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Positioning indicators for cross-disciplinary challenges: the Dutch coastal defense research case

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In this paper, we develop indicators for the responsiveness of the research system to the changing knowledge needs that follow from changes in social and policy priorities. In this paper we use coastal defense research as a case. Using four different approaches — an analysis of coastal defense policy documents to identify the demand knowledge; a document analysis to identify the Netherlands' coastal research field; a bibliometric analysis; and a focus group with involved practitioners, researchers and intermediary actors — we identified the main demand for coastal defense research, the way the research system responds to it, as well as the bottlenecks that hinder optimal responsiveness of the research system.

WHEN IT COMES TO INFORMING national science policy, traditional science, technology and innovation (STI) indicators for assessing national research systems fall short. The main reason is that by merely focusing on input and output indicators, the research system itself is treated as a black box. As a result, traditional STI indicators provide only very limited insight in the (mal)functioning of the research system and provide hardly any leverage point for successful policy intervention. To overcome the limitations of traditional STI indicators a new type of indicator has been suggested, which aims at characterizing the semi-autonomous elements of the overall research system and the relations and interdependencies between these elements (see Barré, 2006, for details). An important characteristic of these so-called *positioning indicators* is that they are developed *ad hoc* to answer specific science policy questions. Creative use of all kinds of existing data is needed to develop positioning indicators (Lepori, 2006).

Positioning indicators can be used for analytic purposes to provide a better understanding of and insight into the *modus operandi* of the science and innovation system. In addition, positioning indicators can be used for evaluative purposes, especially for "science system assessment" (Van den Besselaar, 2006), or for what Arnold (2004) has called "subsystems evaluation" or "bottleneck analysis". Subsystems evaluation is an approach within science policy analysis, which evaluates and analyzes how and whether performance at the science system level is "inhibited by weaknesses of individual subsystems" (Arnold, 2004: 13), such as institutions, organizational forms, clusters and so on. Subsystems evaluation aims to identify structural bottlenecks. It can function as a bottleneck analysis as it "provides the overall 'intelligence' to decide where and how to intervene" (Arnold, 2004: 6).

In this paper we present the methodology and results of a study in which we developed positioning indicators for bottleneck analysis at the meso (research field) level. The aim is to identify systemic problems in the interaction between coastal defense research and coastal defense policies. Although the developed indicators fit the specific objective of

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evaluation as well as the specificities of the type of research field under study (Feeney and Bozeman, 2005), we think the approach can be applied more widely.

The challenge of cross-disciplinarity

Large parts of the Netherlands lie below sea level, and coastal defense research is a national priority in the Netherlands, and it is strongly developed. Whereas the social *importance* of coastal defense research is beyond question, this does not imply that the social *relevance* and *usability* of coastal defense research come naturally. Rather inherent tensions between the internal dynamics of scientific research practices, and the dynamics of social and political priority-setting prevail. There can be different reasons why research may not fulfill its full potential for developing socially relevant knowledge. Interaction and communication between researchers and the intended users of knowledge may be poorly developed or expectations of what scientific research can achieve may be unrealistic. The 'frame of reference' concept was developed as a means to improve the productive relation between coastal policy/management and coastal research (Mulder, 2003; Van Koningsveld, 2003) and aims to tackle this problem. Within this study we have focused on another barrier for socially relevant research, namely the disciplinary organization of the science system. While the last decades may have shown a gradual shift towards more multidisciplinary and strategic research (Nowotny *et al*, 2003) the science system is still predominantly organized along disciplinary lines and it is widely recognized that the disciplinary organization of the science system can impede the development of socially and policy-relevant research (Arnold, 2004; Carayol and Thuc Uyen Nguyen, 2005).

Implicitly this recognition underpins the many calls for interdisciplinary research, which are found nowadays in research programs which aim for social and policy relevancy. It should be noted however that there is not a one-to-one correlation between interdisciplinary research and socially and policy-relevant research. Rather, there is interdisciplinary research that is not immediately socially and policy-relevant and, the other way around, there is policy-relevant research which is not interdisciplinary. Research programs that aim for socially relevant research by stimulating interdisciplinary research often fail. One of the reasons for this failure is that, within science policy, concepts such as interdisciplinary research and the relation between interdisciplinary research and social and policy relevancy are poorly conceptualized and understood. In this paper we use the term 'cross-disciplinarity' as a generic term for research that combines, integrates or transgresses knowledge, methods or concepts from different disciplinary origins. We make a distinction between three different types of cross-disciplinary research: multidisciplinary, interdisciplinary and transdisciplinary research. Which of these types of cross-disciplinary research is needed depends on the type of societal or policy problem (RMNO, 2005).

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We speak of *multidisciplinary research* if respective disciplines contribute to a problem solution, while working alongside each other. Changing circumstances and changing policy priorities may call for a change in the multidisciplinary mix that constitutes a field of research. Past changes in the multidisciplinary mix of coastal defense research include for example the growing importance of earth sciences, geomorphology and morphodynamics in response to the coastal policy of dynamic preservation (see below). Within multidisciplinary research, synthesis of the different disciplinary contributions takes place post hoc, when the individual outcomes of disciplinary research are integrated within a problem solution.

Interdisciplinary research on the other hand requires a more integrated approach throughout the research process:

> Interdisciplinary research requires a joint research approach between researchers from different disciplinary backgrounds. Different disciplinary conceptual frameworks are used and problem definition, methodology and interpretation of results are dealt with in joint consultation. (RMNO, 2005, translation by the authors)

There are several definitions of *transdisciplinarity* but it is generally described as a specific form of interdisciplinarity in which boundaries between and beyond disciplines are transcended and knowledge and perspectives from different scientific disciplines as well as non-scientific sources are integrated (Flinterman, Teclemariam-Mesbah *et al*, 2001; Klein, Grossenbacher-Mansuy *et al*, 2001; Pereira and Funtowicz, 2005)

Transdisciplinary research is needed to solve badly structured societal problems (Hisschemöller, 1998; Hoppe and Huijs, 2003). Problems are defined as badly structured if involved actors have very different problem perceptions, if relevant knowledge is controversial and if uncertainties are big. Transdisciplinarity implies the need to accept local contexts and uncertainties and the need to be action-oriented. There is a need to establish linkages between

theoretical development and professional practice, and the gap between scientific knowledge development and societal decision-making processes needs to be bridged (Lawrence and Després, 2004: 399) This means that other objectives apply than those that normally structure scientific research.

