eine lange, ungestörte Zeitreihe vorliegen zu haben. Durch anthropogene Eingriffe wie Eindeichungen und Fahrrinnenanpassungen wurde das Regime der Elbe verändert. Somit liegt für den Pegel Hamburg keine ungestörte Zeitreihe vor. Diese Maßnahmen haben deutlich geringeren Einfluss auf die Pegelstände am Pegel Cuxhaven, so dass hier von einer quasi ungestörten Zeitreihe gesprochen werden kann. Deshalb bildet dieser Pegel die Grundlage der Untersuchung. Für die Entwicklung der Sturmflut von Cuxhaven die Elbe hinauf nach Hamburg wird die dort berechnete Sturmflut über numerische Modellrechnungen elbaufwärts bis nach Hamburg berechnet.

2 Sturmflutdefinition

Zu Beginn einer jeden Untersuchung zum Thema Sturmfluten stellt sich stets die Frage: "Was ist eine Sturmflut?" Ein Sturm kennzeichnet sich durch starke Winde. Eine Flut ist ein hoher Wasserstand. Demnach ist eine Sturmflut ein durch starke Winde erzeugter hoher Wasserstand.

Neben dieser allgemeinen Umschreibung des Begriffes Sturmflut gibt es in der Praxis und in der Forschung verschiedene Ansätze zur Definition von Sturmfluten. Für die Deutsche Bucht mit dem Bezugspegel Cuxhaven sei hier zum einen die anwenderbezogene Definition des Bundesamtes für Seeschifffahrt und Hydrographie zu nennen. Ab einem Wasserstand von 150 cm über dem mittleren Tidehochwasser (MThw) wird öffentlich vor Sturmfluten gewarnt, da ab diesem Wasserstand die ersten Schutzmaßnahmen (z.B. Sielverschlüsse) ergriffen werden müssen (Müller-Navarra 2008). Nach DIN 4049 gilt ein Wasserstand mit einer jährlichen Häufigkeit von 10 bis 0,5 als Sturmflut. Dieser statistische Grenzwert ergibt sich für den Pegel Cuxhaven zu 150 cm über MThw (DIN 4049-3 1994).

Neben diesen beiden scheitelwertbezogenen Definitionen wird hier eine physikalisch basierte Definition bevorzugt. Eine für den Pegel Cuxhaven erstellte Definition stammt von Siefert (1968): Das Ereignis Sturmflut wird über die Höhe des Windstaus definiert. Der Windstau ist die Differenz zwischen dem vorausberechneten und dem eingetretenen Wasserstand. Es liegt ein Sturmflutereignis vor, wenn der Windstau zu irgendeiner Tidephase 200 cm beträgt. Die Definition wurde von Gönnert (2003) um das Kriterium des BSHs (MThw + 150 cm) erweitert, „weil nur die Wasserstände ausgewählt werden sollen, auf die eine bestimmte minimale Energieeinwirkung Einfluss genommen hat". Diese Definitionen berücksichtigen, dass die maximalen Windgeschwindigkeiten eines Sturmes unabhängig von der Tidephase auftreten.

Für die vorliegende Arbeit wurde eine physikalisch-phänomenologische Definition gewählt. Zunächst wurde der Frage nachgegangen „Was ist ein Sturm?". Nach der Beaufort-Skala werden Windgeschwindigkeiten ab 17 m/s als Sturm bezeichnet. Für den Pegel Cuxhaven liegt die sturmflutrelevante Windrichtung zwischen 230° und 350° (Gönnert 2003). Ein Abgleich dieser meteorologischen Randbedinungungen in der Deutschen Bucht mit den Ereignissen des Kollektivs „Windstau größer 200 cm zu irgendeiner Tidephase" von 1901 bis 2008 zeigte, das 70 % der erfassten Ereignisse zusammen mit einem Sturm auftraten. Bei den restlichen 30 % der registrierten Ereignisse kann der erhöhte Wasserstand durch die Überlagerung von Fernwellen und Windstau aus starken jedoch nicht stürmischen Winden zustandekommen. Um für die kontinuierliche Fortschreibung des Kollektivs die Auswahl der Ereignisse mit geringem Datenaufwand digital zu ermöglichen, wurde überprüft, mittels welcher Grenzwerte bezogen auf die statistischen Scheitelwerten MThw und MTnw diese physikalisch definierten Ereignisse gefiltert werden können. Die Definition für Sturmfluten am Pegel Cuxhaven ergibt sich nach diesen Auswertungen zu:

> Am Pegel Cuxhaven liegt eine Sturmflut vor, wenn der Wasserstand die Grenzwerte 150 cm über dem MThw oder 190 cm über dem MTnw überschreitet.

Das physikalisch-phänomenologisch hergeleitete Kriterium, dass der Wasserstand 150 cm über dem MThw eintreten muß, deckt sich mit den zuvor erläuterten Definitionen des BSHs, der DIN 4049 und von Gönnert (2003). Das Verhältnis der beiden ermittelten Überschreitungsgrenzen 150 cm / 190 cm, welche dem Windstau zum entsprechenden Zeitpunkt entsprechen, beträgt 79 %. Die Länderarbeitsgruppe (1988) ermittelte durch Abgleich der eingetretenen Windstauhöhen ein mittleres Verhältnis des Windstaus von MThw zu MTnw von 73 %. Somit wird dieses Verhältnis bestätigt.

Über die hier hergeleitete Definition treten nach wie vor rund 70 % der Ereignisse zusammen mit Stürmen auf. In den anschließenden Analysen werden die verbleibenden 30 % der Ereignisse mit betrachtet, da bei der Ermittlung der Extremereignisse jegliche wasserstandserhöhenden Faktoren untersucht werden müssen. Zudem wird an dieser Stelle explizit darauf hingewiesen, dass, obwohl die Definition scheitelwertbasiert ist, im Folgenden die gesamte Windstaukurve analysiert wird, da eine Sturmflut nicht nur über ihren Scheitelwasserstand sondern auch über ihre gesamten Kurvenform charakterisiert werden muss.

3 Sturmflutkomponenten

Aus der Betrachtung der Sturmflutdefinitionen geht hervor, dass der Scheitelwasserstand einer Sturmflut nicht nur meteorologisch bedingt ist. Vielmehr setzt er sich aus den Komponenten vorausberechnete astronomische Tide, Fernwelle, Windstau und Seegang zusammmen (Abb. 2).

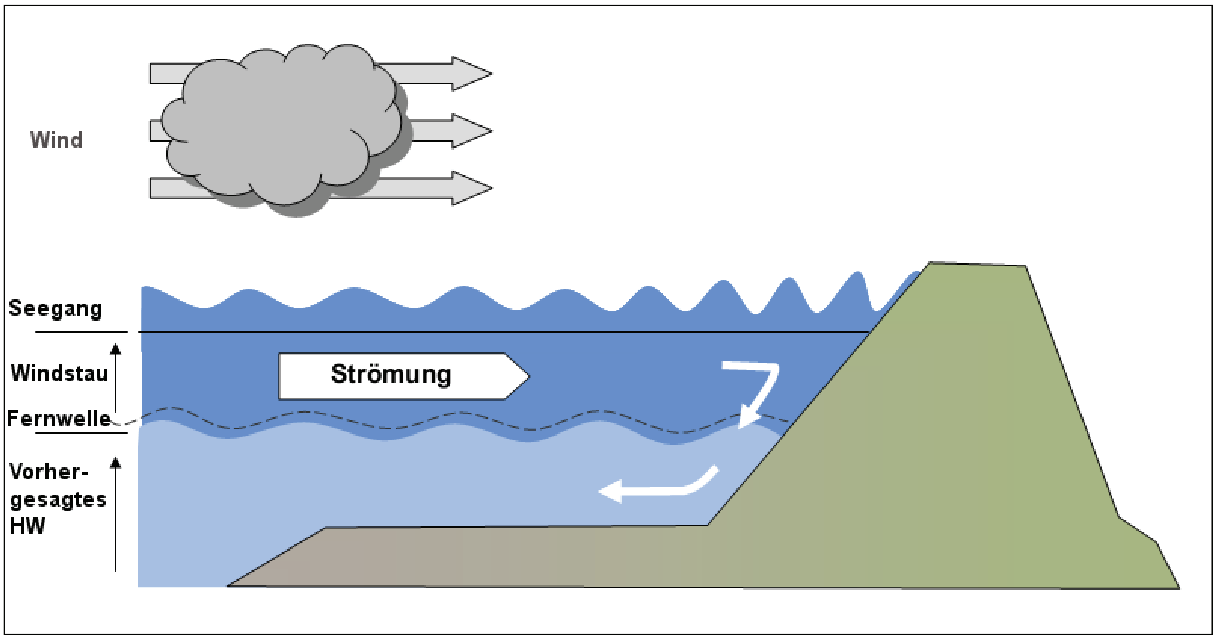

Abb. 2: Komponenten einer Sturmflut

Bei der Untersuchung von Sturmfluten liegt der vorhergesagte Wasserstand zugrunde. Dieser kann, muss aber nicht durch eine Fernwelle aus dem Atlantik überlagert werden. Durch ein Sturmtief über der Deutschen Bucht werden die Wassermassen an die Küste gedrängt. Aufgrund der behinderten Strömung staut sich das Wasser auf. Diese Wasserstandserhöhung über den vorhergesagten Wasserstand hinaus wird Windstau genannt. Der erhöhte Wasserstand wird am Betrachtungsort von dem durch lokale Winde erzeugten Seegang überlagert.

3.1 Astronomische Tidekurve

Die astronomische Tidekurve gibt die periodische Schwingung des Meeres wieder, die verursacht wird durch das Zusammenwirken von Schwer- und Fliehkräften, die bei der Bewegung des Mondes um die Erde und der Erde um die Sonne entstehen. Bei Neu- und bei Vollmond verstärken sich die Gezeiten bedingt durch die Überlagerung der Gezeitenkräfte von Mond und Sonne zur Springtide. Bei Halbmond werden die Gezeitenkräfte des Mondes zum Teil von der Sonne aufgehoben, es entsteht die flachere Kurve der Nipptide.

Die mittlere Tidekurve ist die Ganglinie der arithmetisch gemittelten, einander zur Tidephase entsprechenden Wasserstände mehrerer Tidekurven für einen bestimmten Ort über eine bestimmte Zeitspanne (DIN 4049-3 1994), zumeist der letzten fünf Jahre. Dabei werden Tidekurven unterschiedlicher Mondphasen gemittelt, so dass die Differenzen von Spring- und Nipptide nicht mehr erkennbar sind.

Bisher wurde für Untersuchungen zu Sturmfluten am Pegel Cuxhaven die mittlere Tidekurve verwendet. Diese Auswahl wurde aus rein pragmatischen Gründen getroffen: Die mittlere Tidekurve ist eine mit relativ geringem Rechenaufwand erzeugbare statistische Größe (Siefert 1968). Daneben bilden die mittleren Verhältnisse gut die mittlere physikalische Wechselwirkung Sturmflut – Tide ab, so dass sie einen guten Anhaltswert über die Stauentwicklung im jeweiligen Gebiet geben. (Siefert 1992)

Die astronomische Tidekurve für jeden beliebigen Tag zu berechnen stellte in der Vergangenheit eine große Herausforderung an mathematischem Können und Zeitaufwand dar. Inzwischen stehen Programme zur Verfügung, mit denen die Berechnung der astronomischen Tidekurve mit vergleichbarem Aufwand durchgeführt werden kann. Auf diese Wiese wird es möglich, den astronomischen Einfluss von der Windwirkung formal zu trennen. Zudem erlaubt es empirische Untersuchungen zur Wechselwirkung zwischen Tide und Sturmflut. Somit besteht nun die Möglichkeit die auf Basis der mittleren Tidekurve ermittelten Anhaltswerte zum Charakter von Sturmfluten hinsichtlich der physikalischen Wechselwirkungen detaillierter zu untersuchen.

Zur Berechnung der astronomischen Tidekurve gibt es zwei verschiedene Verfahren, die harmonische Synthese der Gezeiten und das nonharmonische Verfahren. Diese beiden Verfahren unterscheiden sich im Wesentlichen durch ihre räumlichen Anwendungsbereiche. Mittels der harmonischen Synthese kann der gesamte Verlauf der astronomischen Tidekurve berechnet werden. Dies ist jedoch nur für tiefes Wasser möglich, da die Flachwassereffekte nicht berücksichtigt werden können (Müller-Navarra 2008). Astronomische Kenngrößen, die diese Effekte beinhalten, können mit dem nonharmonischen Verfahren berechnet werden. Es können allerdings lediglich die Höhe und die Eintrittszeit der astronomischen Hoch- und Niedrigwasser bestimmt werden.

Harmonische Synthese der Gezeiten

Die sichtbare Gezeitenbewegung setzt sich im Detail aus vielen einzelnen Tidekurven zusammen. Diese einzelnen Komponenten werden Partialtiden genannt. Dabei ist eine Partialtide „nichts weiteres, als eine Sinusfunktion, die über Frequenz f, Amplitude A und Phase φ beschrieben werden kann" (Kastens 2007). Die Frequenzen f der Partialtiden sind aus der Lehre von den Bewegungen des Mondes und der Sonne bekannt und für jeden Ort gleich. Die Amplitude und die Phase hingegen sind ortsabhängig und können aus Zeitreihen der Wasserstände mittels der Harmonischen Analyse abgeleitet werden. Die Harmonische Analyse der Gezeiten ist eine spezielle Form der Fourierzerlegung einer Zeitreihe (BAW 2008) und beruht auf der Zerlegung der Gezeiten in ihre streng periodischen harmonischen Partialtiden (BSH 2008).

Sind die Amplituden und Phasen der einzelnen Partialtiden an einem Ort bekannt, kann mittels der Harmonischen Synthese, d.h. Summation aller Partialtiden, eine Vorhersage des Wasserstandes für einen vorgegeben Zeitraum erfolgen (BAW 2008).

Nonharmonisches Verfahren

Mit dem Nonharmonischen Verfahren können für Orte mit halbtägiger Gezeit die Eintrittszeiten und Höhen der Hoch- und Niedrigwasser vorausberechnet werden. Hierbei werden die Meridiandurchgangszeiten des Mondes mit den mittleren Hoch- und Niedrigwasser-Intervallen sowie den Ungleichheiten in Höhe und Zeit verrechnet. Gegebenfalls können Verbesserungen zur Berücksichtigung von lokalen Besonderheiten mit einbezogen werden (BSH 2008).

Zur Abschätzung von Höhen und Zeiten zwischen den nonharmonisch ermittelten Hoch- und Niedrigwassern wird zu Zwecken der Schifffahrt vom BSH zum einen eine graphische und zum anderen eine rechnerische Einspannung der mittleren Spring- und Nipptidekurven zwischen dem Hoch- und Niedrigwasser empfohlen. Verfahrensbedingt können diese Werte bis zu 10 cm voneinander abweichen (BSH 2008).

Verknüpfung der Verfahren

Für die wissenschaftliche Analyse von Sturmflutereignissen ist eine Ungenauigkeit von 10 cm zu hoch, so dass für die hier dargestellten Ergebnisse das harmonische mit dem nonharmonischen Verfahren mathematisch verknüpft wird. Diese Verknüpfung erfolgt dadurch, dass die harmonisch berechnete astronomische Tidekurve zwischen die nonharmonisch ermittelten Hoch- und Niedrigwasserwerte linear eingehängt wird. Hierdurch erhalten sowohl die zum jeweiligen Zeitpunkt wirkenden gezeitenverursachenden Kräfte sowie die lokalen Reibungs- und Reflektionsanteile Berücksichtigung (Thumm & Gönnert 2009).

3.2 Fernwelle

Fernwellen entstehen durch Änderungen des Luftdrucks, die bei schnell ziehenden Tiefdruckgebieten über dem nördlichen Atlantik in Form von stark ausgeprägten Luftdruckgradienten auftreten. Dies führt zu einer Veränderung des Wasserspiegels in Form einer sowohl an der Oberfläche sichtbaren Welle, als auch einer internen Welle im Wasserkörper. Unabhängig zur Tidephase und ohne periodische Regelmäßigkeit laufen diese Wellen, ähnlich einer Tidewelle und in Abhängigkeit der Zugbahnen der Tiefdruckgebiete in die Nordsee ein (Gönnert 2003).

Das die Fernwelle auslösende Tief und das sturmflutverursachende Tief können ein und dasselbe Tief jedoch auch zwei meteorologisch von einander unabhängige Ereignisse sein. Das bedeutet, dass Fernwellen und Sturmfluten getrennt von einander aber auch zeitgleich auftreten können.

Anhand von Analysen von Aufzeichnungen des BSHs aus 20 Beobachtungsjahren (1971-1995, nicht 1974-1978) wurden 15 Fernwellen mit einer Höhe von 60 cm und mehr ermittelt. Die höchste Fernwelle erreichte ein Maximum von 109 cm. Jede fünfte bis sechste Sturmflut tritt zeitgleich mit einer Fernwelle größer 60 cm ein. Sie erreichen in Cuxhaven in etwa die Höhe der in Aberdeen einlaufenden Fernwellenhöhen mit Schwankungen von etwa +/- 20 % (Gönnert 2003).

3.3 Windstau

Für die Ermittlung extremer Sturmfluten ist es wichtig zu verstehen, wie sich eine Sturmflut zeitlich entwickelt. Dieses ist nur bedingt über den Scheitelwasserstand zu erfassen, da in diesem der windinduzierte Wasserstand von der zugrunde liegenden Tide überdeckt wird. Von Interesse ist also die Betrachtung des Windstaus, der die Differenz zwischen dem eingetretenen und dem vorausberechneten Wasserstand ist. Er spiegelt den zeitlichen Verlauf und die Höhe der in den Wasserkörper eingetragenen Energie und somit den physikalischen Wert einer Sturmflut wieder. Der Windstau am Pegel Cuxhaven wird maßgeblich durch die Windverhältnisse in der Deutschen Bucht geprägt. Desweiteren enthält er Einflüsse aus dem statischen Luftdruck, Änderungen des Luftdrucks, Wassertempereatur und Temperaturdifferenz Luft-Wasser. (Siefert 1968, Gönnert 2003)

Für die Charakterisierung einer Sturmflut sind drei Merkmale der Windstaukurve von Interesse: Die Höhe des Windstaumaximums, dessen Lage zur Tidephase und der Windstauverlauf. Durch die Höhe eines Windstaumaximums kann der Energieeintrag des Windes erfasst werden, durch die Eintrittszeit des Windstaumaximums und die Kurvenform die Auswirkungen auf den absoluten Wasserstand. (Gönnert 2003)

Bei bisherigen Untersuchungen für den Pegel Cuxhaven basiert die Windstauberechnung auf der mittleren Tidekurve. Diese Untersuchungen umfassen ein Kollektiv, das alle Sturmfluten seit 1901 beinhaltet, die 200 cm Windstau und einen Scheitelwasserstand größer MThw + 150 cm erreichten. Bis 2008 umfasst das Kollekitiv 259 Sturmflutscheitel. Sie bilden die Grundlage für die Bemessung des Hochwasserschutzes entlang der Elbe.

Das diesem Projekt zugrunde liegende Kollektiv wird auf Basis der astronomischen Tidekurve berechnet, da es erklärtes Ziel des Projektes ist, nicht nur die Sturmflutkurve, die alle Einflüsse auf den Wasserstand umfasst, sondern auch die Einzelkomponenten und deren Wechselwirkungen physikalisch zu untersuchen.

Werden Untersuchungen, die die Grundlage für den Schutz eines großen Lebensraumes sind, auf veränderter Basis erstellt, muss eine Gegenüberstellung der Ergebnisse erfolgen, so dass erkennbar wird, inwieweit sich maßgebende Grenzwerte bzw. Schlüsselereignisse verändert darstellen.

Zum Erlangen eines ersten Überblickes über die Unterschiede zwischen den auf verschiedenen Tidekurven basierenden Windstaukurven wurden die Windstaumaxima der erfassten Sturmfluten mit einander verglichen. Es wurden für jede Sturmflut die Windstaukurve basierend auf der astronomischen und der mittleren Tidekurve berechnet und jeweils die Höhe und die Eintrittszeit des Windstaumaximums erfasst. Des Weiteren wurden die Höhenabweichungen der Windstaumaxima und die Unterschiede ihrer Eintrittszeiten ermittelt.

Im Durchschnitt liegt das Maximum der Windstaukurve basierend auf der astronomischen Tidekurve 6,5 cm niedriger als das Maximum der Windstaukurve basierend auf der mittleren Tidekurve. Die Abweichungen liegen insgesamt zwischen -59 cm und +51 cm. Die Hälfte der Windstaumaxima weisen eine Differenz von ±15 cm auf. Die maximalen Abweichungen treten zum einen bei Sturmfluten auf, bei denen die Windstaumaxima zeitnah zu den vorausberechneten Hoch- und Niedrigwasserzeiten eintreten, so dass die am Pegel Cuxhaven durch Spring- und Nipptide bedingten Unterschiede in den Tidekurven in den Windstaumaxima wiederzuerkennen sind. Zum anderen ergeben sich die maximalen Abweichungen im Bereich der Tideäste, da die astronomische Tidekurve bedingt durch die täglichen Ungleichheiten auch in diesen Bereichen von der mittleren Tidekurve abweicht.

Die zeitliche Differenz zwischen den Eintrittszeiten der Windstaumaxima beträgt zu 90 % ±90 Minuten. Bei Windstaukurven mit langen Scheitelbereichen kann ein großer zeitlicher Versatz der Windstaumaxima von bis zu 3 Tidezyklen entstehen. Detaillierte Betrachtungen zeigen jedoch, dass es sich hier um in der Höhe variierende Spitzen der Scheitelbereiche handelt, die auch jeweils in der anderen Windstaukurve zu erkennen sind. Es handelt sich nicht um neu ausgeprägte Windstauscheitelbereiche.