Starting from the assumption that the disciplinary organization of the science system may impede the development of socially and policy-relevant research for coastal defense, we have developed positioning indicators for cross-disciplinary challenges. These are field level indicators directed at the cross-disciplinary dimensions of a research field and which can be used to evaluate whether the cross-disciplinary constitution of a research field is well aligned with the knowledge needs that follow from social and policy priorities.

Data and methodology

The indicators for cross-disciplinary challenges were obtained by combining four different methodological approaches, using different kinds of data.

1. Coastal policy documents were analyzed to map the need for multidisciplinary, interdisciplinary and transdisciplinary research as implicated in current social and policy priorities.
2. Annual reports, research assessments, institutional homepages and research databases were used to list the various Dutch research groups and institutes involved in coastal research and to map them in terms of main disciplinary orientation.
3. Bibliometric methods were used to map the international development of the field; to map the relative position of Dutch research in relation to the international field; and to map national patterns of research collaboration.
4. In an expert meeting with involved practitioners, researchers and intermediary actors, we discussed our findings, and the main barriers for what appeared to be one of the most salient cross-disciplinary challenges: transdisciplinary research for integrated coastal-zone management.

Analyzing social and policy needs for cross-disciplinary research

To develop qualitative indicators on the *need* for cross-disciplinary research — as implicated in the social and policy priorities for coastal research — we analyzed coastal policy documents, research policy documents, advisory reports and academic studies that are available for this domain. We often found a general plea for integrated, interdisciplinary or multidisciplinary research (eg NWO, 2005). However, a clear argumentation for these needs was mostly lacking and it appeared that different kinds of rationale were used confusedly. For that reason we decided that we could not trust blindly in the diagnoses available in the various (research) policy documents and that we ourselves had to make the analytical step of translating the various social and policy priorities into specific cross-disciplinary research needs. This was based on a content analysis of relevant documents about coastal defense-related issues.

Mapping research groups and institutes: a bird's-eye view of coastal defense research

When developing indicators on the field level we first need to assess what constitutes the field and where its boundaries lie. There is no one best methodology to do so, as each methodology foregrounds certain aspects while backgrounding others. In that sense there is no natural or given field of research. Rather, what constitutes the field and where its boundaries lie, depends upon the methodology and criteria used to demarcate. Both should fit the research questions. The mapping approach that was developed in this study takes social relevance of coastal defense research as a starting point. This means that we are particularly interested in the way changing political opinions and social priorities influence the cross-disciplinary mix of coastal defense research. Consequently, the main criterion for including a research group is whether it claims to contribute to the development of knowledge relevant for coastal defense.

Institutional websites, research programs, annual reports and research evaluations were used as data sources for finding such claims. The selection of relevant research groups and institutes was checked by consulting some experts within the field of coastal defense research. The identified research groups and institutes then were categorized according to their main (disciplinary) research orientation. Some had a clear cross-disciplinary orientation and were categorized accordingly in more then one subfield, as is visualized in Figure 1. The map forms an indicator of the extent to which the different subfields of coastal research are organizationally integrated in the Netherlands. We consider this a relevant indicator because it has been found that the organizational integration of different disciplines strongly stimulates individual interdisciplinarity (Carayol and Thuc Uyen Nguyen, 2005).

Apart from data on *disciplinary orientation*, we collected data on the research groups' and institutes' main research *activities*.[1] Our objective was to characterize the different groups in terms of their research activity profile, similar to the *research compass card* (Larédo and Mustar, 2000) and the *evaluation in context* method (Spaapen and Dijstelbloem, 2005). We tried as much as possible to use publicly available data, as this makes the method easier to use, and less resource-consuming. However, publicly available data were not sufficient to produce detailed characterizations of research activities. In particular, this was the case for the non-university research institutes, which often report on the activities of the institute as a whole and not at the

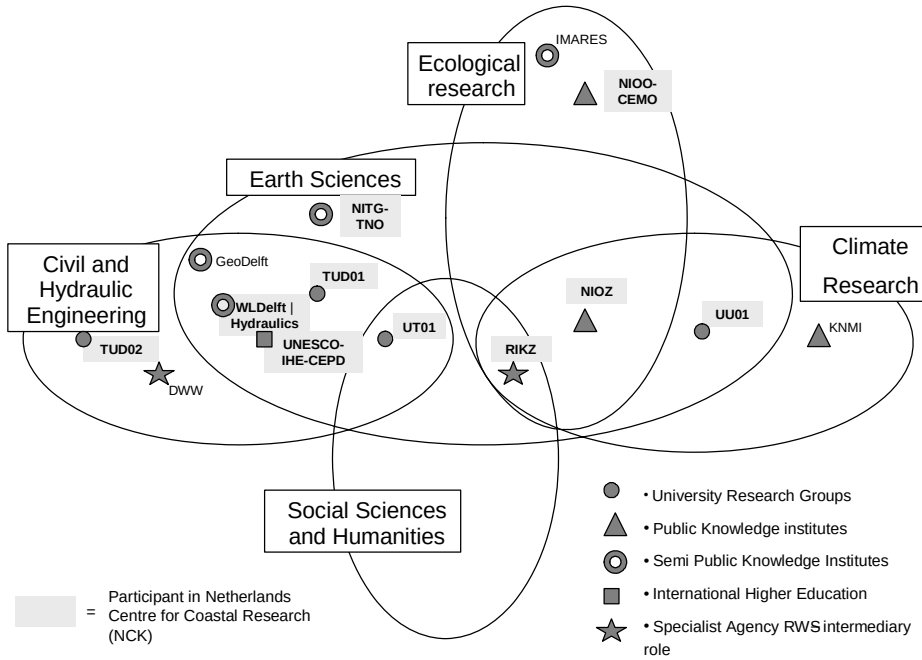

Figure 1. Bird's-eye view of research institutes and research clusters in Dutch coastal defense research

level of the individual research group. We therefore had to use a more traditional approach and characterized research groups according to their *institutional setting*, which to a large extent reflects differences in research profiles. We made a distinction between university research groups, public research institutes, semi-public research institutes, international higher education, and specialist services from the relevant ministry.[2] In Figure 1, different symbols are used to distinguish the different types of organizations. In that way Figure 1 indicates how different types of institutes are distributed over the different subfields of coastal defense research.

Finally, to complete the bird's-eye view, we also mapped the most important formal and informal networks of research collaboration that exist between the different research organizations and which are relevant for issues of coastal safety, coastal management and coastal engineering. The maps of these collaborative networks complement Figure 1, which shows the organizational integration within and between different subfields. The maps of collaborative networks indicate where cross-disciplinary research may originate from interorganizational collaboration.

A drawback of this mapping approach is that by focusing on the level of groups and institutes it disregards the fact that the research profile of individual researchers may differ from the overall research profile of the groups to which they belong. Thus, we run the risk of missing relevant research activities because they are not included in the descriptions on the organizational level. As part of our bibliometric analysis (next section), we therefore collected all Dutch contributions in coastal defense-related journals. This list of publications was checked for organizational addresses that were not yet covered by the bird's-eye view of coastal defense research. This enabled us to map also those research organizations that do some coastal defense research, but have their main activities somewhere else.

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Mapping scientific content and communication – bibliometric indicators

The annual reports of the research groups under consideration, and interviews with specialists resulted in a set of core journals as shown in Table 1. The journals were first of all used for delineating the coastal research field using journal–journal citation relations (Van den Besselaar and Leydesdorff, 1996). To create a reliable map, we used all the different journals as a starting point, and also analyzed developments over time. The resulting map of the field shows more and less important subfields, and related research fields that provide knowledge inputs for coastal defense research. It can also be used to classify research groups in terms of their disciplinary or cross-disciplinary behavior.

Table 1. Journals included in the analysis

Journal	(Sub)field*	Total	% of all	NL arts	% of all NL arts	NL as % of journal**
Journal of Coastal Research	1	1,710	7.6%	42	6.5%	2.5%
Geo-Marine Letters	1	1,192	5.3%	22	3.4%	2.9%
Marine Geology	1	2,601	11.6%	126	19.5%	4.8%
Coastal Engineering	2	779	3.5%	98	15.2%	12.6%
Coastal Engineering Journal	2	118	0.5%	2	0.3%	1.7%
J. Water Port Co. Oc. Eng. Asce.	2	710	3.1%	25	3.9%	3.6%
Coastal Management	3	427	1.9%	3	0.5%	0.7%
Ocean and Coastal Management	3	893	4.0%	17	2.6%	1.9%
Marine Policy	3	819	3.7%	11	1.7%	1.3%
Continental Shelf Research	4	1,783	7.9%	71	11.0%	4.0%
J. Geophysical Res. – Oceans	4	5,760	25.7%	106	16.4%	1.8%
Estuarine Coastal Shelf Science	5	2,589	11.5%	74	11.5%	8.4%
Marine Pollution Bulletin	6	3,079	13.7%	48	7.4%	1.6%
Total		*22,448*	*100%*	*645*	*100%*	*2.9%*

Notes: 1: coastal research and marine geology; 2: coastal engineering; 3: management and policy; 4: physical oceanography; 5: marine ecology/estuarine science; 6: marine pollution
* This classification of journals within different subfields is based on journal–journal citation analysis.
** The share of the Netherlands in science overall is slightly above 2%.

Second, key word analysis was used to map the development of topics and the Dutch contributions in the key journals in coastal defense research over the period 1994 to 2004. The selection of key words was based on inspection of title word frequencies (Appendix 1). Third, the relative share of Dutch researchers in the various subfields and topics can be made visible in this way.

Finally, bibliometric analysis enables us to do a co-authorship analysis, and that informs us about collaboration patterns between the relevant research groups in the Netherlands. This is especially important in cross-disciplinary research, as there not only produced knowledge is important, but also cross-disciplinary collaboration and networking. "Co-author analysis … considers the social aspect of interdisciplinarity and focus on research practice instead of information" (Schummer, 2004: 436).

A focus group approach

Confronting the analysis of current social and policy priorities with the state the field is in, we arrived at a diagnosis of the current state of coastal defense research, of the position of Dutch research, and of the most salient disciplinary challenges for the field. In order to improve the analysis, we organized a focus group with relevant practitioners, researchers and intermediary actors. The aim of the expert meeting was threefold. It served as a check on our analysis of the most salient challenges in the field, as a check and improvement of the analysis of the bottlenecks for disciplinary change, and finally as a source of ideas about the leverage points for policy intervention.

Results

In this section we present the results of the various analyses. Because of space constraints, we cannot give the findings in full detail. They can be found in the reports underlying this paper (Merkx, 2007a,b; Van den Besselaar and Merkx, 2007; Wesselink and Merkx, 2007).

Challenges for the coastal research system

Dutch water safety policy is among the strictest in the world, and is strongly directed at keeping the water out. In the Netherlands, design criteria for defense structures are based on the acceptance of a 1:10,000 years flood risk. In comparison, the American technical norms are based on the acceptance of a 1:100 years flood risk. As a result of these strong safety norms, Dutch policy did not reckon with the possibility that things might go wrong and there has been hardly any attention to measures to reduce damage when flooding occurs (Bijker, 2005). With the rising sea level and increasing river discharge, the limits of the water defense paradigm are coming into sight. Furthermore the strong engineering approach of the water defense paradigm has had negative side effects on ecosystems and spatial quality. As a response, over the last two decades a shift has occurred, moving away from an engineering-based policy focusing on defense against water to an approach focusing on *water accommodation* and *integrated coastal-zone management*. This approach has a different safety policy concept, and entails measurements which can reduce damage when flooding occurs, instead of trying to avoid flooding *per se*. Besides evacuation policy and disaster management, this new policy approach also includes spatial policies. If one accepts spatial solutions for 'living with water', the problem emerges of how to maintain, organize and use the coastal areas, which are, in the Netherlands, the most densely populated parts and the economic centre of the country. An integrated coastal-zone management approach is needed.