Die beiden Sturmfluten, die bei Berücksichtigung der mittleren Tidekurve den höchsten Windstau um Tnw bzw. Thw aufwiesen, wurden aufgrund der neuen Untersuchungen nicht von anderen Ereignissen abgelöst. Das Windstaumaximum lag jedoch in beide Fällen höher als die bisher bekannten Werte, so dass die für den derzeitigen Bemessungswasserstand relevante Windstauhöhe von 385 cm auf 400 cm angehoben werden müsste.

Ergänzende statistische Analysen der beiden so entstandenen Kollektive haben gezeigt, dass sich die statistischen Verteilungsfunktionen über die Jährlichkeit nicht wesentlich voneinander unterscheiden. Dieses Ergebnis ist plausibel, da es erklärtes Ziel der Statistik ist, die mittleren Abweichungen auszugleichen, dies bedeutet, dass auch die Statitisik auf Basis der astronomischen Tidekurve Auskunft über die mittleren Verhältnisse gibt. (Mudersbach & Jensen 2009)

Analysen von Gönnert (2003) haben ergeben, dass die Höhe des Windstaumaximums von der Anstiegsneigung der Windstaukurve abhängt. So können z.B. am Pegel Cuxhaven extrem hohe Windstaumaxima (> 390 cm) nur bei sehr steilem Windstauanstieg entstehen, am Pegel Helgoland sind hierfür flache, langsame Antiege nötig. Desweiteren ist bekannt, dass der maßgebende Einfluss auf die Form der Windstaukurve bei einer gewissen Windgeschwindigkeit von der Tidekurve auf den Wind übergeht (Bremer & Gönnert 2009). Zudem hat ein Vergleich der Windstaukurven auf Basis der astronomischen und der mittleren Tidekurve ergeben, dass die astronomisch basierte Windstaukurve die Windverhältnisse wesentlich besser wiederspiegelt (Abb. 3) (Gerkensmeier 2009).

Diese Ergebnisse zeigen, dass es relevante Unterschiede in der Kurvenform gibt. Diese Unterschiede liefern plausible Indizien dafür, dass die Betrachtung eines Sturmflutereignisses basierend auf der astronomischen Tidekurve physikalisch exakter ist.

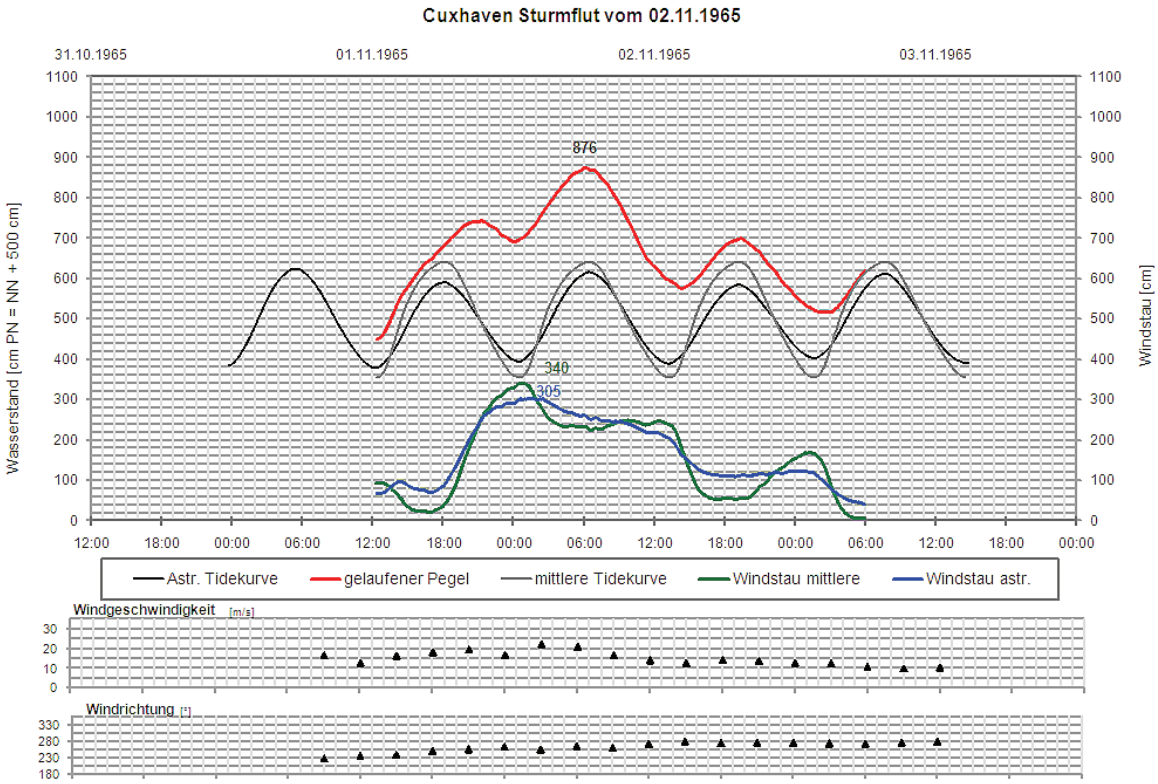

Abb. 3: Vergleich des Windstaus auf Basis der astronomischen und mittleren Tidekurve am Beispiel der Sturmflut vom 02.11.1965 (Gerkensmeier 2009)

3.4 Seegang

Der Seegang wird vom lokalen Wind verursacht. Da die vorliegenden Untersuchungen am Pegel Cuxhaven die Grundlage für die Sturmfluten im 130 km elbaufwärts liegenden Hamburg sind, werden diese lokalen Effekte momentan nicht mit untersucht. Für die letztendlichen Untersuchungen der extremen Sturmfluten in Hamburg werden die dortigen Seegangsbedingungen miteinbezogen.

4 Überlagerung der Sturmflutkomponenten

Eine Wasserstandserhöhung an der Küste entsteht durch die behinderte Rückströmung (Abb. 2). Das Ausmaß der Behinderung hängt von der über die Höhe des Wasserkörpers wirkenden Sohlreibung ab. Bei niedrigem Wasserstand hat die Sohlreibung eine größere aufstauende Wirkung als bei hohen Wasserständen. Aufgrund dieser grundlegenden physikalischen Prozesse bei der Entstehung einer Sturmflut ist davon auszugehen, dass sich die Einzelkomponenten einer Sturmflut nicht linear überlagern. Ziel dieser Untersuchungen ist es herauszufinden, wie sich diese Einzelkomponenten bei zeitgleichem Auftreten gegenseitig beeinflussen.

Untersuchungen zur Fragestellung, wie sich eine Fernwelle auf den Windstau auswirkt, ergaben, dass die zugrundeliegenden Datenauswertungen des BSHs keine ausreichende Grundlage für physikalisch plausible Untersuchungen bilden. Bei der Bestimmung der Fernwellenhöhen wurde mittels der Windbedingungen ein statistisch ermittelter Windstau von dem gemessenen Wasserstand abgezogen. Somit ist bei den zugrunde liegenden Daten unklar, inwieweit die Verläufe des berechneten Windstaus und der berechneten Fernwelle die vorliegenden Prozesse physikalisch korrekt widerspiegeln.

Da bekannt ist, dass der Windstau an der Küste durch die behinderte Rückströmung entsteht, also bei konstantem Wind bei niedrigem Wasserstand höher ist als bei hohem Wasserstand, kann davon ausgegangen werden, dass beim Zusammentreffen einer Sturmflut mit einer Fernwelle, die Komponenten des Windstaus kleiner und die der Fernwelle größer sind als vom BSH berechnet.

Aus verschiedenen numerischen Untersuchungen ist bekannt, dass eine Springtideerhöhung im Vergleich zu einer mittleren Tide bei schweren Sturmfluten nur eine geringe bis hin zu gar keine Auswirkung auf den Sturmflutscheitel hat (Dick 2000; Mayerle et al. 2009).

Erste Ergebnisse von zurzeit noch andauernden empirischen Untersuchungen im Rahmen des Projektes zeigen, dass bei der Betrachtung des Zusammenhangs zwischen Wind und Windstau die zum betrachteten Zeitpunkt vorausberechnete Tide für die Höhe des Windstaus nicht relevant ist. Vielmehr ist analog zu den Erkenntnissen, dass für den Windstau der drei Stunden vor dem Betrachtungszeitpunkt vorherrschende Wind maßgebend ist (Siefert 1968), ein diesem Zeitfenster zugrundeliegender Wasserstand in die Betrachtung mit einzubeziehen. Es ist davon auszugehen, dass dieser zugrundeliegende Wasserstand nicht wie bisher angenommen die vorausberechnete Tidekurve sondern der tatsächlich eingetretene Wasserstand ist. Anhand dieser Ergebnisse ist es plausibel, dass eine Springtideerhöhung sich im Scheitelbereich des Wasserstandes schwerer Sturmfluten nicht niederschlägt, da zu diesem Zeitpunkt und 3 Stunden vorher der vorausberechnete Wasserstand schon um mehr als 300 cm erhöht ist.

Aus diesen Ergebnissen kann gefolgert werden, dass es für den Verlauf der Windstaukurve, d.h. ihre Anstiegsneigung, welche die Höhe des Windstauscheitels maßgeblich beeinflusst, relevant ist, ob eine Spring- oder eine Nipptide vorliegt. Der Höhenunterschied am Pegel Cuxhaven zwischen den Scheitelwerten von Spring- und Nipptide beträgt bis zu 120 cm, welche sich bei schwachen Winden und niedrigen Windstauwerten im eingetretenen Wasserstand niederschlagen.

Zusätzlich zu diesen Untersuchungen der Physik von Sturmfluten unter heutigen Klimabedingungen sollen im weiteren Verlauf des Projektes die Folgen eines möglichen Klimawandels in Form von Meeresspiegelanstieg und Zunahme der Sturmintensität auf die Entstehung von Sturmfluten betrachtet werden.

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GIS-gestützte Analyse des Überflutungsrisikos in Hamburg unter Berücksichtigung der EG-Hochwasserrichtlinie

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Abstract

The "Directive of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks" contitutes standardized and coordinated action in flood risk management. It intends beside a preliminary flood risk assessment the production of flood hazard maps and flood risk maps for extreme event scenarios and events of medium likelihood. Furthermore it demands the establishing of flood risk management plans.
In this study an analysis of the storm surge risk – consisting of hazard analysis, vulnerability analysis and risk assessment – is carried out for Hamburg in respect of the Directive of the European Community.
The damage potential evaluation is based on the digital cadastral map and official statistics. A GIS-based inundation model is used for the simulation of storm surge events and possible burstings of a dike in Hamburg.
The procedure's suitability for the implementation of the Directive is examined in regard to flood risk management plans. Moreover drafts have been prepared for hazard and risk maps according to the Directive.

1 Einleitung

Die EG-Richtlinie 2007/60/EG vom 23. Oktober 2007 über die Bewertung und das Management von Hochwasserrisiken legt ein EU-weit einheitliches und koordiniertes Vorgehen im Bereich des Hochwasserrisikomanagements fest. Die Richtlinie ist in drei aufeinander aufbauende Teilbereiche untergliedert. Sie sieht neben einer vorläufigen Bewertung des Hochwasserrisikos bis Ende 2011 die Erstellung von Hochwassergefahren- und Hochwasserrisikokarten bis Ende 2013 vor, in denen Ereignisse mit mittlerer Wahrscheinlichkeit und Extremereignisse berücksichtigt werden sollen. Darauf aufbauend soll bis Ende 2015 die Erstellung von Hochwasserrisikomanagementplänen erfolgen.

Da die Richtlinie zwar die einzelnen Schritte des Risikomanagements vorgibt, inhaltlich aber nur minimale Festlegungen trifft, wird über die Möglichkeiten zur Umsetzung der Richtlinie und eine Festlegung von einheitlichen Vorgehensweisen viel diskutiert.

Unter dem Begriff „Hochwasser" ist laut der Richtlinie die „zeitlich beschränkte Überflutung von Land, das normalerweise nicht mit Wasser bedeckt ist" zu verstehen (Artikel 2 Absatz 1). Diese Überflutung kann sowohl durch Flüsse oder Gebirgsbäche als auch durch in Küstengebiete eindringendes Meerwasser hervorgerufen werden. Das Hochwasserrisiko wird in Artikel 2 Absatz 2 der Richtlinie als „Kombination der Wahrscheinlichkeit des Eintritts eines Hochwasserereignisses und der hochwasserbedingten potenziellen nachteiligen Folgen auf die menschliche Gesundheit, die Umwelt, das Kulturerbe und wirtschaftliche Tätigkeiten" definiert.

Die durchgeführte Analyse soll einen Beitrag zu dieser Diskussion leisten, indem sie am Beispiel Hamburgs untersucht, wie die Vorgaben der Richtlinie umgesetzt werden könnten. Dabei liegt der Fokus auf dem Sturmflutrisiko.

Der Schwerpunkt der Untersuchung liegt auf der Entwicklung einer GIS-gestützten Methodik zur Abschätzung der Schäden in verschiedenen Sturmflutszenarien, die auch als Grundlage für die Maßnahmenplanung im Risikomanagement herangezogen werden kann. Diese soll möglichst genau und dabei schnell durchführbar und aktualisierbar sein. Ein weiteres Ziel ist die Entwicklung eines möglichen Vorgehens zur Erstellung von Gefahren- und Risikokarten. Dafür wird auf die im Landesbetrieb Straßen, Brücken und Gewässer (LSBG) der Stadt Hamburg zur Verfügung stehenden Daten und Programme zurückgegriffen und deren Eignung für die Umsetzung der Richtlinie untersucht.

2 Untersuchungsgebiete

Um im Rahmen dieser Untersuchung möglichst unterschiedlich strukturierte Gebiete berücksichtigen zu können, wurden als Untersuchungsgebiete zum einen der dicht bebaute Stadtteil Veddel und zum anderen das vergleichsweise ländlich geprägte Überschwemmungsgebiet der Dove-Elbe ausgewählt. Abb. 1 zeigt die Lage der beiden Untersuchungsgebiete (schwarz umrandete Flächen) innerhalb der tief liegenden Gebiete (hellgraue Fläche).

Abb. 1: Lage der Untersuchungsgebiete in Hamburg (Datenquelle: LSBG)

Der Stadtteil Veddel hat eine Fläche von 4,37 km^2. Er liegt östlich des Hamburger Hafens und umfasst die Insel Peute, den östlichen Teil der Insel Veddel sowie einen schmalen Streifen im Norden der Insel Wilhelmsburg. Im Westen des Stadtteils Veddel befindet sich ein vollständig eingedeichtes Wohngebiet, das an seinem westlichen Rand durch den S-Bahn-Damm begrenzt wird. Die Autobahn 255 trennt das Wohngebiet vom Industrie- und Gewerbegebiet auf der Peute im Osten der Veddel.

Das Überschwemmungsgebiet der Dove-Elbe ist 5,31 km^2 groß und wird durch Deiche begrenzt. Im Westen ist es durch die Tatenberger Schleuse von der Elbe abgetrennt. Das Überschwemmungsgebiet der Dove-Elbe liegt in den Vier- und Marschlanden, die für den Blumen- und Gemüseanbau bekannt sind. Im Nordwesten des Gebietes befindet sich ein Wohngebiet; an mehreren Stellen im östlichen

Teil des Untersuchungsgebiets wird Erdöl gefördert. Der landschaftliche Charakter des Gebietes wird allerdings durch Weide-, Acker- und sonstige Grünflächen geprägt.

3 Methodik

Die in der EG-Hochwasserrisikomanagementrichtlinie festgelegte Definition des Risikos als Produkt aus Eintrittswahrscheinlichkeit und potentiellen Schäden entspricht dem Risikobegriff, wie er in der naturwissenschaftlich-technischen Risikoanalyse verwendet wird. Daher erfolgte die Untersuchung des Sturmflutrisikos in Hamburg nach dem grundsätzlichen Vorgehen der Risikoanalyse, die aus den Teilschritten Vulnerabilitätsanalyse, Gefährdungsanalyse und Risikoabschätzung besteht.

Im Folgenden werden das Vorgehen zur Wertermittlung, die im Rahmen der Vulnerabilitätsanalyse durchgeführt wurde, und die in der Gefährdungsanalyse betrachteten Sturmflut-Szenarien vorgestellt. Durch die Zusammenführung der Ergebnisse aus der Vulnerabilitäts- und der Gefährdungsanalyse im GIS kann das Sturmflutrisiko abgeschätzt werden. Die Ergebnisse der Risikoabschätzung werden dargestellt, bevor abschließend geschildert wird, welcher weitere Forschungsbedarf sich aus den Teilschritten der Risikoanalyse ergibt und inwieweit sich das Verfahren als Grundlage zur Umsetzung der Richtlinie eignet.

4 Wertermittlung

Für die Ermittlung des Schadenspotentials in den Untersuchungsgebieten wird eine Wertermittlung vorgenommen. Sie ist Teil der im Rahmen der Risikoanalyse durchgeführten Vulnerabilitätsanalyse, mit deren Hilfe die in den zu untersuchenden Szenarien voraussichtlich betroffenen Menschen und Werte identifiziert werden können.

Die im Rahmen der Wertermittlung betrachteten Schadenskategorien sind in Tabelle 1 aufgeführt. Einwohner und Arbeitsplätze wurden quantitativ, die übrigen Kategorien monetär erfasst (Sossidi 2009). Der Schwerpunkt der Untersuchung liegt auf den direkten tangiblen Werten.

Tab. 1: Untersuchte Schadenskategorien

Schadenskategorie	Datenquelle	Bezugsjahr	Verortung
Einwohner	Amtliche Statistik	2006	Gebäude (Wohnnutzung)
Arbeitsplätze	Amtliche Statistik	2006	Gebäude (wirtschaftliche Nutzung)
Gebäude	Standardisierte Methodik zur Gebäudewertermittlung (Reese 2003), modifiziert	2006	Gebäude
Hausrat	Versicherungen	2008	Gebäude (Wohnnutzung)
Kfz	Amtliche Statistik, DAT-Report	2007	Gebäude (Wohnnutzung)
Verkehrsflächen	Expertenbefragungen	2008	Verkehrsflächen
Ausrüstungsvermögen	Amtliche Statistik	2005	Gebäude (wirtschaftliche Nutzung)
Vorratsvermögen	Relationen zwischen Vorratsvermögen und Ausrüstungsvermögen (Reese 2003)	2003	Gebäude (wirtschaftliche Nutzung)
Bruttowertschöpfung	Amtliche Statistik	2006	Gebäude (wirtschaftliche Nutzung)

Die Methodik greift zu einem großen Teil auf Daten der amtlichen Statistik zurück, um eine einfache Aktualisierbarkeit der Wertermittlung zu gewährleisten. Diese Daten lagen allerdings in unterschiedlicher Genauigkeit vor. So wird beispielsweise das Ausrüstungsvermögen für 14 Wirtschaftsbereiche getrennt aufgeführt, die Anzahl der Erwerbstätigen und die Höhe der Bruttowertschöpfung dagegen werden nur für sechs übergeordnete Wirtschaftsbereiche angegeben. Während diese Daten sich auf ganz Hamburg beziehen, gab es für die Anzahl der Einwohner und Pkws Daten auf Stadtteilbasis. Waren keine Daten aus der Statistik verfügbar, wurden diese durch Expertenbefragungen gewonnen oder wissenschaftlichen Veröffentlichungen entnommen.

Die ermittelten Werte werden in ArcGIS in Gebäuden unterschiedlicher Nutzung verortet bzw. den Verkehrsflächen zugeordnet. Als Grundlage hierfür dient die Digitale Stadtgrundkarte (DSGK) 1:1.000. In ihr sind neben anderen thematischen Layern auch die Gebäude Hamburgs als Polygone enthalten. Zu jedem Gebäude finden sich in der Attributtabelle u.a. Angaben zur Adresse, der Grundfläche, der Anzahl der Geschosse und der Gebäudenutzung. Die Verkehrsflächen werden aus der Digitalen Karte 1:5.000 (DK5) übernommen.

5 Sturmflut-Szenarien

Die Untersuchung von Sturmflut-Szenarien fällt in den Bereich der Gefährdungsanalyse. Durch die Verknüpfung der Ergebnisse der hier vorgenommenen Sturmflutsimulation mit den Ergebnissen der Wertermittlung im GIS können die in den Szenarien zu erwartenden Schäden abgeschätzt werden. Die Simulation der Szenarien erfolgte mit dem Programm HWSIM, das im Folgenden vorgestellt wird. Anschließend erfolgt eine Beschreibung der betrachteten Szenarien und der getroffenen Annahmen zur Identifizierung möglicher Deichbrüche.

Das Programm HWSIM

Das Programm HWSIM wurde als Erweiterung unter ArcGIS für die Durchführung von Hochwassersimulationen für die Elbmarsch entwickelt. Im Programm wurde die öffentliche Hochwasserschutzlinie Hamburgs berücksichtigt, so dass es möglich ist, Deichbrüche und ihre Auswirkungen in der Simulation zu untersuchen. Da die öffentlichen Hochwasserschutzanlagen in Hamburg im Rahmen des "Bauprogramm Hochwasserschutz" laufend bis voraussichtlich 2012 an die Bemessungswasserstände angepasst werden, spiegeln die in der Programmdatenbank enthaltenen Informationen allerdings nicht immer den aktuellen Ausbauzustand der Hochwasserschutzanlagen wider. Im Rahmen des Bauprogramms werden alle Hochwasserschutzanlagen um durchschnittlich 1 m erhöht (Landesbetrieb Straßen, Brücken und Gewässer 2007). An der Aktualisierung der Datenbank wird zur Zeit gearbeitet.