The old engineering paradigm of water defense is reflected in a research infrastructure that is dominated by engineers and earth scientists. The paradigm shift to water accommodation and integrated coastal-zone management leads to new types of questions that require other types of expertise and knowledge, and therefore to a broadening of the knowledge base for water policy with social sciences and humanities research, spatial planning expertise and public administration studies (Min V&W, 2000; NRLO/AWT/RMNO, 2000). Apart from this, the issue of climate change, and its effects on rising sea level and river discharge, has emerged on the political agenda. Space available prevents us from going into more detail. We only summarize the main cross-disciplinary research challenges that emerge from our policy analysis (Merkx, 2007b):

1. Demand for interdisciplinary biogeomorphology research for the dynamic preservation of the coast, including soft coastal engineering;
2. Demand for transdisciplinary research for integrated coastal zone management and eco-engineering, which implies a change in the multidisciplinary mix and in collaboration patterns:
   - integrating social sciences research with science and engineering research;
   - integrating hydraulic and coastal engineering expertise with ecological expertise in order to address issues of eco-engineering;
   - close collaboration between researchers, policy-makers, administrators, engineering consultants and professional practitioners;
3. Demand for interdisciplinary climate change research.

The description of the research groups and institutes (Merkx, 2007a), the bibliometric analysis (Van den Besselaar and Merkx, 2007) and the results of the expert meeting (Wesselink and Merkx, 2007) all provide indicators about the way these new cross-disciplinary research challenges are taken up in Dutch coastal defense research. In what follows we start with a brief description of the research field. Then, we will discuss the first two challenges one by one, integrating the results of the various approaches. We lack space to include the third challenge of interdisciplinary climate change research here.

A brief description of the research field

Using journal–journal citations, the field of coastal research was mapped for all even years between 1994 and 2004, using all the journals listed in Table 1 as starting point for the analysis. The journals were selected because Dutch research groups frequently publish in these coastal journals, and also they were relatively often mentioned when interviewing researchers. Overall, this resulted in a set of consistent maps that indicated the following structural characteristics of the research field (Van den Besselaar and Merkx, 2007).

1. Coastal defense research consists of four different core subfields: coastal research and marine geology, coastal engineering, coastal management and policy, and estuarine ecology (F7, F4, F8 and F2 in Table 2). A subfield is a group of journals that form a factor in the factor analysis of the journal–journal citation analysis. As can be seen from the citation relations between the core subfields, they are not very strongly interconnected. The only stronger relation is marine geology (F7) intensively citing estuarine research (F2).
2. In the citation environment of the *Journal of Coastal Research*, we also find a changing set of other research fields that are knowledge sources for coastal research, such as physical oceanography, and marine pollution (F3 and F10 in Table 2).
3. The bibliometric map (Van den Besselaar and Merkx, 2007) also shows several sets of journals that were not mentioned by Dutch researchers and which do not belong to the main publication media of the Dutch coastal research groups, such as on climate change, on sedimentology and on

Table 2. Results of the factor analysis of the *Journal of Coastal Research*, 2004 – citation relations between the subfields (factors)

	F4	F7	F8	F2	F1	F6	F3	F5	F9	F10
F4 coastal engineering	568	97	2	29	4	10	244	9	–	13
F7 marine geology/coastal research	170	1,705	15	292	618	134	682	343	77	76
F8 coastal management	–	46	168	18	–	2	–	–	–	13
F2 estuarine research/marine ecology	23	561	32	12,538	311	31	1,457	45	809	670
F1 climate change/Quaternary science	14	730	22	1,943	19,509	533	5,045	1,741	481	207
F6 geomorphology	10	117	–	1,013	183	1,337	169	146	8	35
F3 (physical) oceanography	247	703	–	116	2,044	199	28,730	968	265	113
F5 sedimentology	28	750	–	514	1,875	836	1,447	3,440	36	42
F9 marine chemistry	–	49	–	376	56	8	233	10	799	116
F10 pollution research	15	72	14	–	16	23	92	–	46	1,056

Note: Columns: citing; rows: being cited; F4 = fourth factor

geomorphology (F1, F5, F6). The latter fields constitute knowledge inputs for the subfields of coastal research: three subfields of coastal defense research (F4, F7, F8) do cite these factors much more frequently (in relative terms) than vice versa (Table 2).

4. The large factor on climate change (F1) is only visible in the later years, and this is a relevant observation; the role of climate change research indeed is increasingly important for coastal defense issues. We do not pursue this issue further because of space constraints.
5. The Netherlands' research activities are different from the world average. The subfield of coastal engineering is much larger in the Netherlands: 19.4% of all publications are in this subfield, versus 7.1% worldwide. The same is true for coastal research/marine geology (29.4% versus 24.5%). The opposite is the case for coastal management and policy (4.8% versus 9.6%) (Table 1).
6. The relative size of the various research fields can be derived from Table 2. The number of citations from a respective subfield forms an indicator for the total number of papers in this subfield. As is clear, three core coastal research subfields (F4, F7 and F8) are relatively small compared to the other subfields.
7. The *Journal of Coastal Research*, which was generally seen by the respondents as the core journal in the field under study, also appeared as the core journal in the bibliometric analysis. The journal has typical multidisciplinary behavior (Van den Besselaar and Heimeriks, 2001): It is in one of the lower factors (F7), and also has a moderate loading on a few other factors (coastal engineering, marine ecology, water pollution). It does not load on the coastal management factor.

Given this picture of the research field, we now can answer the question of how coastal research is responding to the new societal challenges, as discussed above.

1. Interdisciplinary biogeomorphology research for dynamic preservation policy

The national policy of "dynamic preservation" of the coast (Min V&W, 1990) was implemented in 1990 to stop the structural regression of the Dutch coastline. The policy objective is to preserve the so-called *basal coastline*, the Dutch coastline as it was in 1990. Dynamic preservation implies exploiting natural processes of coast formation, with 'soft' interventions such as sand nourishment as the principle method. In the context of soft coastal engineering and the policy priority of dynamic preservation, interdisciplinary biogeomorphology research is an important research challenge. Biogeomorphology is the study of the interaction between geomorphological features and organisms. This interdisciplinary field combines expertise from ecology and geomorphology.

The bird's-eye view indicates that, on the organizational level of research groups, marine and estuarine ecological research on the one hand, and morphodynamic and geophysical coastal research on the other, are hardly integrated (Figure 1). However, this is not necessarily a barrier for developing interdisciplinary biogeomorphology research, as the lack of organizational integration may be compensated by an emerging bottom-up national network of research collaboration: the biogeomorphology platform. Furthermore, geomorphological researchers and estuarine and marine ecological researchers both participate in the Netherlands Centre for Coastal Research (NCK) (Figure 1). Inspecting the research agendas of research groups in marine and estuarine ecology and in coastal geomorphology, we found biogeomorphology to be an important theme.

At the level of formal scientific communication (in scholarly journals), biogeomorphology research is not yet visible. From the set of journals that we analyzed, the *Journal of Coastal Research* best covers the entire multidisciplinary field of coastal research. The journal–journal citation analysis of the *Journal of Coastal Research* shows marine ecology and geomorphology as two distinctive factors (F2 and F6) of this multidisciplinary journal. At the same time, the information flow between the two fields is very low (Table 2). Also a title words analysis (see Van den Besselaar and Merkx, 2007, for details) did not reveal any words that signify the new subject of biogeomorphology. However, we did find title words indicating research on *soft coastal engineering*, which is a related field. The Dutch share of articles with these title words was well above international average (Figure 2). Although biogeomorphology research is not yet visible in the international research literature, the policy priority of dynamic preservation is clearly on the Dutch research agenda: soft coastal engineering forms one of the core themes in Dutch coastal defense research. We already mentioned that the interdiscipline of biogeomorphology is visible in Dutch research networks and collaborations. Obviously, Dutch researchers are actively participating in these new developments.

2. Transdisciplinary research for integrated coastal-zone management

Worldwide, coastal zones are threatened. Climate change and sea-level rise lead to coastal erosion, salt intrusion, destruction of habitats and a higher risk of flooding. In addition to these natural threats, strong increases in population density and economic activity put further pressure on the coastal zone. Public authorities on different levels (municipal, regional and national) are responsible for maintaining and balancing a number of sometimes conflicting functions of coastal zones. Integrated coastal-zone management (ICZM) entails an administrative approach in which all parties and stakeholders are involved to

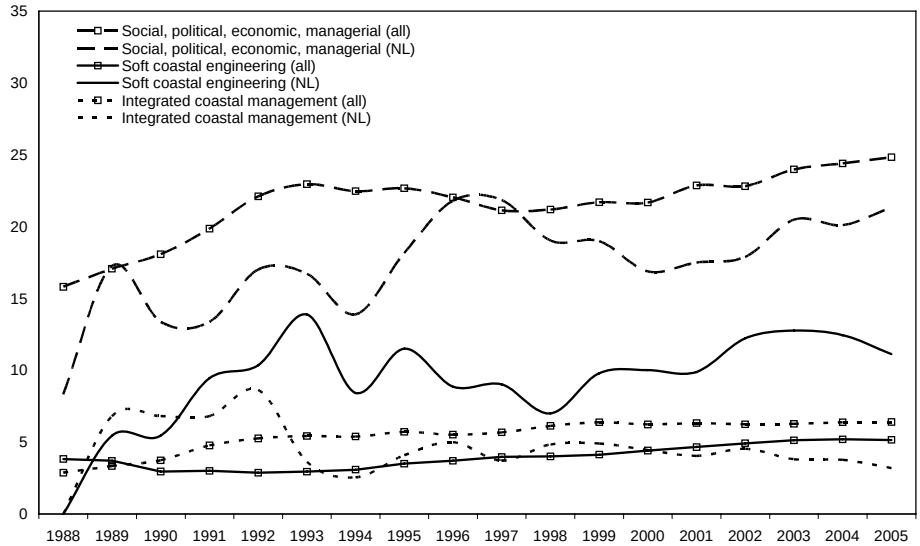

Figure 2. Word patterns in various research topics (five years moving average)

find integrated problem solutions and in which the many problems of the coastal region are dealt with in a coherent way. Examples of such integrated solutions are:

- multifunctional spatial planning;
- combining different spatial functions, such as coastal defense and nature development; or
- accommodation of economic activities to changing natural conditions, such as developing salty agriculture. ICZM is high on both societal and policy agendas and will most probably continue to be so in the future (NRLO/AWT/RMNO, 2000; ESF Marine Board, 2002; Min V&W, 2002; RMNO, 2004; Stel and Luiten, 2004; NWO, 2005: 12).

In ICZM, problem definitions are not clear, different values are at stake, and models used to define solutions have considerable uncertainties. A variety of solutions may exist and the choice of optimal solutions results not only from a creative search but also from processes of political negotiation. The policy of integrated coastal zone management thus entails 'badly structured' problems, which require transdisciplinary research (Hoppe and Huijs, 2003).[3]

The question whether or not the Dutch coastal defense research field is well-directed towards the development of transdisciplinary knowledge in this field has several dimensions. First, ICZM requires integration of relevant social science research with research in engineering and earth sciences (2a). Second, the approach of eco-engineering requires the integration of hydraulic and coastal engineering expertise with ecological expertise (2b). Finally, the fuzzy nature of ICZM problems and solutions asks for an integration of scientific knowledge with local ('practical') knowledge. Therefore research practice should include collaboration of researchers with administrators, engineering consultants, and other professional practitioners (2c).

2a. Integrating social sciences with science and engineering The map of coastal defense research (Figure 1) shows that social sciences and humanities research is underrepresented and that the organizational integration of social sciences and humanities research with science and engineering research is low. We only find two exceptions: a cross-disciplinary research group and a cross-disciplinary governmental institute. The same holds for the networks of research collaboration. For example, in the Netherlands Centre for Coastal Research natural sciences and engineering researchers collaborate, but social sciences and humanities research is absent from this network (Figure 1).