Sturmflutwasserstände am Pegel St. Pauli

Sturmflutscheitelwasserstände einer bestimmten Jährlichkeit können mit Hilfe statistischer Analysen von Pegelaufzeichnungen bestimmt werden. Für die Ermittlung von seltenen und sehr seltenen Scheitelwasserständen in Tideästuaren wie dem Elbeästuar ist die Anwendung von statistischen Verfahren allerdings nicht geeignet, da die Zeitreihen an diesen Pegelstandorten stark durch Ausbaumaßnahmen beeinflusst sind (Gönnert & Ferk 1996) und daher nicht den Anforderungen für Zeitreihenuntersuchungen genügen. Hinzu kommt die Problematik der Tidedynamik im Ästuar und der Einfluss des Oberwasserzuflusses (Jensen et al. 2003).

Scheitelwasserstände mit einem Wiederkehrintervall von 100 Jahren wurden dagegen sowohl für Küstenpegel als auch für die Pegel im Elbeästuar mit statistischen Verfahren ermittelt und durch umfangreiche Untersuchungen verifiziert. Am Pegel St. Pauli beträgt dieser Scheitelwasserstand NN + 6,60 m (Jensen & Frank 2003).

Zur Abschätzung eines Scheitelwasserstandes für ein Extremereignis am Pegel St. Pauli wurden die im MUSE-Projekt (Jensen & Mudersbach 2005) für den Pegel Cuxhaven berechneten extremen

Scheitelwasserstände herangezogen. Anhand der Differenz der für ein 100-jährliches Sturmflutereignis ermittelten Scheitelwasserstände an den Pegeln Cuxhaven und St. Pauli wurde aus den Angaben für den Pegel Cuxhaven ein seltener Sturmflutscheitelwasserstand für den Pegel St. Pauli abgeleitet. Dieser entspricht mit NN + 7,22 m in etwa dem Bemessungswasserstand, auf den die Hochwasserschutzanlagen im Rahmen des Bauprogramms angepasst werden (Gönnert 2007).

In der Datenbank des verwendeten Simulationsprogramms sind bislang nicht für alle Deiche die Sollhöhen entsprechend der neuen Bemessungswasserstände enthalten. Daher ist zu erwarten, dass es bei der Simulation von Sturmfluten mit Scheitelwasserständen in der Größenordnung des Bemessungswasserstands in HWSIM an den noch zu aktualisierenden Deichabschnitten zu Deichbrüchen kommen kann. Ein solcher Sturmflutscheitelwasserstand eignet sich somit gut, um das im nächsten Abschnitt dargestellte Verfahren zur Identifizierung möglicher Deichbrüche anzuwenden.

Auf Grundlage dieser Überlegungen wurden folgende Szenarien berechnet:

- Szenario 1

  Scheitelwasserstand Pegel St. Pauli: 6,60 m NN

  Oberwasserzufluss: 1000 m^3/s

- Szenario 2

  Scheitelwasserstand Pegel St. Pauli: 7,22 m NN

  Oberwasserzufluss: 1000 m^3/s

Deichbrüche

Da während der Sturmfluten 1962 und 1976 Deichbrüche meist an Stellen auftraten, die vorher bereits durch Überströmen oder Wellenüberlauf beschädigt worden waren (Freistadt 1962, Traeger 1962, Zitscher et al. 1979), wurden in der Simulation von Strumflutereignissen diese beiden Schadensmechanismen als mögliche Ursachen eines Deichbruchs in den Mittelpunkt gestellt.

Für die Szenarioberechnungen wurden folgende Annahmen getroffen (Sossidi 2009):

- Ein Deichbruch durch Wellenüberlauf erfolgt bei einer Überlaufmenge > 0,03 m^3 pro s pro m; er beginnt 5 Minuten nach Überschreiten dieses Grenzwertes, hat nach 30 Minuten seine maximale Tiefe (die Deichsohle) und nach 60 Minuten seine maximale Breite (100 m) erreicht.
- Ein Deichbruch durch Überströmen erfolgt bei einer Überströmmenge > 0,0005 m^3 pro s pro m; er beginnt auf der gesamten Breite des betroffenen Deichabschnitts, sobald diese zulässige Überströmrate überschritten wird, und hat nach 30 Minuten seine maximale Tiefe (die Deichsohle) erreicht.
- Der Bruch einer Hochwasserschutzwand erfolgt bei einer Überlauf- bzw. Überströmmenge > 0,2 m^3 pro s pro m sofort auf maximaler Breite und Tiefe (abhängig von den Maßen der Hochwasserschutzwand).

6 Auswertung

Unter den genannten Annahmen ist in Szenario 1 die Deichsicherheit nicht gefährdet. In Szenario 2 kommt es an zwei Deichabschnitten zu Deichbrüchen. Ein Vergleich der Deichhöhen aus der HWSIM-Datenbank mit den in der vom Landesbetrieb Straßen, Brücken und Gewässer der Stadt Hamburg herausgegebenen Karte “Tiefliegende Gebiete in Hamburg mit Hochwasserschutzanlagen“ (Stand: Januar 2007) angegebenen Sollhöhen der Hochwasserschutzanlagen zeigt, dass die Deichabschnitte, an denen es in der Szenarioberechnung zu Deichbrüchen kommt, inzwischen um bis zu 0,9 m erhöht worden sind. Es kann also davon ausgegangen werden, dass eine Sturmflut mit einem Scheitelwasserstand von 7,22 m NN am Pegel St. Pauli unter Berücksichtigung des heutigen Ausbauzustandes der Hochwasserschutzanlagen nicht zu Deichbrüchen führt.

Abbildung 2 zeigt den jeweiligen Anteil der in den Szenarien betroffenen Landfläche der Untersuchungsgebiete. Das Überschwemmungsgebiet der Dove-Elbe ist in keinem der Szenarien von Überflutung betroffen. Dies ist auf die Tatenberger Schleuse zurückzuführen, welche die Dove-Elbe von der Elbe und der Gezeiteneinwirkung im Ästuar abtrennt. Solange die Schleuse während einer Sturmflut geschlossen ist, muss in diesem Gebiet also nicht mit Überflutungen gerechnet werden.

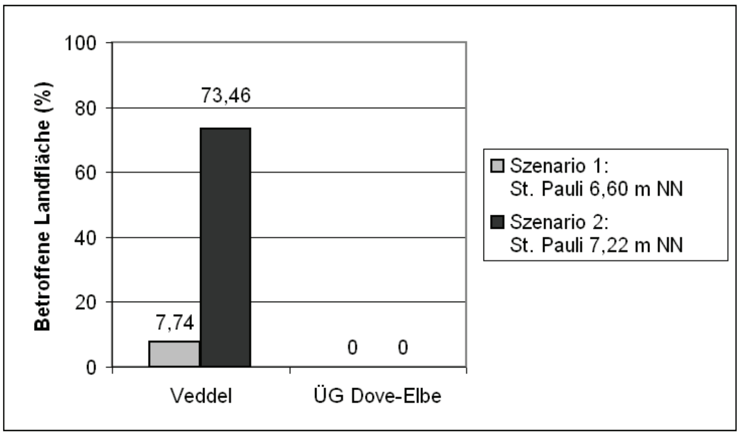

Abb. 2: Anteil der in den Szenarien betroffenen Landfläche

In Szenario 1 sind auf der Veddel 55 der 755 Gebäude von Überflutungen betroffen, in Szenario 2 sind es 505 Gebäude. Abbildung 3 zeigt, dass in beiden Szenarien der größte Teil der betroffenen Gebäude (Szenario 1: 48 Gebäude, Szenario 2: 388 Gebäude) nur über ein Stockwerk verfügt. Betrachtet man nun die Wohngebäude gesondert, zeigt sich, dass in Szenario 1 von den acht betroffenen Wohngebäuden fünf keine Rückzugsmöglichkeit in ein höher gelegenes Stockwerk bieten. In Szenario 2 sind 27 Wohngebäude betroffen, von denen 13 nur ein Stockwerk besitzen.

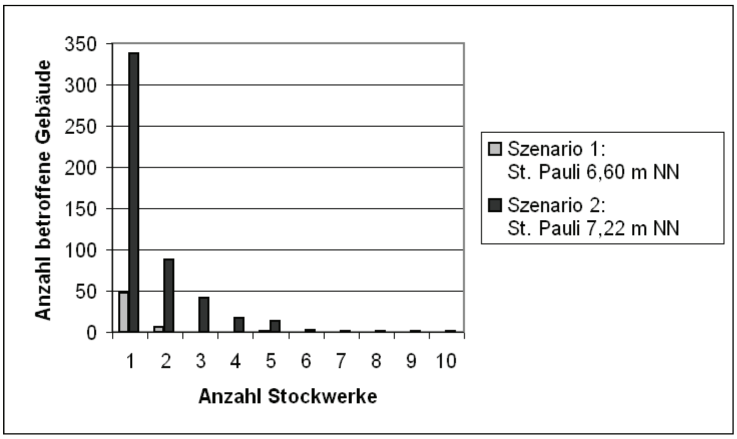

Abb. 3: Betroffene Gebäude auf der Veddel nach Stockwerkszahl

In Szenario 1 wurden ca. 73 Einwohner im überfluteten Gebiet lokalisiert; dies entspricht 1,5 % der Einwohner des Stadtteils. In Szenario 2 leben ca. 539 Personen (bzw. 10,9 % der Einwohner des Stadtteils) im potentiell überfluteten Gebiet.

Das direkte tangible Schadenspotential im betroffenen Gebiet liegt in Szenario 1 bei 31.272.200 €. In Szenario 2 beträgt der Wert 3.791.969.600 €. Diese Angaben beziffern nicht den zu erwartenden Schaden, sondern den Wert des direkten tangiblen Schadenspotentials im überfluteten Gebiet. Abbildung 4 und 5 zeigen den Anteil der einzelnen Schadenskategorien an diesen Gesamtwerten.

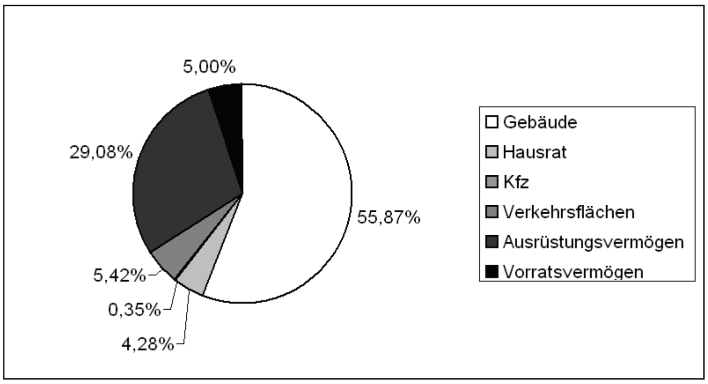

Abb. 4: Anteil der Schadenskategorien am monetären Schadenspotential der betroffenen Gebiete in Szenario 1

In Szenario 1 werden ca. 107 Arbeitsplätze (0,6 % der Arbeitsplätze im Stadtteil) im betroffenen Gebiet lokalisert. Mit diesen ist eine jährliche Bruttowertschöpfung in Höhe von 7.374.412 € verbunden. In Szenario 2 sind es 15.272 Arbeitsplätze (84,8 %) und eine Bruttowertschöpfung von jährlich 1.307.798.659 €.

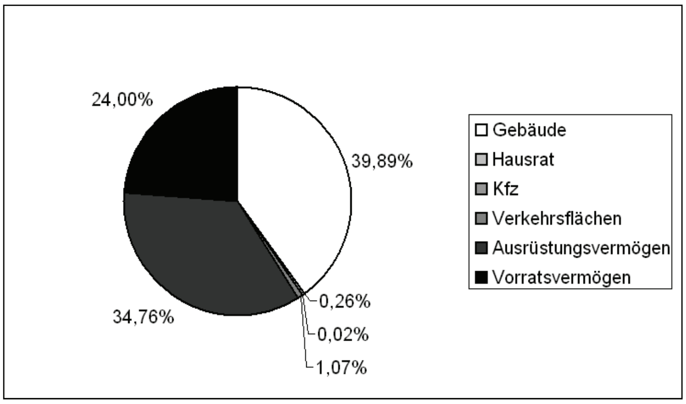

Abb. 5: Anteil der Schadenskategorien am monetären Schadenspotential der betroffenen Gebiete in Szenario 2

Auf Grundlage der in dieser Untersuchung erzielten Ergebnisse konnten Entwürfe für Hochwassergefahren- und Hochwasserrisikokarten entsprechend den Mindestanforderungen der EG-Hochwasserrisikomanagementrichtlinie erstellt werden. Abbildung 6 zeigt die Hochwasserrisikokarte für das Szenario 2. In dieser wird die Überflutungshöhe in 5 Klassen angegeben. Als weitere Informationen sind die Scheitelwasserstände an nahe gelegenen Pegeln sowie die Lage der öffentlichen Hochwasserschutzanlagen eingezeichnet Als Kartengrundlage wird die Digitale Stadtgrundkarte (DSGK) mit dem Basismaßstab 1:1.000 verwendet.

In der Risikokarte (Abb. 7) ist die Landnutzung in den in Szenario 2 betroffenen Gebieten dargestellt. Straßenflächen sind in den verwendeten Landnutzungsdaten nicht berücksichtigt, so dass diese in der Karte nicht dargestellt werden, obwohl sie im überfluteten Gebiet liegen. Als weitere Informationen sind die Standorte von Anlagen eingezeichnet, die bei Überflutung Wasserverschmutzungen verursachen können. Diese wurden aus der Online-Datenbank des Europäischen Schadstoffemissionsregisters (EPER) übernommen. Die Anzahl der potentiell betroffenen Einwohner wird durch die Zahl der Einwohner in den einzelnen Stadtteilen repräsentiert, die aus der Amtlichen Statistik (Statistisches Amt für Hamburg und Schleswig-Holstein 2008) übernommen wurden. Diese Angabe bezieht sich somit nicht speziell auf die im von Überflutung betroffenen Gebiet lebenden Menschen. Als Kartenhintergrund wurde die Digitale Stadtkarte (DK) mit dem Basismaßstab 1:20.000 verwendet.

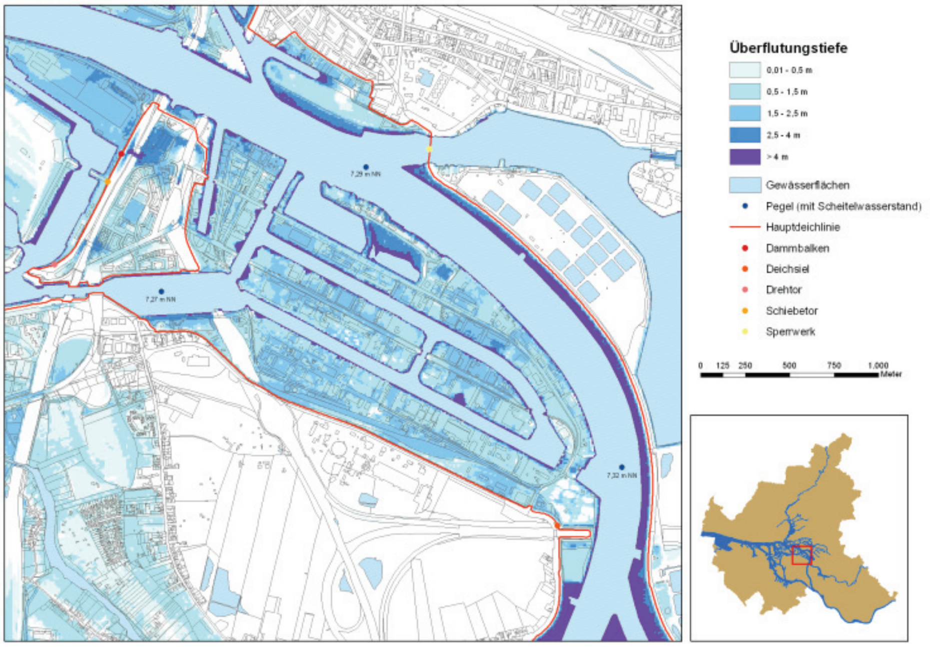

Abb. 6: Entwurf einer Hochwassergefahrenkarte (Veddel): Szenario Pegel St. Pauli 7,22 m NN

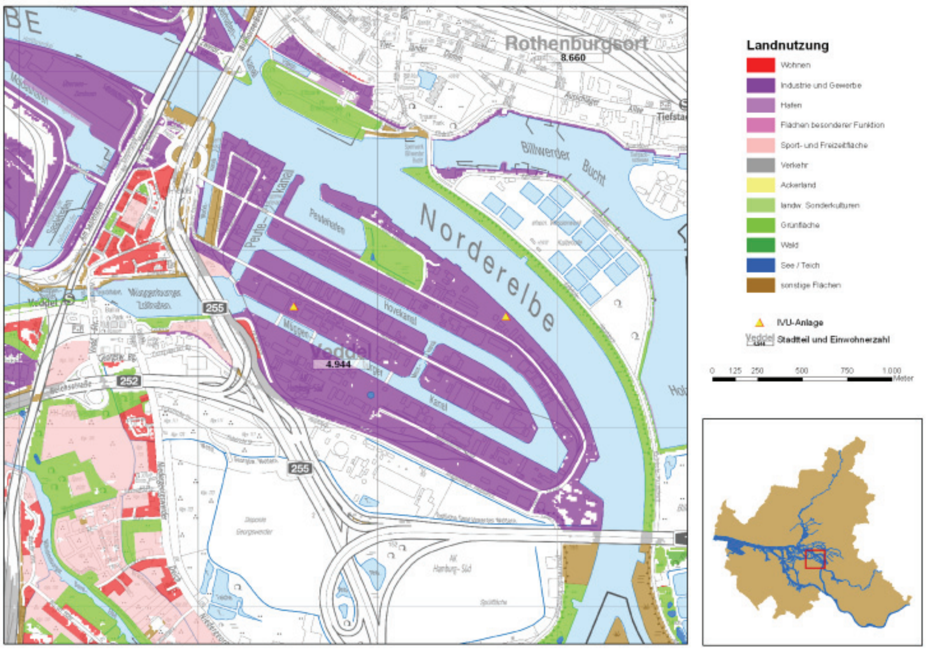

Abb. 7: Entwurf einer Hochwasserrisikokarte (Veddel): Szenario Pegel St. Pauli 7,22 m NN

7 Fazit

Die im Rahmen der Hochwasserrisiko-Analyse vorgenommene Wertermittlung sollte auf der einen Seite möglichst genau erfolgen, auf der anderen Seite schnell und kostengünstig durchführbar sowie aktualisierbar sein. Die Aktualisierbarkeit ist durch die Verwendung von Statistiken gewährleistet, da diese jährlich erstellt und veröffentlicht werden. Auch die verwendeten Kartengrundlagen werden in regelmäßigem Abstand aktualisiert, so dass Veränderungen des Baubestandes oder der Gebäudenutzung ohne großen Aufwand Rechnung getragen werden kann. Für die Überprüfung der Werte, die nicht auf Statistiken beruhen, kann eine erneute Expertenbefragung durchgeführt werden. Für eine nutzungs- bzw. gebietsspezifische Bestimmung von Gebäudewerten wären Vor-Ort-Untersuchungen zur stichprobenhaften Ermittlung von Gebäudewerten in Hamburg nötig. Aus den so ermittelten Daten könnten Durchschnittsangaben zum Wert einzelner Gebäudeklassen entwickelt werden.

Statistische Analysen von Pegeldaten im Elbeästuar sind nicht möglich, da aufgrund einer Vielzahl von Eingriffen in das hydrologische System keine homogene Datenreihe vorhanden ist. Die Ableitung eines Sturmflutscheitelwasserstands einer für den Pegel Cuxhaven ermittelten Eintrittswahrscheinlichkeit stellt eine Möglichkeit dar, Sturmflutscheitelwasserstände für Extremereignisse in Ästuaren abzuschätzen. Dieses Vorgehen ermöglicht allerdings nicht die Angabe einer Eintrittswahrscheinlichkeit für den Scheitelwasserstand am Pegel St. Pauli, da bei diesem Verfahren weder die Tidedynamik im Ästuar noch der Einfluss des Oberwasserzuflusses ausreichend berücksichtigt werden können. Für die Bestimmung von Scheitelwasserständen mit einem bestimmten Wiederkehrintervall für einzelne Pegel im Elbeästuar sind demnach weitere Untersuchungen nötig.

Die Simulation von Sturmflutszenarien mit dem Programm HWSIM bietet eine gute Möglichkeit, die in Folge einer Sturmflut mit einem bestimmten Scheitelwasserstand voraussichtlich von Überflutungen betroffenen Gebiete abzuschätzen. Da die überfluteten Flächen als Grid mit einer Auflösung von 10 x 10 m berechnet werden, können die räumliche Ausdehnung und die Höhe der Überflutung im Gelände allerdings bisher nur sehr ungenau bestimmt werden. Das gewählte Vorgehen bei der Simulation von Sturmflutereignissen lässt keine Quantifizierung von Unsicherheiten bezüglich des Überflutungsverlaufes im Allgemeinen und der Deichbrüche im Speziellen zu. Für die Bestimmung solcher Unsicherheiten sind weitere Untersuchungen notwendig. Für eine belastbare Ermittlung der Folgen verschiedener Sturmflutszenarien als Grundlage für Karten und Planungen, wie sie die EG-Hochwasserrisikomanagementrichtlinie erforderlich macht, sind außerdem zusätzliche Modifikationen des Programms notwenig, um einen höheren Detailgrad der Simulationsergebnisse erreichen zu können.

Eine Abschätzung von Schäden auf Grundlage von Überflutungscharakteristika wie beispielsweise der Überflutungshöhe war im Rahmen dieser Untersuchung nicht möglich. Hierfür wäre die Entwicklung von Schadensfunktionen erforderlich. Da das letzte große Schadensereignis mehr als 30 Jahre zurückliegt und es daher keine umfangreiche Datenbasis zur Aufstellung solcher Schadensfunktionen gibt, müssten die benötigten Schadensinformationen durch eine “Was-wäre-wenn”-Analyse (Buck 2006) ermittelt werden. Auf Grundlage der für die durchgeführte Untersuchung herangezogenen Daten ist es außerdem nicht möglich, die Überflutungshöhe für einzelne Gebäude zu ermitteln. Zwar lässt sich die Überflutungshöhe für jeden Punkt im GIS abfragen, doch bezieht sich diese Angabe auf die Überflutungshöhe im Gelände und lässt keine Aussage über die Höhe des Wasserstandes in den einzelnen Gebäuden zu, da das Höhenniveau des Erdgeschosses nicht automatisch mit dem Geländeniveau gleichzusetzen ist.