Also the bibliometric map of the coastal defense research shows only a weak integration of the science and engineering subfields (factors 4 and 7 in Table 2), on the one hand, and the social science-oriented subfield of coastal management and policy (factor 8 in Table 2) on the other: the first two hardly cite the journals belonging to the latter subfield. This is confirmed by a further analysis of the subfield of coastal engineering, which is strongly represented in the Netherlands (Table 1). Because coastal engineering is directed at the design of coastal structures, it is the most obvious candidate subfield to develop relations with social sciences. But this appears not to be the case. An analysis of the citation environment of

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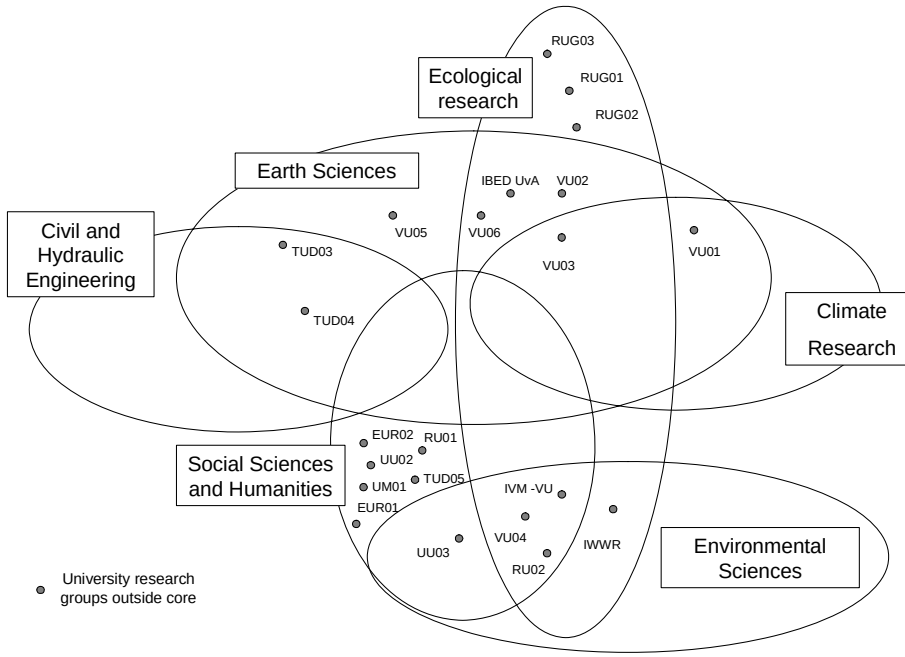

Figure 3. Bird's-eye view of academic research groups with a marginal involvement in coastal defense research

the journal *Coastal Engineering* shows the absence of coastal management and social sciences research in the environment of coastal engineering. The other way around we found the same: coastal engineering research does not form part of the citation environment of coastal management and coastal policy journals either.

It is interesting to note that, whereas the social sciences are hardly visible in the citation environment of the main journals of the coastal defense research field, the title keyword analysis shows a frequent use of contextual terms that relate to societal and managerial aspects of coastal defense (Figure 2). This suggests that broader societal, managerial and policy aspects are being addressed, but that this does not seem to involve substantial contributions from social research.[4] The analysis of research output underpins these findings, as we find a rather large number of papers with Dutch authors in engineering journals, but only a few papers in the coastal management and policy journals.

If we include in the analysis several research institutes that are only marginally involved in coastal defense and ICZM research, a somewhat stronger integration of science and engineering research and social science research is found (Figure 3). Compared to Figure 1, the inclusion of these other institutes does add a new field to the map: environmental sciences. In this research field, and in the field of ecology, the integration with social science research seems somewhat stronger than in the rest of coastal research and engineering.

2b. The transdisciplinary challenge of eco-engineering Eco-engineering[5] integrates civil engineering expertise with ecological expertise. It is a type of engineering in which both technological and ecological boundary conditions form the basis for the design. Within the final design, the technically feasible and the ecologically desirable are jointly optimized. Successful eco-engineering requires that engineering and ecological disciplines are willing to collaborate and to be open for the types of arguments used by the other.

Our map of the research field indicates that at the level of research organizations eco-engineering is not yet visible: there are no cross-disciplinary research groups or institutes that cover both the field of coastal engineering and the field of ecological research (Figure 1). At the level of formal research collaboration there is some interaction between the two fields as groups from both subfields participate in the Netherlands Centre for Coastal Research (NCK). However, a content analysis of the research programs, annual reports, and websites shows that eco-engineering is not addressed within the NCK. This is supported by an analysis of co-authorship relations. Over the period 2000–2006, research institutes in marine biology and marine ecology have not co-authored with the hydraulic and coastal engineering groups and institutes.

Coastal eco-engineering research would imply ecological literature in the citation environment of coastal engineering literature. However, this was not visible in our journal–journal citation analysis. The other way around, an analysis of journals in aquatic and applied ecology showed that engineering literature is not part of the citation environment of ecological journals. In other words, eco-engineering is not yet visible in the formal research literature. However, a relatively new journal with the name *Ecological Engineering* does exist. An analysis of the citation environment of this journal shows that it does focus on the coastal zone, but also that it has no

relations with engineering literature whatsoever. In other words, the focus of this journal is on issues of ecosystem restoration and not on integrating engineering and ecology.

2c. The challenge of integration of formal and informal (practical) knowledge Transdisciplinarity entails the integration of different forms of formal scientific knowledge with the informal and tacit knowledge of practitioners, administrators and policy-makers. The formation of knowledge networks that bring these two worlds together is a way to achieve and improve transdisciplinary integration. The existence of such networks would provide an indicator that the challenge of transdisciplinary research is seriously addressed. In the field of coastal defense research and integrated coastal zone management we have found two promising network activities that do so: EncoraNL and the biogeomorphology platform. The European coordination action Encora aims to improve and stimulate the interaction and sharing of knowledge between coastal science, policy and practice. It is a new initiative and therefore it is too early to judge whether it is effective. A second transdisciplinary network is the biogeomorphology platform, which brings together geomorphologists, ecologists and 'end users'. Several bibliometric indicators may inform us about the level of transdisciplinary collaboration — using the journals mentioned in Table 1.