Auch wenn eine Schadensschätzung in Abhängigkeit von der Überflutungshöhe ohne die Verwendung von Schadensfunktionen nicht möglich ist, bietet das hier vorgestellte Verfahren eine gute Möglichkeit, sich einen Eindruck über die Anzahl der möglicherweise betroffenen Personen und die Höhe der möglichen Schäden in den im Sturmflutfall voraussichtlich von Überflutung betroffenen Gebieten zu verschaffen. Auf dieser Grundlage können im Bedarfsfall (beispielsweise in Gebieten, in denen Wertekonzentrationen ermittelt wurden) genauere Untersuchungen zum Schadenspotential durchgeführt werden.

Die Digitale Stadtgrundkarte (DSGK) stellt eine gute Grundlage für die Planung von Risikomanagementmaßnahmen dar. So ist mit ihrer Hilfe beispielsweise die Ermittlung und Lokalisierung von Gebäuden ohne Rückzugsmöglichkeit in ein höheres Stockwerk oder Gebäuden, in denen sich möglicherweise hilfsbedürftige Menschen aufhalten (Krankenhäuser, Kindergärten), möglich.

Die Erstellung von Entwürfen für Hochwassergefahren- und Hochwasserrisikokarten gemäß der EG-Hochwasserrisikomanagementrichtlinie war im Rahmen der durchgeführten Untersuchung möglich. Die für die Gefahrenkarten notwendigen Informationen konnten mit Hilfe des Programms HWSIM generiert werden. Aufgrund der groben Auflösung der berechneten Ergebnisse ist die Darstellung der überfluteten Flächen in Gefahrenkarten in einem Maßstab größer als 1:15.000 nicht zu empfehlen. Für die Darstellung der wirtschaftlichen Tätigkeiten in den betroffenen Gebieten wurden die von Überflutung betroffenen Gebiete im GIS mit Landnutzungsinformationen verschnitten. Da diese nicht alle erforderlichen Informationen enthielten, sollte für die Erstellung von Risikokarten der Empfehlung der LAWA (Länderarbeitsgemeinschaft Wasser 2008) gefolgt werden, auf die Flächennutzungsinformationen des Amtlichen Topographisch-Kartographischen Informationssystems (ATKIS-Basis-DLM) zurückzugreifen.

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Effects of Changes in Sea Level on the Tidal Dynamics of the River Weser

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Abstract

A system study was conducted with the aid of a 3D hydrodynamic numerical model to enable the impact of changes in sea level on the estuary of the River Weser to be estimated more accurately. During the study the mean tide level and mean tidal range were raised and the results were subsequently analysed with regard to the tide-related characteristic values. The results show an increase in the tidal range in the estuary along with an increase in the current velocities, in particular in the flood current velocity. In addition, an intrusion of high salt concentrations further upstream was observed. Within the range of values examined, the system variables within the estuary reacted linearly to the changes introduced at the boundaries of the model.

1 Background

The rise in mean sea level (IPCC 2007) is directly affecting the mean tide level in the estuary of the River Weser. In addition, the amphidromic points in the North Sea are likely to be influenced so that changes in the phases and amplitudes of the partial tides can be expected (Plüß 2004). This in turn is affecting the tidal range which determines how much energy enters the estuary.

As a starting point for modelling climate change scenarios it is important to be able to estimate the reaction of the estuary to such changes and to understand their causes and relationships. The parameters “mean tide level” (MTL) and “tidal range” (TR) were therefore varied and the changes in the mean conditions in the estuary analysed in the system study described in this paper.

2 Model and concept of the investigation

The investigations were conducted with the combined UnTRIM-SediMorph modelling system. The UnTRIM numerical method was used to solve non-steady state, non-linear equations for free surface flow problems (Casulli & Zanolli 2002). The morphodynamic modelling method SediMorph (Malcherek et al 2005) was used to calculate the bottom friction.

The model covered the entire area of the Jade-Weser estuary, for which the hydrodynamics and salt transport were calculated in a high resolution 3D data set. The model was validated for present-day conditions using measured data and it delivers realistic results. It was steered via the water levels on the seaward boundary and the fresh water inflow from the Weser on the landward boundary. The period of time selected for the analysis was a spring-neap cycle.

The boundary conditions for MTL and TR were varied both separately and jointly in the system study. The changes in MTL ranged from -20 cm to +80 cm and those in TR from -20 cm to +40 cm. All other boundary conditions in the model were identical. Thus the freshwater inflow was a constant 180 m^3/s in all variations of the model and was therefore in the range of the most frequent freshwater inflow.

3 Results – Tide-related characteristic values of water level, current and salt content

An increase in the two parameters TR and MTL in the seaward boundary conditions resulted in an increase in the high water elevation (HW) along the Weser estuary (Figure 1, left panel). The specified changes in the boundary values were sustained virtually unaltered in HW up to the tidal limit.

Increasing TR in the boundary conditions resulted in a lowering of the low water elevation (LW) while, by contrast, raising MTL led to an increase in LW. Figure 1 shows that changes in LW introduced at the seaward boundary decreased towards the tidal limit, in contrast to HW. TR thus increased in the direction of the tidal limit. At the same time, the duration of the ebb tide increased between W-km 20 and W-km 100 compared with the duration of the flood tide.

It is noticeable that the tide-related characteristic values reacted approximately linearly to the changes in the boundary values. Thus the changes in the tide-related characteristic values can be expressed by varying MTL and TR by means of regression equations. In particular, there was a good correlation between the characteristic values of the water level obtained in this way and the values obtained in the simulation (Figure 1, right panel).

Furthermore, an increase in TR and MTL in the seaward boundary conditions resulted in greater current velocities. The increase in the flood current velocities was more pronounced than the increase in the ebb current velocities so that several of the areas previously dominated by the ebb current were subsequently dominated by the flood current (Figure 2).

An increase in MTL and TR at the seaward boundary of the model also resulted in saltwater intruding further upstream. Thus, for example, water with a mean salt content of 5 psu intruded up to 5 km further upstream for MTL +55 cm and TR +30 cm.

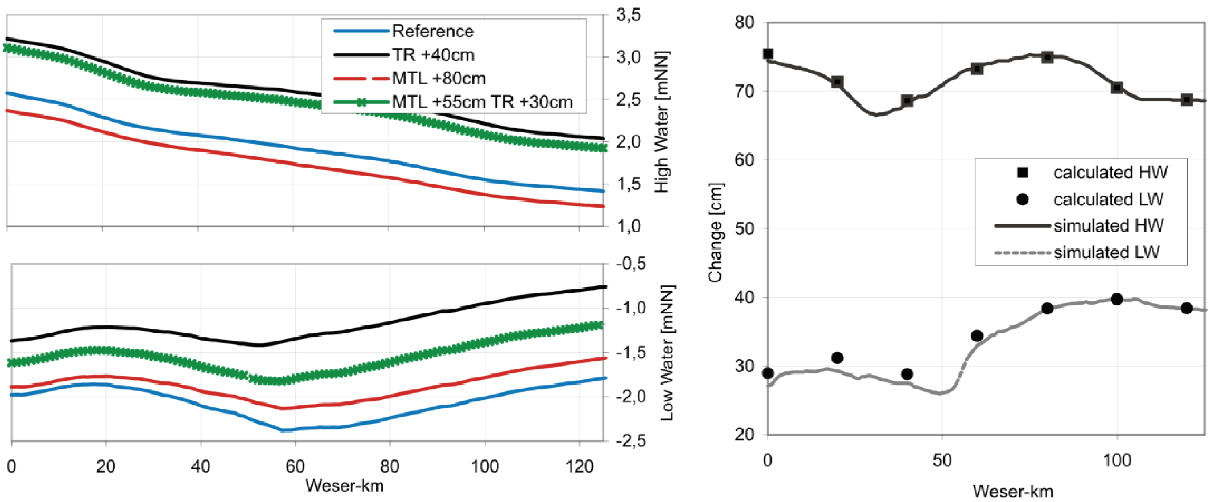

Figure 1: High water (HW) and low water (LW) along the Weser navigation channel with km-0 close to the tidal limit and km-125 at the end of the navigation channel in the North Sea. The left panel shows depth-averaged results of the reference run, two runs with variation only of tidal range (TR) and mean tide level (MTL) respectively and one with variation of TR and MTL. The right panel shows the change (relative to the reference run) in HW and LW for MTL +55 cm and TR +30 cm calculated with the help of linear regression equations and compared to simulated values.

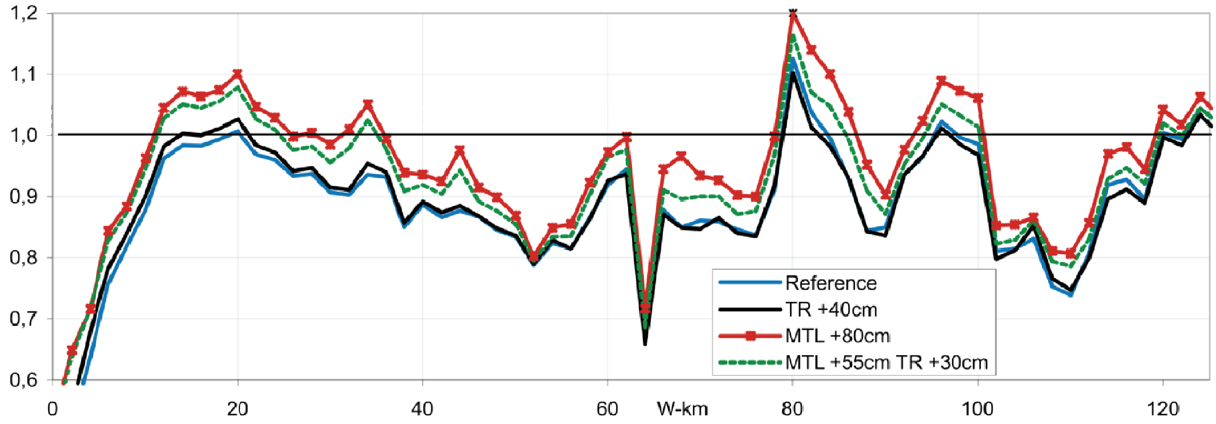

Figure 2: Ratio of mean flood current velocity to mean ebb current velocity. Values above 1 indicate flood current dominated sections.

4 Discussion and conclusion

The investigations described above show that the reactions in the system caused by a rise in mean tide level are basically similar to those caused by a deepening of the estuary. Thus changes in water levels at high water are sustained virtually unchanged throughout the estuary while changes in the water level at low water decrease in the upstream direction. The resultant increase in the tidal range leads to higher current velocities, with the flood current velocities increasing to a greater extent than the ebb current velocities owing to the less pronounced effect of bottom friction.

The strengthening of the flood current is significant for the transport of suspended matter. If the ebb current becomes weaker than the flood current it will no longer be capable of removing the sediment transported upstream by the flood current. This can result in greater siltation of the areas dominated by the flood current.

The intrusion of water with a higher salt content further inland owing to the rise in the mean water level principally affects the flora and fauna in those areas and has an impact on the suitability of the river water for agriculture.

Finally, it should be pointed out that the aim of the system study described above was not to model climate scenarios but to analyse the behaviour of certain state variables under two modified boundary conditions. Climate scenarios would cover additional boundary conditions, such as changes in temperature, wind speed, wind direction and freshwater inflow. The system study described in this paper was conducted with a fixed fresh water inflow, i.e. the quantitative statements made in this study only apply to the selected fresh water inflow situation.

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Costs of sea-level rise under different climatic and socio-economic scenarios: an application of the DIVA model

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Abstract

The world's coastal zones are due to a high population and a high concentration on material assets among the most vulnerable areas in the world to a, through climate change altered, sea-level rise. To better protect these potential endangered areas vulnerability assessments are necessary to evaluate the potential risks, impacts and costs of climate change. In this work the DIVA model version 2.0.2 was applied to indentify the potential costs of sea-level rise under different climatic and socio-economic scenarios. The DIVA runs were made for Germany, the Netherlands and the United Kingdom with the IPCC SRES scenarios A1FI, A2 and B2. The results outline the need for adaptation under all three scenarios with highest values in the A1FI and the lowest in the B2 scenario. They clearly show that the costs will rapidly increase at least after 2070 without adaptation. The results also outline the huge benefit of proactive adaptation compared with reactive adaptation. Even if the DIVA model is a global model the results are in a logical context to the physical and socio-economic conditions of the countries and scenarios applied and provide useful insights on the vulnerability for long-term coastal management even on smaller scales.

1 Introduction

The coastal zones contain a large part of the world's population. Daschkeit and Sterr (2003) indicate that around 50 % of the world's population lives within 50 km of the shoreline. These areas also have a high concentration on material assets with large socio-economic relevance. Therefore and due to an, through climate change altered, sea-level rise the coastal regions are among the most vulnerable areas in the world. New estimates about sea-level rise indicate that it possibly could rise between 0.55 m and 1.40 m until 2100 (Rahmstorf et al. 2007). To better protect these potential endangered areas vulnerability assessments are necessary to evaluate the potential risks, impacts and costs of climate change. Until now there are numerous concepts of vulnerability assessments available but they are mostly static and do not take into account the dynamic feedback between various coastal processes, their socio-economic consequences as well as the way humans respond in form of adaptation. They are also mostly performed to inform local and national decision-makers rather than to provide comparable data for regional and global purposes. The relatively new DIVA model addresses some of these limitations as it is a global and dynamic tool to assess the vulnerability on different scales taking into account adaptation.

2 Methodology

In this work the DIVA (Dynamic Interactive Vulnerability Assessment) global impact and adaptation model version 2.0.2 was applied. This model is part of the DIVA tool which consists of a global coastal database, the integrated model (figure 1) and a graphical user interface. The DIVA model consists of various modules which provide knowledge about the coastal sub-systems. They are linked to each other as well as to the database.

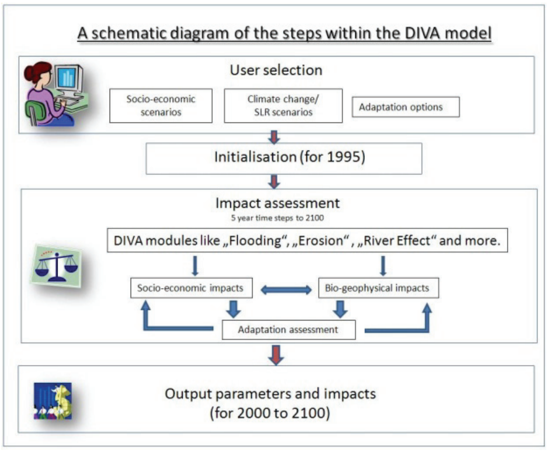

Figure 1: Schematic overview of the DIVA model

The cases in DIVA are a combination of the selected SRES based scenarios (A1FI, A2 and B2) in land use, population and economic concerns, the climate scenario, the input data and the selected adaptation option. Next to the three SRES scenarios three different adaptation options have been applied: Costs-benefit-analyse based adaptation, full adaptation and no adaptation.

Within this work the following output parameter are used:

1. Total costs compounded of total adaptation costs and total residual damage costs.
2. Total adaptation costs compounded of sea-and river dike costs, and costs for beach-, wetland-, and tidal basin nourishment.
3. Total residual damage costs compounded of costs for land loss, migration, salinity intrusion as well as sea- and river floods.
4. Number of people actually endangered by flooding.

These output parameters were applied for Germany, the Netherlands and the United Kingdom and for a time frame from 2000 until 2100.

3 Results

The results clearly show that without any adaptation the costs and the number of people at risk will increase rapidly at least after 2070 (figure 2). This applies for all countries and in all scenarios. With adaptation however the damage costs and the number of people at risk will decrease significantly. The two adaptation scenarios are used as a proactive adaptation option and the no adaptation scenario as a reactive adaptation option. The results show the benefit of proactive adaptation versus reactive adaptation (figure 3).

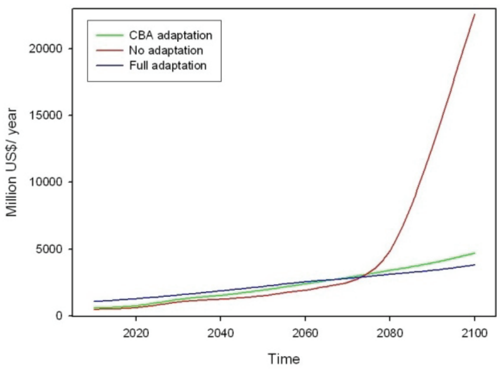

Fig. 2: Trends of total costs in Germany in A1FI

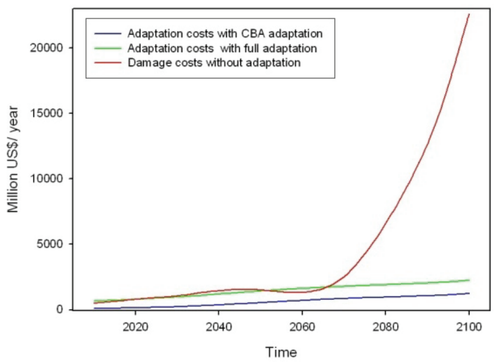

Fig. 3: Proactive versus reactive adaptation

The main trends between the scenarios are nearly the same but the costs will be highest in the A1FI scenario and lowest in the B2 scenario. The main contributors to the damage costs are salinity intrusion into deltas and estuaries, sea flood costs and within the no adaptation scenario migration costs. The main contributors to the adaptation costs are sea dike costs, beach and tidal basin nourishment. The percentage distribution of the contributors is extremely different between the countries reflecting the different physical conditions and main hazards.

The A2 scenario is not the most vulnerable scenario for the three countries studied in this thesis despite its high population growth because these countries have a declining population.

The most vulnerable country in this work based on size, population and GDP compared to the costs is the Netherlands followed by the UK and lastly Germany.

4 Discussion and conclusion

The results reflect how the projected future the socio-economic- and the climatic development in the countries together with climate change contribute to the impacts to climate change. They outline the large impact of different socio-economic developments and show that the impacts of sea-level rise are only detectable after 2030. The results also show that even if a country have a high adaptive capacity like all three countries used in this work the protection level will fall over time if they are not adjusted to climate change which will lead to an increase of impacts and costs.

For the interpretation of the DIVA results there are three key limitations to be aware of. Firstly, the DIVA model is a global model. Due to a spacious data resolution DIVA is not suitable to be used on smaller scales than on country level. Secondly, there are more adaptation options available than implemented in DIVA and thirdly, the assessment of DIVA is limited because it only represents a sub-set of possible impacts. Besides these limitations the results are in a logical context to the physical and socio-economic conditions of the countries and scenarios applied and yield information about the nature of the most serious impacts, about the possible affected land area, and about the number of people at risk as well as about vulnerable hotspots.

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From coastal flood defence towards coastal flood risk management

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Abstract

Climate change induced sea level rise will lead to higher coastal flood risks. Adaptation strategies in Germany traditionally focus on technical flood defences that ensure defined safety standards. In this paper, after a short discussion of sea level rise scenarios, possible constraints of flood defence schemes are described. It is argued that a sustainable adaptation strategy implies a holistic coastal flood risk management consisting of the elements prevention, protection, preparedness, emergency response, recovery and review. These integral components are described as parts of a control loop. In an outlook, the EU Flood Directive and its implications for coastal flood risk management in Germany are described.

1 Introduction

Storm surges may cause temporal flooding of coastal lowlands. When the flooding is perceived by society as a threat to life and property, it becomes a hazard that needs consideration or, rather, risk management. Risk may be defined as a combination of the occurrence probability of a hazard and its harmfulness for society, i.e., the damage expectations. Hence, coastal flood risk management (CFRM) may be implemented by controlling the occurrence probability of flooding (by technical means) and/or by controlling the damage expectations (figure 1). The classical approach in Germany to reduce or limit the risk of coastal flooding is protection by technical measures like dikes. These defences are designed with a certain safety standard in order to prevent flooding up to a defined storm water level. Today, after more than 2,000 years of coastal flood defence, about 2.5 million people live in the coastal lowlands of Germany.

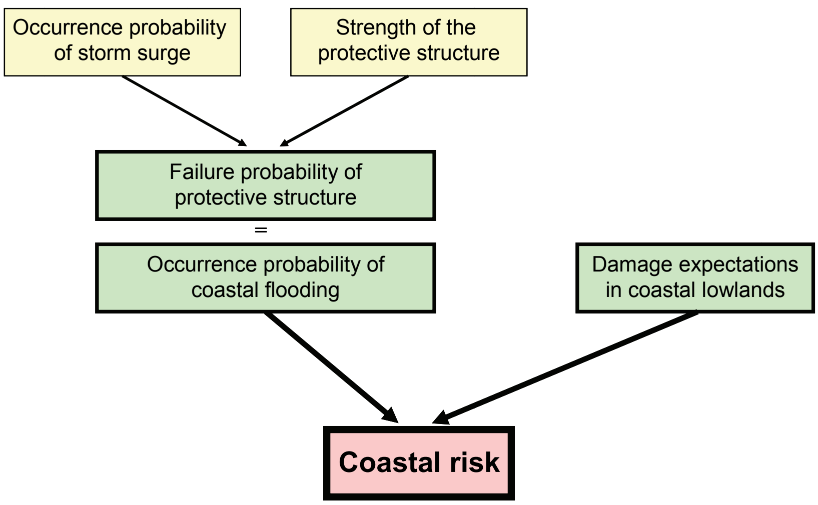

Figure 1: Schematic presentation of coastal flood risk (adapted from Probst 1994)

Implementing CFRM through controlling the damage expectations in coastal lowlands is increasingly getting attention in science and administration (CPSL 2005, Hofstede 2007a). So far, such options have only exceptionally been implemented in Germany. In contrast to technical flood defences, these solutions may cause development constraints in the coastal lowlands and result in more personal responsibilities and higher efforts for the affected population. The possible consequences of climate change for maintaining the existing safety standards and other possible constraints of flood defences justify the evaluation of alternative and complementary options for CFRM.