First, what types of organizations do publish in the academic journals? Of all authors, 42% are university-based, 16% are from public research institutes (which have also application and policy tasks), 34% are from engineering and consulting companies, and 8% are from (non)governmental organizations (Table 3). This broad variety suggests that the coastal defense research field has a transdisciplinary dimension, in which knowledge is developed within the context of application. When looking at the relative share of publications that are authored by non-research organizations, it proves that universities and (semi)public research organizations are the big publishers, together responsible for more than 90% of all publications. Still, almost 10% of all publications is authored by someone based in a (consultancy or engineering) company, a governmental organization, or an NGO. This number is rather high, given that we have only included research literature in journals included in the Web of Science database.

Furthermore there is quite a large amount of co-authored publications[6] — about 11% — that includes authors from research organizations as well as non-research organizations (Table 4). Also this indicates that the field of coastal research has indeed to some extent a transdisciplinary orientation.

When looking at the strongest co-authorship relations, we find that most of the research collaboration is between two public research institutes and a few research groups based in three of the universities. Since both public research institutes have a strong orientation towards knowledge application, policy advice and public services,[7] this forms yet another indication that coastal defense research in the Netherlands has a transdisciplinary dimension. One may counter-argue that it is still a small part of all papers. However, the number of co-authored reports and other (informal and practical) documents is expected to be much higher than the academic papers we are focusing on here.

Table 3. Dutch organizations in coastal research, 1988–2006

Category	N	%	Papers*	%
Companies	25	33.8	54	6.2
Governmental organizations	2	2.7	16	1.8
Non-governmental organizations	4	5.4	7	0.8
Universities	31	41.9	448	51.2
Public research organizations	12	16.2	350	40.0
Total	74	100	865	100

Note: * integer counting

Summary of the findings

The concept of transdisciplinarity entails two types of boundary crossing. First, in transdisciplinary research, boundaries are crossed between the world of science and the world of practice. The results of our study indicate that in this respect the field of coastal defense research has indeed a transdisciplinary dimension. Research is quite strongly application-oriented, and non-research organizations contribute to knowledge development.

Transdisciplinarity also entails the crossing of boundaries between and beyond different disciplines. This dimension of transdisciplinarity is under-developed in the field of coastal defense research. Integration between disciplines within the field of eco-engineering is marginal or absent, and this is also the case for integration of science and engineering, and social science research, both nationally and internationally. Transdisciplinary research for integrated coastal zone management forms an important challenge and the various indicators suggest that this challenge is not yet sufficiently taken up. On the other hand, the weak integration of social science research may be closer to solution. Whereas social science research is weakly represented in the

Table 4. Co-author relations in coastal research, 1988–2006

Co-author relations	N	Share
Within the research organizations/universities	267	88%
Within the set of companies and (N)GOs	4	1%
Between the two groups	33	11%

Transdisciplinary research for integrated coastal zone management forms an important challenge and the various indicators suggest that this challenge is not yet sufficiently taken up

core of Dutch coastal research groups and institutes, there is a fair number of social sciences research groups that have at least some involvement with issues of coastal defense, integrated coastal zone management, or integrated water management (Figure 3). A social research base seems available, to strengthen this part of the multidisciplinary mix.

Bottleneck analysis: identifying barriers for transdisciplinary research

What structural features of the science system create the barriers for the development of transdisciplinary research? To clarify this, a focus group was held, which also confirmed the analysis and findings reported above. Main outcomes were the identification of the main barriers for developing transdisciplinary knowledge. These bottlenecks are located both within and outside the science system.

A first barrier is at the skills level. Researchers have to be able to communicate and collaborate with researchers from different backgrounds, using different languages, concepts and methods, and educated within different paradigms. One of the conclusions of the focus group was that researchers often lack the communication skills required to engage effectively in transdisciplinary research collaboration. The same is true for collaborating and communicating with a variety of practitioners — who at their side also find it often difficult to work with each other and with researchers.

The second mentioned barrier is the research funding system. Although the number of funding instruments in the Netherlands for transdisciplinary research has increased over the last years (Versleijen *et al*, 2007), it was felt that in the process of project selection the 'traditional' criteria of scientific (disciplinary) excellence are more important than the usability related criteria (see also Kamphuis, 2005). This is even stronger the case when the research councils are involved in project and program selection. This may change in the future, as there is increasing interest in the development of new evaluation methods that take the societal value of research into account (Spaapen and Dijstelbloem, 2005), and which therefore may enlarge the space for researchers to engage in transdisciplinary research.

A related systemic barrier is the way in which research is organized in the Netherlands. Many transdisciplinary projects are carried out by PhD students and post-doc researchers, who have an interest in doing disciplinary research: That is the predominant way to get into the academic system. As a consequence, what starts as a transdisciplinary program easily breaks apart into a set of parallel disciplinary research projects. More generally, the scientific reputation system seems to be a barrier, as it is difficult to build an academic career on transdisciplinary research because scientific excellence and output in disciplinary-oriented journals form the dominant evaluation criteria for researchers. Therefore researchers are inclined to focus on disciplinary questions and output — after they have got the funding. This also is the case in the large programs that explicitly are meant for knowledge production that helps solving specific social problems.

A fourth barrier for the development of transdisciplinary research is formed by the dominant model for science–society interactions and the way in which societal steering of research is generally organized, as a process of demand and supply: science is expected to produce knowledge which is then applied to societal problems. In this model, societal steering of research is organized by means of a process of agenda setting, in which also societal stakeholders, such as representatives from industry and policy are involved. This model may work when social problem definitions are clear and stable. If problems are badly structured, one may need another model for societal steering of research. In this case an ongoing and intensive interaction between researchers on the one hand and practitioners and policy-makers on the other hand is needed during the research project. Here the skill argument fits in once more: Also policy-makers need the capacity to communicate and collaborate with people with different (disciplinary) backgrounds. One needs a certain level of expertise to be able to translate social demand in research questions and to communicate with researchers. Therefore, government needs to employ people with relevant research competence and expert knowledge.

The last identified main barrier for transdisciplinary knowledge development is located at the political level. Transdisciplinary knowledge is developed when addressing societal problems and designing and realizing concrete solutions. Therefore transdisciplinary knowledge production requires a long-term political commitment to work on the problems, as there is a need for social experimentation and learning by doing. A missing sense of urgency of the problems to be solved is one of the causes preventing transdisciplinary research projects from being successful. Another issue here is that many social problems involve various administrative levels that are co-responsible for decision making (NRLO/AWT/RMNO, 2000).