In this paper, after a short discussion of sea level rise scenarios, possible constraints of technical flood defences are described. Further, the CFRM cycle as a holistic and integrated approach is elaborated in detail. The paper ends with an outlook.

2 Sea level rise scenarios

Anthropogenic sea level rise (SLR) will result in higher storm surge water levels and, therewith, in higher coastal flood risks. The fourth assessment report of the Integovernmental Panel on Climate Change (IPCC 2007) delivered a range of global SLR scenarios. Depending on the models and emission scenarios, the values range from 0.19 to 0.58 m of SLR between 1980/99 and 2090/99 Accelarated melting of the Greenland icecap may contribute up to 0.2 m of extra SLR to these values.

In its report of 2007, IPCC pinpoints a number of uncertainties and unknown factors that may cause deviations from the published values. For example, IPCC states that dynamical processes related to ice flow on Greenland and the West Antarctic Peninsula that are not included in current models but suggested by recent observations could increase the vulnerability of the ice sheets to warming, thereby increasing future SLR (Shepard and Wingham 2007). Understanding of these processes is limited and there is no consensus on their magnitude. Other unknown factors that are recently discussed are the possibly reduced capacity of the oceans and tropical rain forests to store carbon dioxide as well as possible emissions of nitrous oxides (laughing gas) from the ocean floors and the permafrost regions. Laughing gas is a highly effective greenhouse gas. Both meachnisms may result in increased SLR. On the other hand, if fresh water input in the North Atlantic Ocean from the melting icecap on Greenland increases substantially, a blocking off of the Gulf Stream could occcur. Previous models (on the basis of moderate fresh water input) suggest that this hazard only has a very low probability in this century. An expert judgement from leading climate researchers (Zickfeldt et al. 2007) yielded the following result. If global temperature increases by 4o C, two third of the respondents estimated the probability of a collaps of the Gulf Stream in this century among 10 and 60 %. A collaps could result in a reduction in SLR, at least in the North Atlantic region (as well as in a recovery of the Arctic marine ice cover). Finally, SLR will not terminate at the end of this century but is expected to continue for centuries. Quantification is highly uncertain as it includes even more unknown factors.

The unknown factors give way to a number of alternative SLR scenarios (table 1).

Table 1: Sea level rise scenarios (in m) from different authors

Author	Regional (2100)	Global (2100)	Global (2200)	Global (2300)
IPCC (2007)	-	0.19 - 0.58	-	-
Rahmstorf (2007)	-	0.5 - 1,4	-	-
MPI (2006)	0.41 – 0.48 (North Sea)			-
WBGU (2006)	-	-	-	2.5 – 5.1
Horton et al. (2008)	-	0.54 - 0.89	-	-
Delta Commissie (2008)	0.65 - 1.30 (NL coast)	0.55 - 1,10	1.5 - 3.5	-
Grinsted et al. (2009)	-	0.9 - 1.3 (A1B)	-	-

Rahmstorf (2007) published a semi-empirical approach to estimate SLR among 1990 and 2100. His relationship connects observed global SLR to observed global mean surface temperature rise during the 20th century. Applying this relationship for the IPCC temperature scenarios, Rahmstorf delivered SLR projections until 2100 among 0.5 and 1.4 m. His approach is controversially discussed in the scientific community. The Max-Planck-Institute for Meteorology (MPI 2006) delivered global SLR projections among 0.21 and 0.28 m until 2100. They calculated that changes in the ocean circulation may lead to an extra SLR of about 0.2 m in the North Sea. If global temperature increase is limited to 3°C, the Scientific Advisory Board of the German Government on Global Environmental Changes (WBGU 2006) expects a long-term SLR until 2,300 among 2.5 and 5.1 m, mainly due to melting of the large icesheets on Greenland and the West Antarctic Peninsula. Horton et al. (2008) applied the semi-empirical relationship from Rahmstorf to the coupled global climate models that were used for the fourth IPCC report. With a mean of 0.71 m, the resulting global scenario values ranged among 0.54 and 0.89 m. Horton et al. (2008) states that: "Both the IPCC values and the semi-empirical SLR projections are likely to underestimate future SLR if recent trends in the Polar Regions accelerate." Grinsted et al. (2009) used a physically plausible four parameter linear response equation to relate 2,000 years of global temperatures and sea level. Future sea level was projected from IPCC temperature scenarios and past sea level from multi-proxy reconstructions (assuming that the established relationship between temperature and sea level holds from 200 to 2100). In result, SLR until 2090/99 was projected to be 0.9 to 1.3 m for the IPCC A1B scenario, with low probability of the rise being within IPCC confidence limits. In 2007, the Dutch Government installed an independent Delta Commission with the merit to evaluate and recommend possible flood risk adaptation strategies and measures (Delta Commissie 2008). The Commission decided to apply regional "worst-case scenarios" varying among 0.65 and 1.3 m of SLR until 2100 and among 2 and 4 m until 2200.

From this discussion it becomes clear that SLR will probably be higher than the lower IPCC values; a range among 0.5 and 1.4 m may be more realistic. Apart from the magnitude, the large range calls for flexible and sustainable (i.e., no-regret) adaptation measures and strategies. With respect to the starting date for most SLR projections (1990), it is interesting to note that, at least along the Dutch and German coasts, in 2008 (i.e., after 20 % of projection period) no indications of an accelerating SLR could be observed (figure 2; Hofstede 2007b).

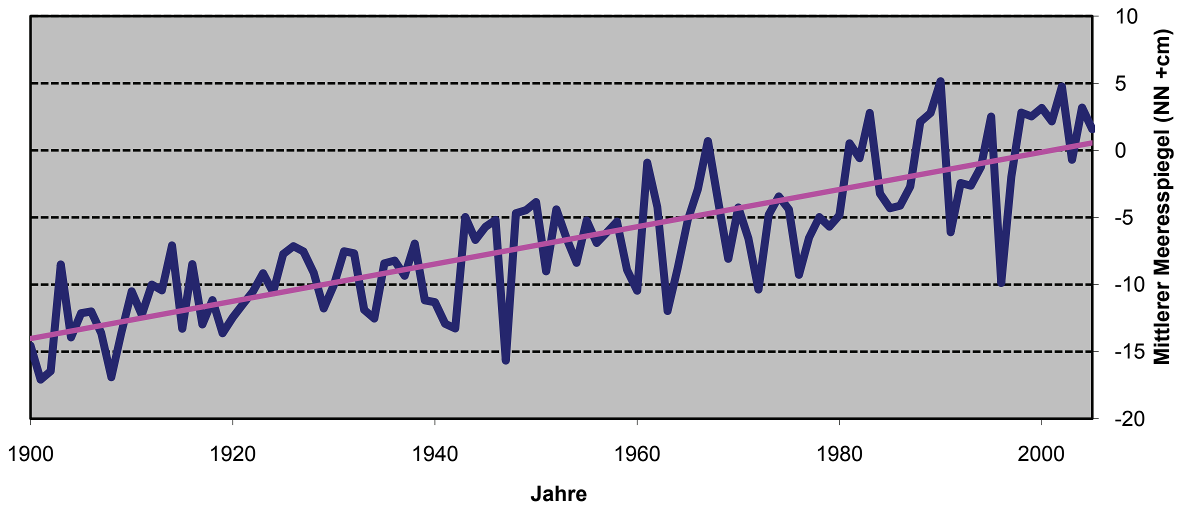

Figure 2: Development of mean sea level since 1900 AD along the Baltic and North Sea coastlines of Germany and the Netherlands, averaged from 17 long-term tidal gauge stations (Hofstede 2007b)

Apart from SLR, meteorological processes control the height of future storm surge water levels and, therewith, the necessary dimensions of flood defences. According to Woth et al. (2006), storm surges in the Inner German Bight may become up to 0.4 m higher in the period 2071-2100 compared to 1980-1999. Grosmann et al. (2006) included projections for SLR and came with a mean extreme water level projection of 0.50 m in 2085 for the city of Cuxhaven at the mouth of the Elb-estuary. Depending on the models and emission scenarios applied, the values range from 0.42 to 0.61 m. For Hamburg, the corresponding values amount to 0.48, 0.63 (mean) and 0.82 m. As with the SLR projections, these values include many uncertainties and assumptions. Further, due to the governing meteorological processes, the projections show strong local variations. For the German Baltic Sea coast, no projections are available.

3 Constraints of the present approach

CFRM in Germany focusses mainly on flood defences. Due to the fact that almost 2.5 million inhabitants of the coastal lowlands rely upon flood defences, maintaining and adapting these defences will remain a corner stone of CFRM in Germany. Dike relocation on a large scale would be financially unfeasible and ecologically unfavourable (e.g., huge costs and vast energy consumption to relocate people and activities, creation of extensive – former natural – areas for housing, infrastructure and other purposes). It is highly probable that such a massive migration would cause major economic and social disruption. Finally, at least for administration, it is clear that acceptance of the affected cannot be expected. On a local scale, dike relocations may be attractive, especially when they increase coastal resilience against climate change, when they have positive ecological effects and when the area is uninhabited. Some successful examples of dike relocation in Germany exist, for example on the barrier island Langeoog, at Geltinger Birk outer Flensburg Fjord and at the Karrendorfer Wiesen near Greifswald.

Technical flood defences underly a number of constraints.

- Flood defences are designed to withstand a defined maximum storm surge water level (figure 3). This level does not only result from technical elaborations, but also includes financial and social considerations. The result is a safety standard that is accepted by society. Higher water levels and other loading cases (e.g. terror attack, ice load) may result in failure of the structure and flooding. Hence, technical flood defences cannot guarantee absolute safety. The residual risk needs to be managed (Oumeraci 2005).

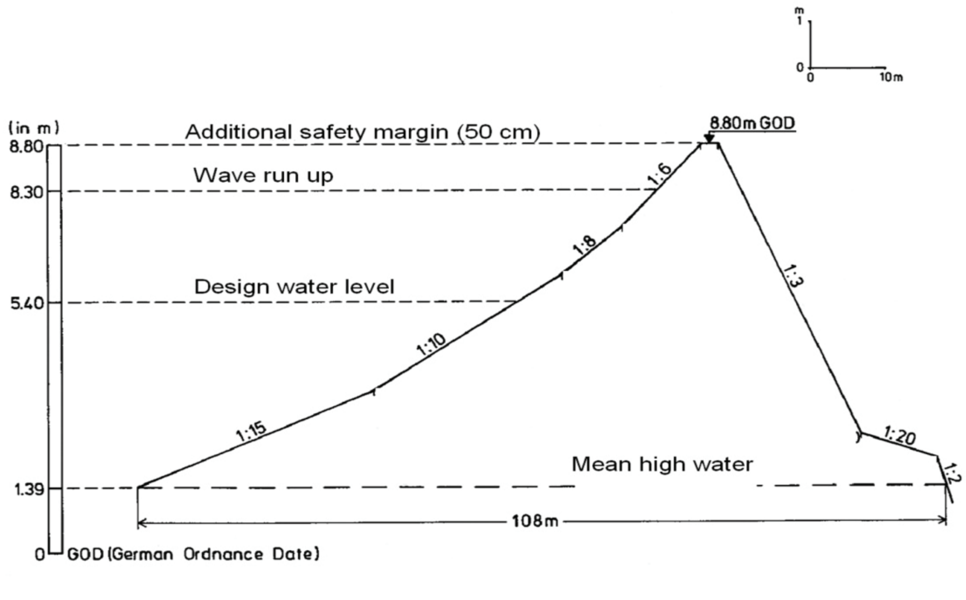

Figure 3: Dimensions of a State dike in Schleswig-Holstein

- The safety level directly depends on the willingness of society to spend money on flood defence. This willingness is governed by the awareness for coastal flood risks that rapidly sinks with time passing by since the last flooding event. Low public budgets together with low risk awareness may reduce the funds available for flood defences. Although it is questionable that a (politically) fixed safety standard will officially be reduced, a cut in financial means may lead to this. Examples are neglected maintenance or delayed strengthening of the defences (determined by SLR).
- Climate change and its consequences may reveal the financial limits of technical flood defences. Above a certain threshold the necessary financial efforts to maintain safety standards could become unacceptable for society. In this case, alternative and additional coastal risk management options become inevitable. It should be stated that technical solutions to counteract a SLR of several meters in a long-term perspective exist.
- Technical flood defences interfere with nature and may reduce the natural resilience of the coasts with respect to SLR. Examples are the fixation of the coastline in an unfavourable and artificial location or the interruption of natural sand redistribution patterns. Hence, wherever possible, natural hydromorphological processes should be allowed or furthered. In this case, however, alternative measures to reduce the risk of flooding (i.e., the damage expectations) of the hinterland may become necessary.

Apart from these constraints, focussing on (ever higher) dikes has some inherent disadvantages. The higher the dike, the stronger the inundation processes (currents, water depths) after dike breach, and the more severe the consequences will be. Further, high and strong dikes may lead to the (false) impression of absolute safety. Hence, the dependence on one single measure or dike line makes society more vulnerable.

4 The coastal flood risk management cycle

From the above considerations it becomes clear that a sectoral approach towards CFRM that only focuses on technical measures is not sufficient. The challenges arising from climate change as well as the constraints of technical structures imply that the classical flood defence schemes should be an integral part of a holistic management that combines technical measures with non-structural methods (Hofstede et al. 2005a). Sustainable CFRM may be defined as a cycle (control loop) that consists of six integral components: prevention, protection, preparedness, emergency response, recovery, and review (figure 4).

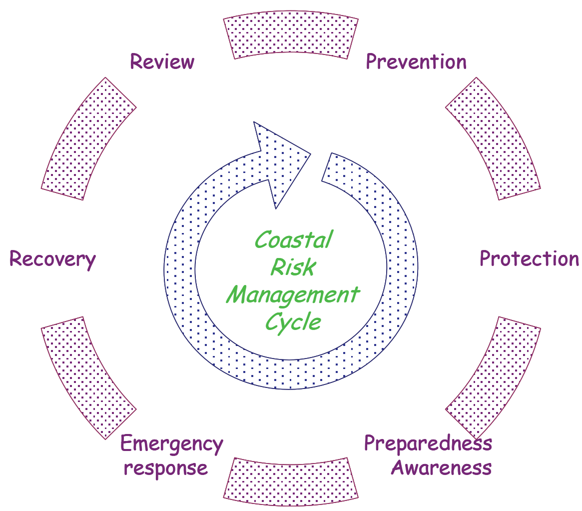

Figure 4: The coastal risk management cycle (Hofstede 2007a)

Prevention to avoid or minimize damages from flooding. As stated in the introduction, coastal flooding is a natural event. Some environments like salt marshes depend on regular inundations. Flooding becomes a hazard when society starts to utilize the flood-prone area for infrastructure, housing, etc. Controlling the development in flood-prone coastal lowlands is, thus, the first step in the CFRM cycle.

Main tool to control utilization of coastal lowlands is spatial planning. It constitutes a formalized and systematic way to influence (regulate) the distribution of people and activities geographically. The guiding principle of spatial plans and programs is a sustainable spatial utilization and development which balances the social and economic requests upon a region with its ecological functions (ROG 1998). Spatial planning in Germany is realized at regional, State and national levels. At the local level, municipalities are responsible for building or town planning. The local and regional levels have the most potential for CFRM.

On a local level, specific regulations for building areas may substantially reduce damage expectations due to coastal flooding. For example, in the 1970ies, a new building area was established near the Baltic Sea in Germany. Flood defence consisted of relatively low dikes. To keep damage expectations low, in the local building code, it was regulated that living room should be realized in the upper floors. On ground-floor level, only garages and/or storage rooms were allowed. Three decades later, these stipulations are not abided anymore. The absence of flooding events and lacking risk communication resulted in very low risk awareness and corresponding behaviour. Another actual example is the "Hafencity Hamburg". This new building area lies outside the public flood defence line in the harbour area of Hamburg. In the building code for the area it is stipulated that the whole area has to be raised up to a level that cannot be reached by extreme floods. This regulation became well-known as the "dwelling-mound-principle". In order to control the residual risks (see chapter 3), houses at the waterfront should have special arrangements for flooding, and evacuation routes are foreseen.

On a regional level, the identification of buffer zones and flood hazard zones constitute promising non-structural measures to control coastal flood risks (CPSL 2005). Coastal buffer zones, demarcated by setback lines in spatial plans may provide protected zones between the sea and the hinterland, where human utilization and development are strongly restricted. As the term "buffer" already implies, this measure provides a zone that allows for retreat of the coastal flood defence line or reserves space for necessary flood defence measures. In this way, the natural resilience of the coast is enhanced as well. In coastal flood hazard zones, human activities can be managed (regulated) in such a way that the vulnerability of the area is reduced. This could be realized by specific requirements or recommendations defined in the spatial plans. For example, certain roads could be constructed in elevated position (like dams) to allow for evacuation and to limit the inundated area. In specific high hazard zones, the "dwelling-mound-principle" for new building areas could be prescribed. The simple fact that flood hazard zones are depicted in the spatial plans could already increase the awareness of the risk.

Protection constitutes the second element of the CFRM cycle. It becomes necessary when flood-prone lowlands are utilized or, rather, when potential flooding is perceived by society as a threat to life and property. As stated before, with respect to the 2.5 million inhabitants of coastal lowlands, protection by technical flood defences will remain a corner stone in future CFRM in Germany. With reference to climate change and SLR, reserving space for strengthening campaigns by depicting buffer zones in regional plans is a sustainable measure.

Necessary measures may be implemented in a more sustainable way that minimizes the impacts on ecology and the natural resilience of the coasts. CPSL (2005) list a number of such solutions like performing sand nourishments (figure 5) to balance SLR as well as dune management techniques to stabilize and sustain the dune systems as natural flood defences. Necessary dike maintenance and strengthening may be performed in a sustainable way that minimizes the ecological interferences. Coastal defence administration already implements this minimizing principle, e.g. by performing dike relocations where appropriate (see above), by strengthening dikes to the landward side and by taking the necessary clay from the inland (wherever possible). Unavoidable interferences with nature are compensated.

Figure 5: Sand nourishment on the island of Sylt (Germany)

With respect to the large uncertainties in the scenarios, more flexible (no-regret) flood defence measures are investigated and implemented. Sand nourishments balance the observed SLR or, rather, the sediment deficit resulting from SLR (figure 5). If SLR increases, more sand may be deposited and vice versa. Nourihments, thus, present a flexible no-regret measure. Further, they increase the natural resilience of the coast and pose a relatively low impact on nature. On the other hand, strengthening a dike for an expected SLR of 1.5 m may turn out to be highly ineffective, namely if SLR takes two centuries to reach this level. In this case, it is much more cost-effective to spread the costs over the centuries by performing two or three strengthening campaigns. Considering building reserves (for extra heighthening) may be more appropriate and flexible. In its almost finished strengthening campaign, the city of Hamburg included a static building reserve of 0.8 m to allow for future heighthening of its flood defences (sheet pile walls, sluices, etc.).

Preparedness, being the third component in the CFRM cycle, is closely related to risk awareness. Aware people are prepared to personally undertake preventive and emergency actions. Further, they (are prepared to) accept the high costs for flood defences and other possible constraints of CFRM like flood-proof housing or living in the upper floor. In consequence, appropriate coastal risk awareness or, rather, a high level of preparedness may significantly reduce the damages resulting from flooding. The main tool to achieve coastal risk awareness (apart from flooding) is risk communication.

A public opinion poll consisting of 2,000 questionnaires that were distributed in five coastal towns around the North Sea showed that the awareness for coastal risks is not well developed (Hofstede et al. 2005b). Although the cities are situated in protected coastal lowlands, 30 % of the 411 respondents thought that their house could not be flooded after dike-breach (figure 6). Furthermore, 90 % of the respondents who estimated the probability of flooding in their region to be very high had not taken any precautionary measures. This indicates that the information flow about the risk towards the population is either insufficient, does not reach the recipients or is not taken seriously (ignored or disclaimed). The study concluded that there is an apparent deficit in coastal risk communication.

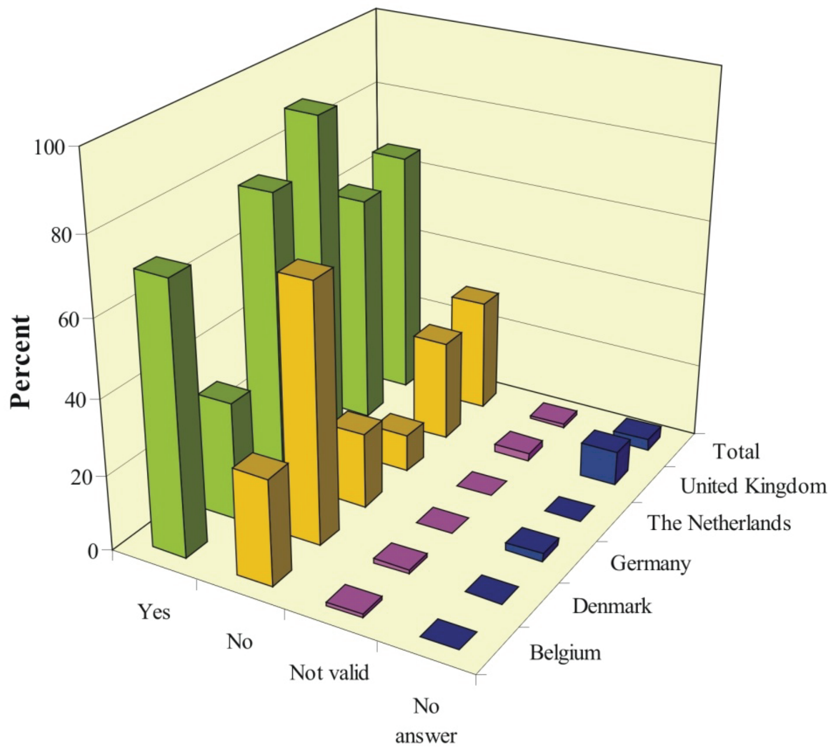

Figure 6: Response to the question: “could your house be hit by floodwater in case of a coastal flooding?” (Hofstede et al. 2005b)

Emergency response in the CFRM cycle includes all measures related to impending or real coastal floodings. The aim is to prevent or reduce catastrophic consequences and, therewith, the flood risks. Emergency response includes measures like flood warnings (based on flood forecasts by hydrological services), evacuation, placing sand bags, and aftercare. During an emergency, the responsible disaster management authority may access the capacities of other authorities like health services, fire departments, flood defence administration, etc.