Policy implications

The analysis leads to a series of policy implications, which are of course specific for the local situation. These range from the implications for the research funding system, for the organization of PhD programs, for the organization of the public research institutes, and for systems for research evaluation. To give one example, in recent years there has been a tendency to merge research institutes with related fields into larger research facilities — as the idea is that the larger these research institutions are, the better they will function. As a consequence, existing research organizations that have also practical and policy tasks (specialist services from the ministry) are split up. This may result in large field-specific research institutes but, as our analysis clearly indicates, this may be detrimental to the development of crucial transdisciplinary linkages.

Conclusion

At present social relevancy of scientific research is high on the science policy agenda. This constitutes a change compared to prior policy in which 'internal' scientific quality was dominant. In this paper we developed an approach for the evaluation of societal responsiveness on the meso level of a specific research field, in terms of cross-disciplinary challenges. Using a multi-method approach compensates some of the weaknesses of *ad hoc* indicators (Lepori, 2006) or weak benchmarking indicators. Triangulation of measures with non-overlapping weaknesses is a standard technique in the social sciences (Tashakkori and Teddlie 1998) and the use of a range of techniques would be a way of minimizing the risk of failure to measure important aspects of research (Thelwall, 2004: 65).

The multi-method approach enabled us to distinguish different types of cross-disciplinary challenges, to assess whether or not cross-disciplinary challenges are taken up, and to identify structural barriers hindering the development of cross-disciplinary research in the field of coastal research. We could therefore go beyond the science policy mantra that socially relevant research requires interdisciplinary research. The result is a much more detailed analysis of the challenges and of the systemic bottlenecks, and it leads to specific suggestions for improving the functioning on the science system — which partly go beyond the specific research field under study.

Appendix 1. Key words used to determine the research topics

Topic	Query
Integrated management	Like "*Manage*" Or Like "*Integrated*" Or Like "*Assess*" Or Like "*ICZM*" Or Like "*Integrated Coastal Management *" Or Like "*Integrated Coastal Zone Management*"
Management, social, policy, economic issues	Like "*Adapt*" Or Like "*Admin*" Or Like "*Agree*" Or Like "*Assess*" Or Like "*Benefi*" Or Like "*Budget*" Or Like "*Community*" Or Like "*Coopera*" Or Like "*Cost*" Or Like "*Damag*" Or Like "*Decison*" Or Like "*Diagno*" Or Like "*Eco*" Or Like "*Environm*" Or Like "*Exploita*" Or Like "*Financ*" Or Like "*Forecast*" Or Like "*Govern*" Or Like "*Implica*" Or Like "*Legal*" Or Like "*Legis*" Or Like "*Manag*" Or Like "*Participa*" Or Like "*Polic*" Or Like "*Polit*" Or Like "*Predic*" Or Like "*Preserv*" Or Like "*Regula*" Or Like "*Responsi*" Or Like "*Soci*" Or Like "*Strateg*" Or Like "*Sustainab*" Or Like "*Touris*" Or Like "*Uncertai*" Or Like "*Vulnerab*"
Soft coastal engineering	Like "*Budget*" Or Like "*Sand*" Or Like "*Long-Term*" Or Like "*Soft*" Or Like "*Nourish*" Or Like "*Replish*"

Notes

1. Based on research assessment reports, annual reports, research programmes, information obtained from institutional websites, from the online research information database METIS, and from the online Dutch Research Database (NOD).
2. In general, apart from doing academic research, university-based research groups are involved in teaching at the bachelor and master levels. In that respect they differ from public research institutes, which are only doing research. That is not to say that public research institutes have no involvement with teaching. But this teaching is concentrated on the supervision of MSc and PhD students and takes place in collaboration with university-based research groups. Public research institutes are primarily funded by public money and have a strong academic orientation. Semi-public knowledge institutes combine publicly funded research with research and consultancy for the private sector. Furthermore these semi-public knowledge institutes are positioned to carry out applied and strategic research and to form a bridge between academic research and the application context. The specialist services of the Directorate General of Public Works and Water Management carry out research for policy support, and for monitoring. They also take up an intermediary role as much of their research budget flows to subcontractors. UNESCO Institute for Higher Water Education is an international institute, located in the Netherlands. As it takes part in Dutch research networks and receives funding from Dutch agencies, we include it here.
3. This is more generally the case in water-related research, such as in integrated water management and in integrated North Sea management (NRLO/AWT/RMNO, 2000; RMNO, 2004; Stel and Luiten, 2004).
4. This lack of involvement of social scientists is also found in the process of setting the research agenda. De Wit and Van Mansfeld (2004) commented on this practice claiming that "There is a tendency among well-disposed scientists to formulate the research agenda for 'the others'" (De Wit and Van Mansfeld, 2004: 21–22, my translation) The authors stress the importance of involving social sciences and humanities researchers in setting the research agenda.
5. Eco-engineering was put on the research agenda in 2001 by

Water-Front, an independent advisory council for knowledge development and application in the hydraulic engineering and spatial planning sector. It consists of a large variety of parties: the private hydraulic engineering sector, knowledge institutes, NGOs and public organizations <www.water-front.nl>.

6. The analysis is based on the 13 mentioned journals and covers the period between 1988 and 2006. In this set we find 639 unique Dutch papers, of which 166 (26%) are co-authored by Dutch authors working within different research institutes. The number of research groups in the network of inter-institutional co-authored papers is 57, and they are coupled through 304 co-author relations. The rate of inter-organizational co-authored papers increases sharply over time, from some 15% in the early 1990s to almost 40% in the more recent years. Indeed, of the 166 co-authored papers, 120 were published in 2000 or later.
7. *WL | Delft Hydraulics* is a semi-public research institute which covers a wide range of research and specialist consultancy on water-related issues, including coastal engineering and integrated coastal zone management. It is positioned to form a bridge between fundamental research and practice. The *National Institute for Coastal and Marine Management* (RIKZ) is one of the six specialist services of the Directorate General of Public Works and Water Management. The RIKZ provides policy advice and data directed at: protecting the country by flooding by the sea, and the sustainable use of coasts and seas.

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