SLR and, in reaction, higher dikes as well as increased utilization of coastal lowlands have the potential to intensify flooding catastrophies. If a dike-breach occurs, the water levels in the flooded area will rise faster and higher, thereby increasing the damage expectations. Accordingly, the importance of adequate emergency response increases.

Recovery aims at restoring the affected area to its previous state. It starts after immediate needs like closing the breaches or social and medical aftercare, are addressed. Recovery actions are primarily concerned with measures that involve repair of essential infrastructure and rebuilding of destroyed property. Hence, in a strict sense, recovery is not part of the CFRM cycle as it does not directly control or reduce the risks. However, effective recovery should take advantage of a “window of opportunity” (Alexander 2002) for the implementation of preventive and protective measures that might otherwise be unpopular. Citizens of affected areas are more likely to accept these measures when a recent disaster is in fresh memory. Implemented in this way recovery can contribute to the aims of CFRM.

Review stands for monitoring and regular (scientific) evaluation of all integrated CFRM components. In a broader sense, it also includes research on changes in SLR, storm surges and spatial development in coastal lowlands as these factors determine future coastal flood risk. Based on the outcomes of the evaluations and research, the next CFRM cycle may be optimized.

In an administrational structure, CFRM may be seen as a safety chain. It starts with spatial planning authorities that control/minimize the vulnerability of lowlands (prevention). Coastal flood defence administration is the next chain that guarantees a certain safety standard in the utilized flood-prone lowlands (protection). Disaster management – the third administrative body in the chain – starts with preparation, mainly through risk communication (but also by training and exercising). Conducting emergency response measures (from warnings till aftercare) is the second and main task of disaster management. Rebuilding society after the disaster (recovery) is not a public responsibility and, last but not least, the reviewing process is a task for all responsible authorities.

From the above elaborations it becomes clear that all CFRM elements complement one another. For example, depicting buffer zones in spatial plans facilitates the long-term implementation of coastal flood defence. Raising awareness by effective information or "intelligent" recovery inceases the acceptance of necessary planning measures like living in the second floor. Vice versa, the depiction of flood hazard zones in spatial plans increases the awareness and preparedness. Finally, an appropriate reviewing process is prerequisite for developing optimal information tools like travel exhibitions. Hence, in combination, the six integral components present a holistic approach towards CFRM.

5 Outlook

Justified by the common goal (controlled coastal flood risks), the complementary character of and the interactions among the elements, holistic implementation of the cycle is a precondition to achieve sustainable CFRM. This fact is acknowledged by the EU-Flood Directive. Purpose of this Directive is to establish a framework for the assessment and management of flood risks, aiming at the reduction of the adverse consequences for human health, the environment, cultural heritage and economic activity associated with floods in the Community. Based upon a preliminary flood risk assessment, flood risk areas shall be delineated. For these areas, flood hazard and risk maps as well as flood risk management plans shall be established. Focussing on prevention, protection and preparedness, all aspects of the CFRM cycle should be addressed in these plans. In order to achieve tailor-made solutions and to raise risk awareness, Member States shall make all products available to the public. Further, active involvement of interested parties in the production, review and updating of the flood risk management plans shall be encouraged. Concordingly, the implementation requires close coordination among competent authorities (coastal flood defence, disaster management, spatial planning) and active involvement of the affected parties. In Germany, where public procedures still show sectoral aspects, the Flood Directive may be seen as a chance.

This paper focusses on public-administrational aspects of CFRM. It is evident to realize that the most important partners in CFRM are the affected; the inhabitants and private investors in the coastal lowlands. Only if they adequately perceive the risks, accept their personal responsibility, and act accordingly, coastal flood risks remain manageable and a long-term sustainable development in the coastal lowlands is possible.

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Neue Herausforderungen im Datenmanagement für das europäische Meeresmonitoring

Das Projekt MDI-DE Marine Daten-Infrastruktur in Deutschland

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Abstract

The increasing pressure on the intensively used coastal and marine areas demands a thematic cross-analysis of all required data for the conservation of habitats, their functioning and protection. Additional needs for a common marine data infrastructure are the increasing complexity of current questions targeting anthropogenic changes in marine ecosystems, global change and the resulting challenges for coastal protection. Not least the reporting obligations for the main European directives in the marine area, as for the EU Water Framework Directive, the Flora-Fauna-Habitat Directive and in particular the Marine Strategy Framework Directive, recently entered into force, strongly require a certain data management.
At the same time data of the marine monitoring according to the INSPIRE Directive (Infrastructure for Spatial Information in Europe) should be provided for a common use. This requires an infrastructure and appropriate software tools, which join the technical capabilities with the requirements of EU directives.
Important networking components have already been developed within the North- and Baltic Sea Coastal Information System (NOKIS) and also at the participating data nodes of the central government and the federal states by developing local data infrastructures. Since these do not meet all requirements, the project "MDI DE - Marine data infrastructure in Germany" will play a decisive role to support the integration of different technical infrastructures and distributed skills of experts on marine and coastal data.

1 Kurzfassung und Einleitung

Der steigende Druck auf die intensiv genutzten Küstenregionen und Meere erfordert zunehmend eine themenübergreifende Auswertung aller für den Erhalt der Lebensräume, ihrer Funktionsfähigkeit und den Schutz erforderlicher Daten. Weitere Gründe für eine übergreifende marine Dateninfrastruktur sind in der zunehmenden Komplexität aktueller Fragestellungen im Zusammenhang mit den anthropogenen Veränderungen mariner Ökosysteme, in der globalen Klimaveränderung und den daraus resultierenden Anforderungen an den Küstenschutz zu sehen. Nicht zuletzt erfordern die gesetzlichen Anforderungen der europäischen Berichtspflichten, wie die der EU-Wasserrahmenrichtlinie, der Flora-Fauna-Habitat-Richtlinie sowie insbesondere der jüngst in Kraft getretene Meeresstrategie-Rahmenrichtlinie ein spezielles Datenmanagement.

Dabei sollen Fachdaten aus dem Meeresmonitoring nach Maßgabe der übergreifenden INSPIRE-Richtlinie (Infrastructure for Spatial Information in Europe) für eine gemeinsame Nutzung herangezogen werden können. Hierzu bedarf es einer Infrastruktur und geeigneter Softwarewerkzeuge, die diese technischen Möglichkeiten mit den Anforderungen aus den EU-Richtlinien verbindet.

Wichtige Bausteine zur notwendigen Vernetzung konnten durch das Nord-Ostsee-Küsten-Informationssystem NOKIS mit den beteiligten Datenknoten des Bundes und der Länder sowie durch den Aufbau lokaler Dateninfrastrukturen bereits entwickelt werden. Da diese den gestellten Anforderungen ebenfalls noch nicht gerecht werden, kommt dem Projekt „MDI-DE - Marine Daten Infrastruktur für Deutschland“ eine wichtige unterstützende Rolle bei der Zusammenführung der technischen Infrastrukturen und verteilten Kompetenzen der Experten für Meeres- und Küstendaten zu.

2 Aufbau und Ziele der MDI-DE

Einen wesentlichen Anstoß zum Aufbau einer Marinen Dateninfrastruktur in Deutschland haben die nachfolgend beschriebene Abkommen und EU-Richtlinien und die damit verbundenen Berichtspflichten gegeben.

Abkommen und Richtlinien zum Schutz der Meeresumwelt

Generell muss zwischen den traditionellen Meeresschutzabkommen wie HELCOM, OSPAR und dem TMAP sowie den von der Europäischen Union erlassenen Richtlinien (s. u.) unterschieden werden. Im Gegensatz zu den EU-Richtlinien können durch die Abkommen nur Empfehlungen ausgesprochen, jedoch keine gesetzlich wirksamen Beschlüsse verabschiedet werden.

HELCOM

HELCOM selbst ist eine zwischenstaatliche Kommission, die für den Schutz der Meeresumwelt im Ostseeraum agiert. Gegründet wurde die Kommission von den Ostsee-Anrainern. Das entsprechende Abkommen wurde 1992 verabschiedet und trat im Jahre 2002 in Kraft.

OSPAR

OSPAR (auch OSPARCOM) ist die Abkürzung für das Übereinkommen zum Schutz der Meeresumwelt des Nordost-Atlantiks. Es ist nach den beiden Vorläufern benannt, der Oslo-Konvention (OSCOM) von 1972 und der Paris-Konvention (PARCOM) von 1974. Vertragsabschluss war am 22. September 1992 in Paris Der Begriff wird für den Vertrag an sich und für die exekutive OSPAR-Kommission verwendet.

Trilaterales Monitoring- und Bewertungsprogramm (TMAP)

Im Rahmen des trilateral abgestimmten Beobachtungs- und Bewertungsprogramms (TMAP; CWSS 2008), das seit 1994 gemeinsam in Dänemark, Deutschland sowie in den Niederlanden im Wattenmeer umgesetzt wird, sind die Anforderungen an das Monitoring bereits sehr konkret festgelegt worden. Auf Basis der dringlichen Problemfelder und den bereits bekannten Wirkungsgefügen wurde eine Auswahl der zu erfassenden Parametern festgelegt. Dies sind vor allem ökologische Parameter, wie die zeitliche und räumliche Verteilung von Vogel- und Robbenbeständen und die chemischen Belastungen z. B. in Sedimenten, aber auch sozioökonomische Parameter wie Besucherzahlen. Die Daten werden nach abgestimmten Methoden erhoben und in einer trilateral einheitlichen Datenstruktur gespeichert. Sie werden alle fünf bis sechs Jahre ausgewertet und die Ergebnisse in einem Qualitätszustandsbericht veröffentlicht (z. B. Essink et al. 2005). Dieser gibt einen Überblick über die Entwicklung der erfassten Parameter, die Auswirkungen z. B. von Nähr- und Schadstoffeinträgen auf das Ökosystem und bietet eine Bilanz über das Erreichen der wattenmeerweit gemeinsam formulierten Ziele (Targets) sowie Empfehlungen (Recommendations) für ein verbessertes

Management. Im Gegensatz zu den Monitoring-Anforderungen und Datenformaten ist die Berichtsform wenig formalisiert.

Natura2000

Natura 2000 ist ein EU-weites Netz von Schutzgebieten zum Erhalt der in der EU gefährdeten Lebensräume und Arten. Es setzt sich zusammen aus den Schutzgebieten der Vogelschutz-Richtlinie und denen der Flora-Fauna-Habitat-Richtlinie.

Flora-Fauna-Habitat-Richtlinie (FFH)

Die FFH-Richtlinie (Richtlinie 92/43/EWG) sieht nicht nur die Einrichtung eines einheitlichen, europaweiten Schutzgebietsnetzes vor, in denen ein Mindestschutz gewährleistet und Eingriffe und Veränderungen zuvor auf ihre Verträglichkeit mit den Schutzzielen hin geprüft werden. Es sollen auch Schutzregelungen für europaweit gefährdete Arten mit großräumig genutzten Lebensräumen getroffen werden, die nicht durch Schutzgebiete geschützt werden können.

Die Mitgliedstaaten müssen regelmäßig alle sechs Jahre über den Stand der Umsetzung, die Situation der Lebensraumtypen und Arten in und außerhalb der FFH-Gebiete sowie über ergriffene Schutzmaßnahmen berichten. Die Berichtsform ist EU-weit standardisiert vorgeschrieben.

Vogelschutz-Richtlinie (VSR)

Bereits in der 1979 in Kraft getretenen Vogelschutzrichtlinie (Richtlinie 79/409/EWG) ist eine regelmäßige Berichtspflicht im Abstand von drei Jahren vorgesehen. Die Richtlinie ist mit dem Ziel des Schutzes wildlebender Vogelarten und ihrer Lebensräume innerhalb der EU erlassen worden. Sie schreibt die Einschränkung und Kontrolle der Jagd sowie die Einrichtung von Vogelschutzgebieten als wesentliche Maßnahme zur Erhaltung der Lebensräume von Arten vor und beinhaltet gleichzeitig ein Verschlechterungsverbot. Seit 1983 wurde aufgrund der herausragenden Bedeutung für viele Watt- und Wasservogelarten das Gebiet des Schleswig-Holsteinischen Wattenmeers und Nationalparks zum Vogelschutzgebiet erklärt.

Abb. 1: Monitoring der NATURA2000 Programme

Europäische Wasserrahmenrichtlinie (EU-WRRL)

Die EU-Wasserrahmenrichtlinie (Richtlinie 2000/60/EG) hat den holistischen Schutz aller Gewässer inkl. der Fließ- und Küstengewässer sowie der Seen und des Grundwassers zum Ziel. Maßgabe ist ein allgemeines Verschlechterungsverbot und das Erreichen eines guten ökologischen und chemischen Zustandes bis zum Jahr 2015. Als wichtiges Kontrollinstrument wird von den Mitgliedstaaten wie bei den bei den zuvor genannten Richtlinien die Durchführung eines Monitorings verlangt (Art. 8, WRRL). Im Gegensatz zur FFH-Richtlinie liegt der Schwerpunkt hier weniger auf der Erfassung und Bewertung des Zustandes von Arten und Lebensraumtypen, als vielmehr auf der Erfassung und Bewertung von abgegrenzten Wasserkörpern mit Hilfe von biologischen, physikalisch-chemischen und hydro-morphologischen Parametern. Auch diese Richtlinie findet im Bereich des Schleswig-Holsteinischen Wattenmeeres Anwendung. Dies hat zur Folge, dass das bestehende Monitoring an die spezifischen Erfordernisse dieser Richtlinie angepasst werden muss. Wie bei der FFH-Richtlinie gibt es Vorgaben für die Erfassungen und Bewertungen, die derzeit national wie international im Detail ausgearbeitet, abgestimmt und operationalisiert werden. In festgelegten Zeitabständen von maximal 6 Jahren sind thematische Berichte und Bewirtschaftungspläne an das Water Information System for Europe (WISE) zu liefern.

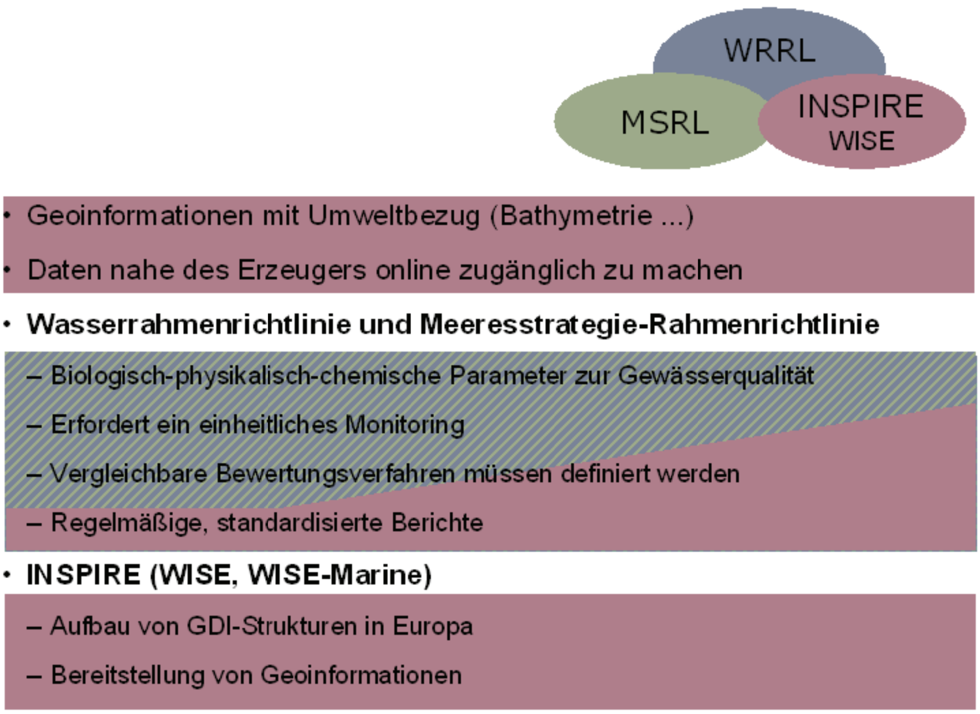

Abb. 2: Monitoring und Datenmanagement für die EU-Wasserrahmenrichtlinie, Meeresstartegie Rahmenrichtlinie und INSPIRE

Europäische Meeresstrategie-Rahmenrichtlinie (MSRL)

Die im Jahr 2008 in Kraft getretene Meeresstrategie-Rahmenrichtlinie (Richtlinie 2008/56/EG) verknüpft die Anforderungen aus der FFH-Richtlinie, der EU-WRRL und der INSPIRE-Richtlinie, deren Vorgaben und Verfahren für die Berichtsaufgaben im Rahmen der MSRL zu verwenden sind.

Inhaltlich ist wie in den zuvor genannten Richtlinien die Analyse der wesentlichen Kennzeichen und Merkmale der marinen Gewässer unter Berücksichtigung der verschiedenen Lebensraumtypen, biologischen Komponenten, physikalisch-chemischen Merkmale und der Hydromorphologie vorgeschrieben. Auch hier soll ein guter Umweltzustand erzielt werden. Qualitative Deskriptoren für die Beschreibung des guten Umweltzustandes sind z. B. die Verbreitung und Populationsdichte von Arten wie Seevögeln und Meeressäugern, das Vorkommen nicht-heimischer Arten sowie der Zustand kommerziell befischter Fisch- und Schalentierbestände. Überwachungsprogramme sind für die laufende Bewertung des Umweltzustandes der Meeresgewässer auch außerhalb des Hoheitsgebietes im Bereich der ausschließlichen Wirtschaftszone durchzuführen.

Die Meeresstrategie-Rahmenrichtlinie geht über die anderen Richtlinien hinaus, da sie nicht nur die Bereitstellung von Umweltdaten sondern auch die von Daten mit Umweltbezug (Anhang I, II, III) verlangt und mit dieser Anforderung dem Ansatz von INSPIRE entspricht (Abb. 2).

INSPIRE-Richtlinie

Im Gegensatz zu den anderen bisher genannten Richtlinien wird durch INSPIRE (Richtlinie 2007/2/EG) nicht die Erfassung und Bewertung von Daten, sondern deren Bereitstellung geregelt. Diese EU-Richtlinie ist im Mai 2007 in Kraft getreten und verpflichtet die Mitgliedstaaten, stufenweise interoperable Geobasisdaten wie Karten und Luftbilder sowie bereits vorhandene Geofachdaten - zunächst zur Umwelt und Landwirtschaft - bereit zu stellen. Als erster Schritt ist die Erstellung einheitlicher Metadaten (Informationen über Herkunft, Inhalt, Erhebungszeitraum, Zugriffsrechte usw.) vorgesehen. Bei der Nationalparkverwaltung in Schleswig-Holstein wird hierfür die Software des Nord- und Ostsee Küsteninformationssystems NOKIS (Lehfeldt et al. 2006) eingesetzt, mit dem bereits ein Großteil der Metadaten über Geodaten aus dem schleswig-holsteinischen Wattenmeer EU-kompatibel bereitgestellt wird. Ziel ist es, alle verfügbaren und entsprechend aufbereiteten Daten Nutzern aller EU-Staaten über Portale bereitzustellen. Um dies zu erreichen, wird die strenge Ausrichtung an bestimmten technischen Vorgaben vorgeschrieben. Durch die Veröffentlichung der Daten soll den Bürgern ein sehr umfassendes Instrument an die Hand gegeben werden, um sich über räumliche Vorgänge (z.B. Planungen und Bauvorhaben) zu informieren.

Die Bereitstellung von Geo- und Fachdaten im Internet wird als Pilotprojekt von der Nationalpark- und Umweltverwaltung Schleswig-Holsteins mit dem Tool Cadenza der Firma disy durchgeführt. Es ist auch ein Werkzeug zur Recherche, Analyse und Auswertung von Daten, mit der Möglichkeit, PDF-Berichte dynamisch zu erzeugen. Ein direkter Zugriff von NOKIS-Metadaten auf die Geodaten wurde testweise bei der Nationalparkverwaltung erfolgreich umgesetzt.

Besondere Anforderungen im Küsten- und Meeresgebiet

Geodateninfrastrukturen entstehen in den letzten Jahren für die unterschiedlichsten Aufgaben. Deren Ansprüche und Regeln gelten auch für eine Marine Dateninfrastruktur. Allerdings bestehen im Bereich der Küsten- und Meere besondere Bedingungen, aus denen sich veränderte Schwerpunkte und zusätzliche Erfordernisse für den Aufbau einer Dateninfrastruktur ergeben. Dies ist allein schon aufgrund der hohen Dynamik in diesem Gebiet ersichtlich: Alle sechs Stunden fallen mehrer tausend Quadratkilometer Watten trocken oder werden überflutet. Sände, Watten und Inseln werden verlagert, verschwinden oder entstehen neu, so dass Schiffsrouten teilweise mehrmals im Jahr angepasst werden müssen.

Bei einem zur Infrastruktur gehörenden Gazetteer, einem Instrument zur Verknüpfung von Ortsnamen mit ihrer Ortslage (Kohlus 2009), ist daher nicht nur die Zeitgültigkeit bei den Namen zu berücksichtigen sondern auch dass die benannten Objekte temporären Charakter haben, sich ihre Form und Lage verändert oder sie gar zerstört werden. Ob Messungen der Algendichte, der Wassertemperatur oder Beobachtungen des Verhaltens von Vögeln, sie gelten nur für ein kurzes

Zeitfenster. Die Beschreibung von Messwerten und Zeitreihen, von Messzeitpunkten und Periodizitäten nimmt damit einen anderen Stellenwert als im terrestrischen Gebiet ein.

Um diese dynamischen Prozesse zu verstehen oder Wirkung von Eingriffen abschätzen zu können, werden zunehmend hydro- und morphodynamische Modelle benötigt. Daher müssen beim Aufbau einer marinen Dateninfrastruktur Anknüpfungspunkte und Einbindungsmöglichkeiten für Computermodelle berücksichtigt werden.

Die Wandelbarkeit des Raumes schlägt sich auch direkt bei den rechtlich-organisatorischen Aufgaben nieder. So werden die unter Hoheit und Recht der Bundesländer stehenden Wattenmeernationalparke während der Flut zu großen Teilen zu einer Bundeswasserstrasse. Die Verknüpfung von Aufgaben der Länder und des Bundes sind im marinen Milieu komplexer miteinander verwoben und unterliegen oft Sonderbedingungen. So ist z. B. abweichend vom gesamten nationalen Hoheitsgebiet der Bundesstaat im Bereich der Ausschließlichen Wirtschaftszone für den Naturschutz zuständig.

Architektur der MDI-DE

Um den Anforderungen verschiedener Zielsysteme und bestehender Berichtspflichten bei der Bereitstellung von Fachdaten und Informationen besser zu entsprechen, werden die unabhängig voneinander entwickelten Systeme NOKIS und GDI-BSH in einer neuen „Marinen Daten Infrastruktur" für Daten und Informationen der deutschen Küstenzone und dem angrenzenden Meeresbereich verknüpft. Mit dieser neuen technischen Grundlage wird die notwendige integrative und harmonisierte Vernetzung von weiteren Informationssystemen durchgeführt und deren effiziente Nutzung unterstützt.

NOKIS und die Geodateninfrastruktur des BSH

Die Produkte aus den Projekten NOKIS (2001-2004) und NOKIS++ (2004-2008) bilden den ersten wichtigen Schritt zu einer konsistenten Informationsinfrastruktur. Sie werden inzwischen in den meisten Küstendienststellen im Routinebetrieb eingesetzt.

Speziell für die Dokumentation von Daten aus der Küstenzone wurde das NOKIS Metadatenprofil aus dem ISO 19115 abgeleitet. Es kann durch standard-konforme Erweiterungen für alle Fragestellungen im Küstenraum verwendet werden. Das Küstenzonenprofil enthält das Profil der Geodateninfrastruktur Deutschland (GDI-DE). So können die Metainformationssysteme PortalU und GeoPortal.Bund auf Bundes- wie auf Länderebene (z.B. SH-MIS in Schleswig-Holstein, Kohlus et al. 2009b) bedient werden. Das Küstenzonenprofil hat darüber hinaus drei weitere Ausprägungen, mit denen sich Forschungsprojekte, Simulations-Szenarien und Modelle sowie Messstellen und Messplattformen (z.B. Forschungsschiffe) beschreiben lassen.

Die Metadatenerfassung und -pflege erfolgt mit dem browserbasierten NOKIS Metadaten-Editor, der bei allen Datenlieferanten im Einsatz ist. Interaktive Online-Visualisierungen von numerischen Simulationen sind mit digitalen Atlanten für Wind, Strömungen und Seegang implementiert. Mit den Datendiensten für Zeitreihen, flächenhafte Verteilungen und Bewertungen liegen exemplarisch implementierte Web-Services vor, die für weitere Datenbestände genutzt werden können (www.nokis.org).

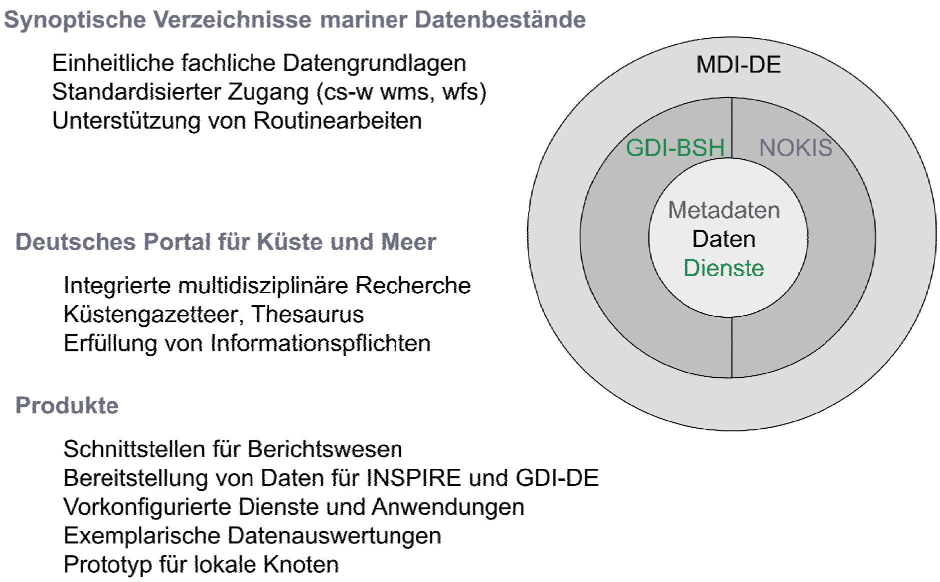

Abb. 3: Bestandteile und Aufbau der Marinen Dateninfrastruktur Deutschland (MDI-DE).

In der Geodateninfrastruktur des Bundesamtes für Seeschifffahrt und Hydrographie (BSH) werden die Geobasis- und Geofachdaten des BSH (Melles & Soetje 2006) zur Verfügung gestellt. Über den Internetzugang des GeoSeaPortal (www.bsh.de/de/Meeresdaten/Geodaten/index.jsp) können Nutzer nach Daten und Informationen suchen, diese auf verschiedene Arten kombinieren und in einem interaktiven Web-GIS darstellen. Für eine Vielzahl von Fachsystemen wurden Web-Kartendienste eingerichtet, die im Internet als OGC-konforme WMS verfügbar sind.

Das BSH liefert mit seiner Geodateninfrastruktur einen wichtigen Baustein für die nationale Geodatenbasis von Deutschland (NGDB). Gleichzeitig werden über das Geodatenportal des Bundes (GDI-DE) die Daten des BSH für INSPIRE bereitgestellt.

Integration in die nationalen und internationalen Infrastrukturen

Die MDI-DE stellt Informationen und Werkzeuge zur Verfügung, die zur Erfüllung von Daueraufgaben im Zusammenhang mit den EU-Richtlinien notwendig sind und die bei wasserbaulichen, raumplanerischen, naturschutzfachlichen, wissenschaftlichen und ökologischen Systemanalysen sowie zur Unterstützung der Schifffahrt verwendet werden. Sie fügt sich als Informationsplattform für die Nord- und Ostsee in bestehende Infrastrukturen wie der GDI-DE und dem PortalU (Kruse et al. 2009) ein und ergänzt und harmonisiert den Informationsfluss in idealer Weise. Die MDI-DE unterstützt den Reportingprozess für die EU-Richtlinien durch die Bereitstellung von Services, die Berichtsdaten auf dem Weg zum Berichtsportal „Wasser“ (www.wasserblick.net) bei der Bundesanstalt für Gewässerkunde aggregieren und harmonisieren. Insbesondere für die Umsetzung der MSRL kommt der MDI-DE bei der geforderten Bereitstellung von Daten eine besondere Rolle zu. Weiter Einbindungen in bestehende Infrastrukturen und Netzwerke sind der Abbildung 4 zu entnehmen.

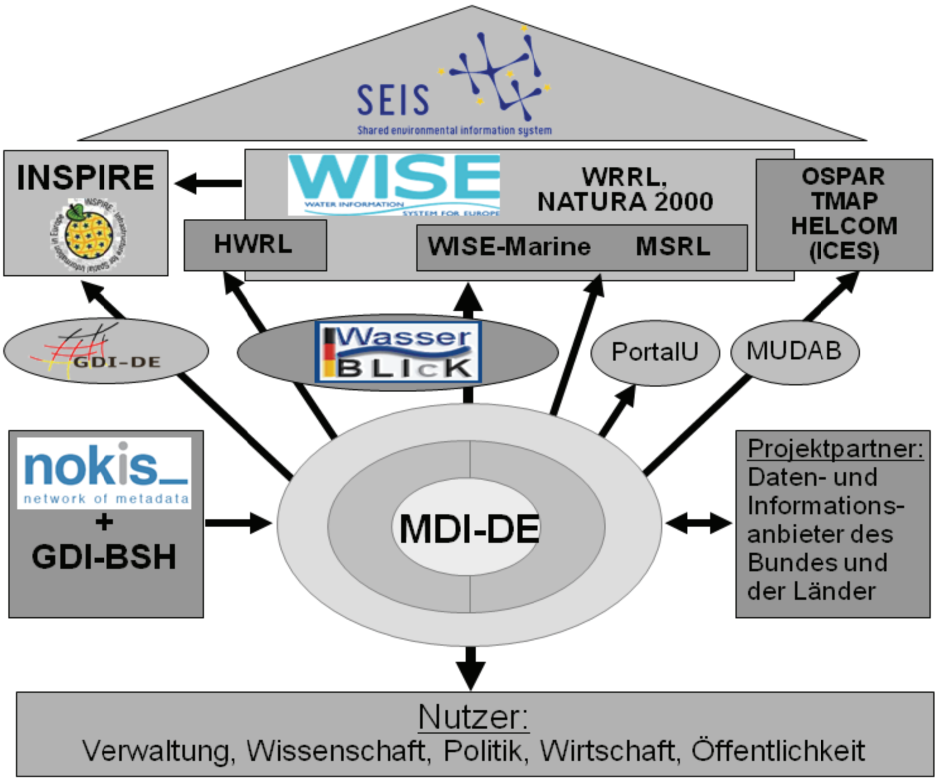

Abb. 4: Integration der MDI-DE in die nationalen und internationalen Berichtssysteme

Datenknoten bei den Partnern

Für die oben dargestellten Richtlinien gilt in den meisten Fällen, dass zwar der Bund die nationalen Verpflichtungen eingeht und Ansprechpartner für den Nachweis zur Erfüllungen der Berichtspflichten auf europäischer Ebene ist, die kostenintensive Umsetzung der Messprogramme und Aufbereitung der Daten dagegen bei den Bundesländern liegt. Mit der INSPIRE Richtlinie geht die EU neue Wege beim Berichtswesen, denn die zugrunde liegenden Daten sollen möglichst nah bei den erhebenden Einrichtungen digital einsehbar sein, d.h. kontrollierbar vorliegen.

Sich wandelnde Aufgaben, wechselnde Zuständigkeiten sowie die fortlaufende Umstrukturierungen der Verwaltungen waren schon bei NOKIS (Kohlus 2005) Gründe, die Informationsaufbereitung und Bereitstellung in Form der Vernetzung einzelner Knoten zu organisieren. Diese Knoten stellen Geodaten, Zeitreihendaten, gegebenenfalls Webservices für die Darstellung und Transformation sowie die beschreibenden Metadaten für die Nutzer bereit.

Partner in solch einer Infrastruktur können hierbei einen eigenständigen Knoten betreiben, mit dem Informationen für die Dateninfrastruktur und deren Aufgaben verfügbar gemacht werden. Neue und zusätzliche Teilnehmer an der MDI-DE können jederzeit einen eigenen Knoten aufbauen, der dann mit geringem Aufwand in das Netz integriert werden kann. Teilnehmer können sich für den Betrieb eines Knotens zusammenschließen oder bei Trennung in neue organisatorische Einheiten kann durch Dopplung des alten bestehenden Knotens eine nahtlose, sukzessive Überführung in die neue Struktur vorgenommen werden.

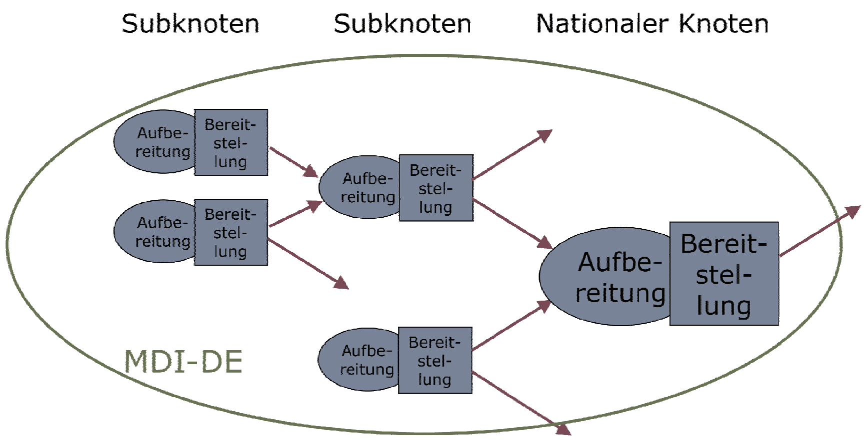

Abb. 5: Flexible Infrastruktur durch kaskadierbares Knotenprinzip

Semantik

Die größte Hürde bei der gemeinsamen Nutzung von Daten liegt in der Semantik. Ein Feld, das bisher nur zögerlich angegangen wird. Entscheidend für die gemeinsame Nutzung von Daten ist, dass für qualitative Bezeichner Synonyme auffindbar, übersetzbar, kategorisierbar und vergleichbar definiert sind. Ihre Nutzung als Stichwort wird durch Thesauri unterstützt, die die Verwendung von Begriffen in einen semantisch hierarchischen Zusammenhang stellen und damit z. B. eine Suche mit Synonymen oder hierarchisch verwandten Ausdrücken ermöglichen. Für die Aufgaben der MDI-DE sind zudem Schlüsselbegriffe der Hydrologie, Morphologie und des Küstenzonenmangements zu erschließen.

Eine übergreifende, besonders anspruchsvolle Aufgabe ergibt sich durch das biologische Monitoring. Für manche Arten gibt es zahlreiche Synonyme und konkurrierende systematische Ansätze. In einigen Fällen können Lebewesen nicht mit akzeptablem Aufwand bis auf das Artniveau bestimmt werden. Thesauri können dazu beitragen, verwandte oder synonyme Bezeichner miteinander oder abstrahiert als übergeordnete Gruppe zu nutzen.

Ein Gazetteer schafft ein ähnliches begriffliches Schema für Ortsnamen, gibt ihnen zudem eine räumliche Referenz mittels Erdkoordinaten und sollte im marinen Bereich zeitliche Bezüge sowohl für die Bennungsformen als auch für die Georeferenz ermöglichen (Kohlus 2009).

Semantische Probleme liegen nicht nur in der Terminologie. So sind Messwerte nur im Kontext der verwendeten Methoden, deren Beschreibung und der Definition den Daten nachvollziehbar zuzuordnen. Die Verwendung unterschiedlicher Maße lässt sich meist vollständig mittels Transformationen auflösen. Um eine gemeinsame Nutzung zu ermöglich, können Transformationen aber auch auf Daten angewendet werden, die nach unterschiedlichen Methoden erhoben wurden. Lösungen hierfür sind allerdings meist auf beschränkte Wertebereiche und die Ausdeutung der Messwerte für spezifizierte Fragestellungen unter Berücksichtigung weiterer Randbedingungen beschränkt. Somit bilden Services, die eine Transformation von Werten für eine gemeinsame Verwendung leisten, notwendige Bestandteile einer Dateninfrastruktur.

3 Einsatz im Umweltberichtswesen

Vom Monitoring zum Bericht

Von der Felderhebung bis zur Erstellung von Datenprodukten und Berichten gibt es einen charakteristischen Verarbeitungsablauf (Kohlus et al. 2009 a, Reimers 2008, 2009). Messdaten werden in der Regel grafisch als Karten oder Diagramme dargestellt, wobei meist eine spezifische Auswertung der Daten hinsichtlich der Fragestellung der Berichtsanforderungen erfolgt. Bewertungen sind entweder in beschreibender Form abzugeben oder haben wie bei der Wasserrahmenrichtlinie einem festen Klassifizierungsschema zu folgen. In diesem 5-stufigen Schema werden ähnlich wie bei der Arbeit mit Grenzwerten Messkriterien festgelegt, die vom sehr guten bis zum schlechten Qualitätszustand reichen. Das Bewertungsschema kann sich dabei auf ein Qualitätskriterium aber auch mehrere differenziert erfasste Faktoren stützen. Auch bei einem Qualitätsfaktor kann es erforderlich sein, dass Ergebnisse unterschiedlicher Monitoringaktivitäten dabei eingehen. Diese werden dann auf der Ebene der Bewertung miteinander verknüpft.

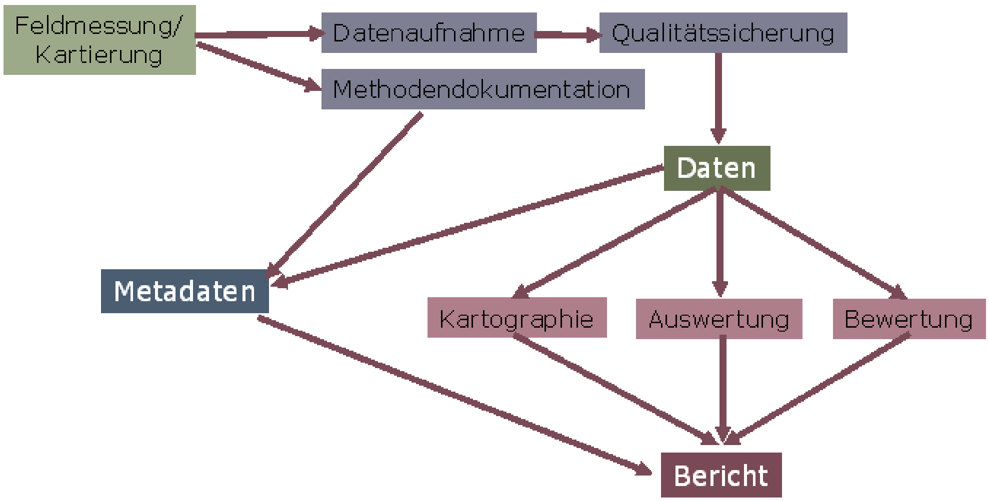

Abb. 6: Ablauf der Bearbeitung beim Monitoring

Als Beispiel sei hier der ökologische Zustand der am Anfang des 20. Jh. weiträumig ausgestorbenen Seegräser genannt. Dieser bildet für die WRRL einen wichtigen Qualitätsfaktor. Einerseits wird durch die Nationalparkverwaltung im Landesbetrieb für Küstenschutz, Nationalpark und Meeresschutz (LKN) die räumliche Ausbreitung von Seegraswiesen per Fernerkundung untersucht (Reise & Kohlus 2008 a). Anderseits ist nicht nur die Ausbreitung sondern auch der Zustand der Bestände entscheidend für die Beurteilung (Reise & Kohlus 2008 b). So werden einzelne Seegraswiesen im Rahmen eines Programms des Landesamtes für Landwirtschaft, Umwelt und Ländliche Räume (LLUR) durch Begehung und Probennahme untersucht. Das Verfahren wurde für die Bewertung im Sinne der Wasserrahmenrichtlinie angepasst und mit der räumlichen Erfassung gekoppelt. Die Ergebnisse der Fernerkundung können damit Verifiziert und räumlich differenzierte Zustandsunterschiede auf Dauer erkannt werden. Für die Bewertung der Wasserkörper nach diesem Qualitätskriterium müssen dann die qualitativen Beobachtungen über sechs Jahre mit den jährlichen Beobachtungen der Ausbreitung verknüpft werden.

Die Verknüpfung beider Verfahren kann nach bisherigem Kenntnisstand nur auf der Ebene der Bewertung der jeweiligen Untersuchungen vorgenommen werden. Hierfür wurden vorläufige algorithmisch formulierbare Regeln vereinbart.

Servicebasierte Bewertungsverfahren

Es wird allgemein erwartet, dass Warn- oder Belastungssituationen des ökologischen Zustandes von den Spezialisten in einfacher Form kommuniziert werden. Dabei besteht der nachvollziehbare Wunsch, dass Untersuchungsergebnisse in einen vordefinierten Ablauf der Analyse und Bewertung einfließen. Automatisierte algorithmische – und damit nachvollziehbare – Auswertungen brauchen definierte Verfahrenswege. Einfache und gegen Sekundärwirkungen robuste Verfahren, die eine eindeutige Interpretation und Auswertbarkeit der gemessenen Monitoringparameter ermöglichen, wird es nur wenige geben.

Zu bedenken ist auch, dass wenn Verfahren angepasst und verbessert werden müssen, die technische Umsetzung erneut zu fassen ist. Kostensparend und effektiv sind automatische Verfahren nur dann, wenn Beurteilungsregeln längerfristig gelten und eine Kontinuität bei den verwendeten Bewertungsfaktoren besteht.

Für die Umsetzung automatisierter Services zur Bewertung heißt dies, dass die Ergebnisse von den jeweiligen Experten interaktiv kommentierbar und veränderbar sein müssen. Zudem muss eine explizite Freigabe einer solchen automatisierten Vorbewertung erfolgen.

Trotz dieser Schwierigkeiten sollen für einige Parameter testweise Umsetzungen auch von bewertenden Services im Rahmen des den Aufbau der MDI-DE tragenden Projektes entwickelt werden.

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Feasibility Study for Optimisation of Land Drainage by Using Renewable Energy

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Abstract

Water management at the coasts secures the drainage of the marsh region along the North Sea as part of flood protection and to guarantee a productive agriculture. Changes in coastal morphology such as silting of the outer deep and climatic changes such as the sea level rise will lead to degradation or renunciation of natural drainage. A conventional solution, replacing sluices by coastal pumping stations represents an intervention with a high energy demand. This results in great financial burdens for the drainage associations since the cost of energy is increasing rapidly. The aim of this study is to analyse sustainable solutions in order to optimise the land drainage in coastal regions by using renewable energy.

The historical development of drainage methods shows that wind-driven pumps are highly relevant for the drainage of the land. For this reason, analyses of the energy demand of a pumping station and the supply of wind energy were carried out over a period of three years in the coastal regions of the North Sea in Dithmarschen. It was found that there is a relation between the investigated quantities and as a result it could be shown that the energy demand of a coastal pumping station could be predominantly supplied by a wind energy plant. In addition a feasibility study was carried out for an investigation area in Dithmarschen in Northern Germany. Three alternatives to use wind and/or hydro power were reviewed for feasibility and evaluated on the basis of calculations of economic efficiency. The analysis indicated that electric wind pumping systems were highly appropriate for use in sustainable drainage systems.

1 Introduction

Motivation and Objectives

Water management at the coasts secures the drainage of the marsh region along the North Sea as part of flood protection and to guarantee a productive agriculture. Therefore in the hinterland the run-offs are drained off in a system of ditches and channels that leads the water to either sluices or pumping stations in order to pass the dike. Sluices are preferred as drainage structures since no additional energy supply for drainage is required since the sluice gates close at high tide respectively open at low tide due to the water level differences. Nowadays natural drainage using sluices is becoming more problematic due to changes in coastal morphology where the slope of the outer deep is reduced. As a result there is a shortening of the sluice time at low tide and the amount of water discharge that passes the dike is reduced which leads to a higher risk of flooding since the run-offs are not sufficiently drained. Moreover, climatic changes such as the rise of the sea level will also lead to degradation or renunciation of natural drainage (Maniak et al. 2005). A conventional solution, such as pumping water beyond the dike through the use of coastal pumping stations represents an intervention with a high energy demand. This results in great financial burdens for the drainage associations since the cost of energy is increasing rapidly.

A new concept for optimisation of land drainage by using renewable energy is therefore required. For this purpose, wind energy represents one appropriate alternative as a possible energy resource for pumping stations. The historical importance of using wind energy for the drainage of the land is documented. For example wind-driven water pumps have been used in order to drain the low lying areas in The Netherlands since the 15th century. Another possible renewable energy resource represents hydro power that could be utilized within the process of a cascading drainage system where the water discharge is increased by a high lying polder. Therefore the main objective of this study is to analyse sustainable solutions in order to optimise the land drainage in coastal regions by using renewable energy.

Investigation Area

Dithmarschen is a county on the North Sea coast of the federal state Schleswig-Holstein in Northern Germany (figure1). The coast area consists of polder surrounded by dikes as flood defences. In the hinterland the run-offs are drained off in a system of ditches and channels that leads the water to either sluices or pumping stations in order to pass the dike. This water management is important to prevent floods from inland discharges and to maintain an efficient agriculture which represents the main economic sector of this region.

For the feasibility study, the pumping station Hillgroven with a pumping capacity of 160 kW and a catchment area of 1.200 ha and the sluice Steertloch with a catchment area of 6.300 ha are investigated in more detail. Due to changes of the coastal morphology the slope of the outer deep of the sluice Steertloch is reduced and therefore gravity drainage becomes insufficient. For this reason, the water management of this area has to be improved and sustainable solutions were analysed. The data of the pumping station Hillgroven were used as a first estimation of the pumping times since the boundary condition in form of water level differences of high and low tide are assumed to be almost equal for the nearby sites.

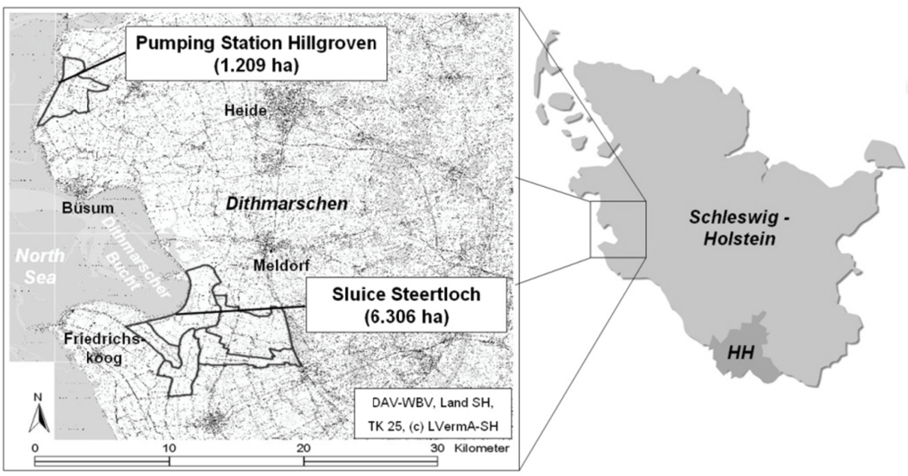

Figure 1: Investigation Area in Dithmarschen, Northern Germany

2 Analysis of energy demand of a pumping station and supply of wind energy

As wind energy was identified as being highly relevant for drainage methods (IPAT 1989), analyses of the energy demand of a pumping station and the energy supply of a wind energy plant (WEP) were carried out in more detail over a period of three years in the coastal regions of the North Sea in the county Dithmarschen.

Energy Balance with Monthly Data

In order to compare the distribution in time of the energy demand of a pumping station and the energy production of WEP an energy balance with monthly data was carried out. Therefore the electric power consumption of a coastal pumping station with monthly values over a period from 2005 till 2007 was analysed. The data were provided for the pumping station Hillgroven by the drainage association *Deich- und Hauptsielverband Dithmarschen*. Furthermore, the wind data were taken from an analysis of the Chamber of Agriculture Schleswig-Holstein *Landwirtschaftskammer Schleswig - Holstein* (LKSH 2008) where the production of wind energy was investigated for the coastline of the North Sea in Schleswig-Holstein.

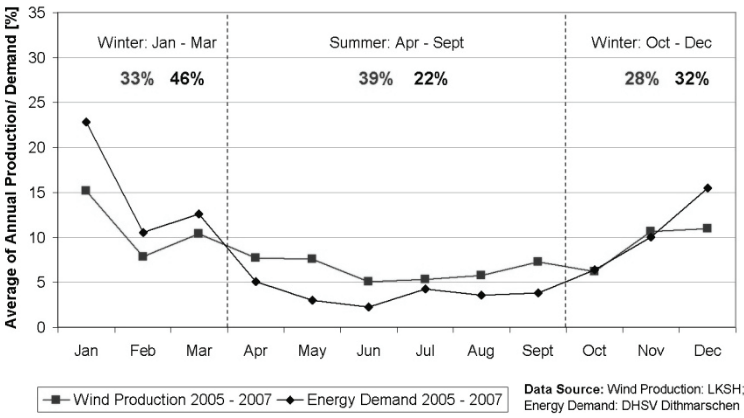

Figure 2: Comparison of energy demand of a pumping station and wind energy production along the west coast of Schleswig-Holstein (Average monthly values of the annual demand/ production for the years 2005 till 2007)

The results show seasonal fluctuations of the annual distribution of the energy demand of a pumping station as well as of the production of wind energy (figure2). During summer time from April till September a very low energy demand with monthly values of 3 % to 5 % and in total a percentage of 22 % of the mean annual need is required. Likewise during summer the production of wind energy is lower and amounts 39 % of the mean annual output. During winter time higher values are reached. Especially during the months January till March almost half (46 %) of the mean annual energy demand is recorded. In the same time period the production of wind energy is also slightly larger (33 %). During the months October till December the energy demand amounts 32 % and the wind energy production 28 % of the annual demand respectively production.

Energy Balance with Hourly Data

The results of the first energy balance on the basis of monthly data show the annual distribution of energy demand of a pumping station and wind energy production. From these results of monthly averages it is not possible to conclude whether the wind energy supply would be sufficient for a pumping station since there is a great variation in wind speed with significant changes in shorter time periods such as hours. For this reason, the temporal resolution of the calculation is increased and hourly data of the energy demand of a pumping station and the energy production of a WEP were analysed over a period of three years from 2005 until 2007. The main goal of this analysis is to investigate the percentage of energy supply of a pumping station that can be directly covered by a WEP and how high the percentage of the remaining energy is that has to be taken from the local power supply system.

For the energy demand the data of pumping times of the coastal pumping station Hillgroven were provided by the drainage association Deich- und Hauptsielverband Dithmarschen. In order to consider a variance in pumping power the total engine power of the pumps was ranged with values from 220 kW to 660 kW. It should be noted that for the following calculations the pumping power is set to a constant value, viz. 220 kW or 660 kW for each calculation. This could be an overestimation if the constant value is equalized to the rate of the required pump capacity depending on the catchment area. In reality the pump capacity is divided into several pumps which are operated as required.

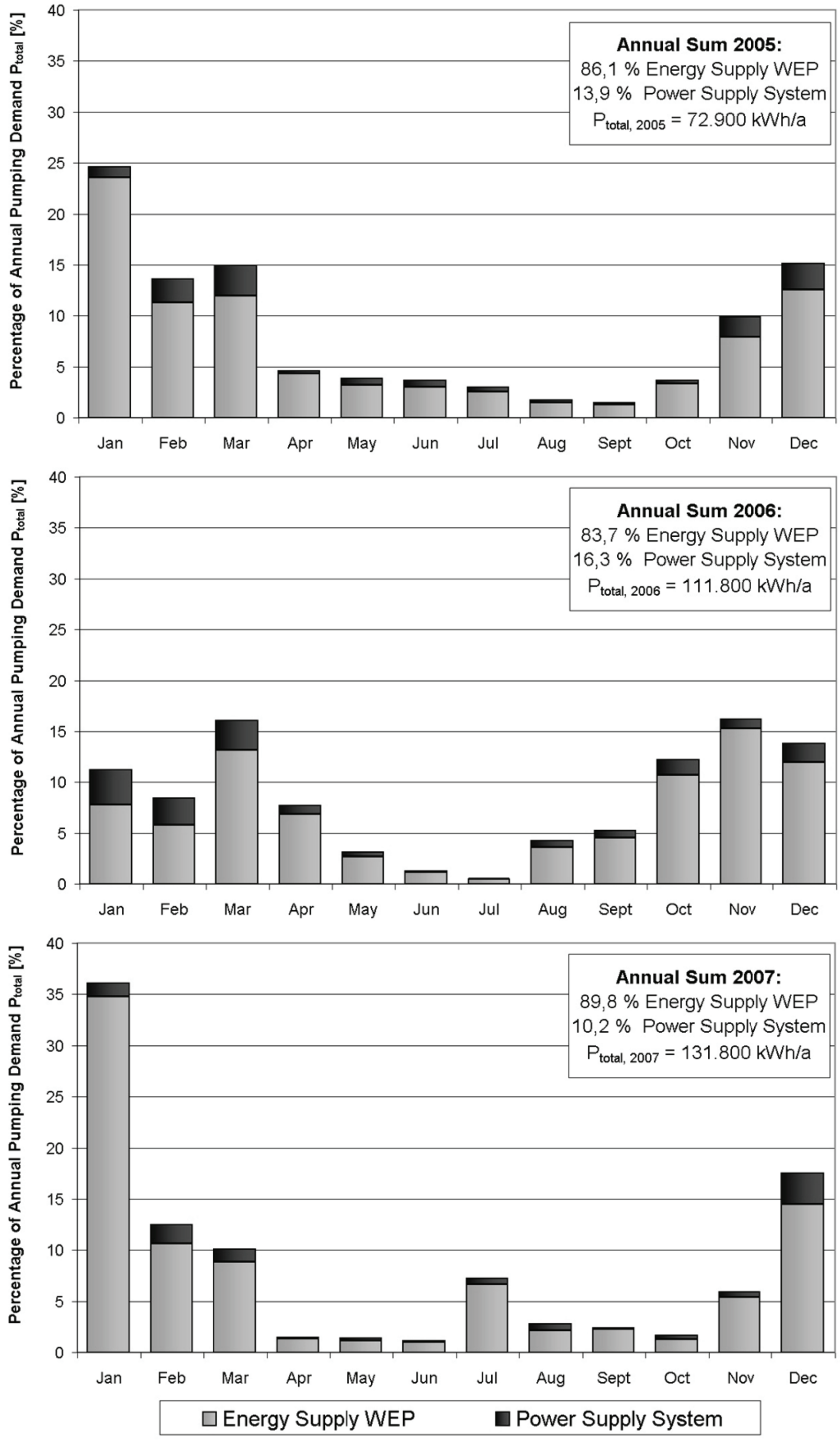

Figure 3: Electrical power supply of a pumping station with a constant pump capacity of 220 kW for the years 2005, 2006 and 2007 differentiated in energy supply by a WEP (800 kW) and by the local power system

For the production of wind energy the data were estimated using a power curve of a wind turbine. The power curve relates wind speed to the electrical power output of a WEP. As an example of a possible WEP the model Enercon E 48 with 800 kW wind turbine was applied. As input data of this calculation using the power curve of the model E 48 hourly data of the mean wind speed were used. The wind data were measured by the German Meteorological Service Deutscher Wetterdienst at the weather station Büsum in Dithmarschen.

As an example the results in form of the electrical supply of a pumping station with an engine power of 220 kW for the years 2005 till 2007 are shown with monthly values in figure 3. The diagrams show that the energy demand of the pumps can be predominantly supplied by a WEP. In total the percentage of WEP supply was calculated from 83.7 % (2006) up to 89.8 % (2007) of the annual need for the pumping station. Furthermore, in this calculation the pump capacity was ranged from 220 kW up to 660 kW. As a result the mean annual power supply by the WEP was estimated between 86.5 % for 220 kW pumps and 72.1 % for 660 kW pumps.

3 Feasibility Study for Drainage Methods Using Renewable Energy

In order to analyse different drainage methods using renewable energy three alternatives to use wind and/or hydro power were reviewed for feasibility and evaluated on the basis of calculations of economic efficiency for the sluice Steertloch in Dithmarschen as follows (figure 4): (1) pumping station with WEP, (2) reservoir with wind-driven pump with a mechanical (a) or electrical (b) power transfer and (3) cascading drainage system using WEP and hydro power.

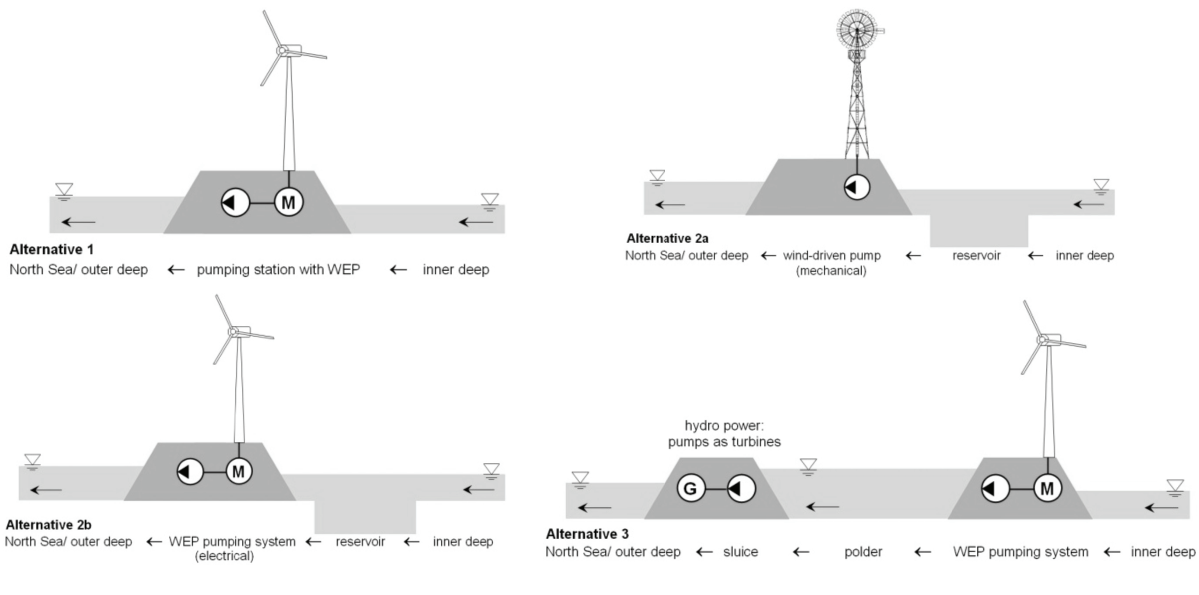

Figure 4: Sketches of the alternatives analysed in the feasibility study (with M = motor and G = generator)

Alternative 1: pumping station with WEP

The first alternative is composed of a pumping station combined with a WEP. Between the wind turbine and the pumps there is an electric power transfer. During windless periods there is the possibility to receive energy from the power supply system. This alternative is already realised by the waterboard *Bremischer Deichverband am rechten Weserufer* for the pumping station Wasserhorst and is well approved. In Bremen the energy supply of a WEP (600 kW) for the pumps with a total rated power of 560 kW averages 50 % of the annual demand (DVR-Bremen 2008). As the energy balance with hourly data showed for the site in Dithmarschen a higher wind energy supply from about 72 % to 86 % depending on the pumping capacity can be expected since the capacity of the WEP (800 kW) is higher and the surface roughness of the terrain affects the wind to a lesser extent. For the catchment area of Steertloch the total required pump capacity was estimated to about 600 kW. This equates a possible wind energy supply from approx. 75 % which represents 240 MWh. Moreover, there is a remaining energy production of 2,400 MWh by the WEP.

Alternative 2: reservoir with wind-driven pump

As the second alternative the feasibility of a reservoir with wind-driven pumps was examined. It is noted that a mechanical power transfer between the wind turbine and the pumps is not feasible since mechanical pumping systems only achieve a maximum of 10 kW as rated capacity (Gasch & Twele 2005) which falls below the value of the required pump capacity of 600 kW.

With an electrical power transfer the alternative 2b corresponds to alternative 1 including an additional reservoir. By means of the reservoir there is the advantage of adopting the operation of the pumps. Since the water can be stored in the reservoir the pumping times are adjustable to periods with sufficient wind energy supply. For the existing reservoir of the sluice Steertloch the storage volume was calculated by an elevation model covering the data of the bathymetry and the terrain with the software ESRI ArcView. Between the water levels -1.5 mNN and 0.0 mNN the storage volume was estimated to 425,000 m^3. With a design discharge of 12.6 m^3/s the storage time amounts 9.3 hours. This alternative offers the use of control and feedback control systems where the operation of the pumps can be adjusted to the wind energy supply. Therefore the wind energy supply is estimated as a greater value than in alternative 1, viz. greater than 75 %.

Alternative 3: cascading drainage system using WEP and hydro power

The third alternative is composed of a cascading drainage system using wind energy and hydro power. Therefore at first the water is pumped by a WEP into a high lying polder. From the higher polder the water can be drained by gravity and at the same time hydro power can be gained by powering a generator with the discharge of the water. As a type of generator, pumps as turbines can be applied since the boundary conditions of a changing flow rate and a low head have to be considered. Compared to the wind energy production with a total of 2,600 MWh the production of hydro power with 240 MWh is rather low.

4 Results

Besides the review of technical feasibility the alternatives were evaluated on the basis of calculation of their economic efficiency. The costs have been estimated considering the investment and operating costs as well as the tariffs for wind energy and hydro power due to the Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz/ EEG). In order to give some example of the expanses the investment costs of a WEP comparable to the model Enercon E-48 (800 kW) amount to 1.2 million euro. The investment costs of the pumping system were neglected since these values are the same for each alternative. The operating costs mainly consist of energy costs which average up to 310,000 euro/year with an electricity tariff of 15 cent/kWh for a conventional pumping station. For wind energy the tariffs following EEG 2009 are summed up to 160,000 till 170,000 euro/year for a period of 20 years. The tariffs of hydro power result in a maximum of 30,000 euro/year.

Table 1 shows the results in terms of the annuities for the different pump capacities of 220 kW and 660 kW. It can be seen that alternative 3 with the cascading drainage system using hydro power is not economic. By contrast the alternatives using energy of a WEP for a pumping system are profitable. In comparison with a conventional pumping system annual costs of up to 47,000 euro/year can be saved.

Table 1: Results of evaluation of economic efficiency in terms of annuities considering investment, operating coast as well as tariffs for wind energy and hydro power after EEG (2009) for a period of 20 years

Pump capacity	Alternative 0: Conventional pumping station	Alternative 1: Pumping station with WEP	Alternative 2: Reservoir with WEP pumping system	Alternative 3: Cascading drainage using hydro power
220 kW	-16,000 euro/year	+20,000 euro/year	> +20,000 euro/year	-337,000 euro/year
660 kW	-48,000 euro/year	-1,000 euro/year	< -1,000 euro/year	-338,000 euro/year

5 Summary

Wind energy was identified as being highly relevant for drainage methods, therefore analyses of the energy demand of a pumping station and the supply of wind energy were carried out over a period of three years in the coastal regions of the North Sea in Dithmarschen. It was found that there is a relation between the investigated quantities and as a result it could be shown that the energy demand of a coastal pumping station could be predominantly supplied by a wind energy plant. Three alternatives to use wind and/ or hydro power were reviewed for feasibility and evaluated on the basis of calculations of economic efficiency. The analysis indicates that electric wind pumping systems are highly appropriate for use in sustainable drainage systems and from the economic point of view the annual costs can be reduced by a factor of 48 compared to conventional pumping systems.

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