Monitoring the Ems estuary; towards a bilateral integrated monitoring programme

Position Paper Ems
Monitoring the Ems estuary; towards a bilateral integrated monitoring programme
Colophon

Monitoring the Ems estuary; towards a bilateral integrated monitoring programme is produced under the scientific direction of the Wadden Academy in co-operation with Henk Smit (E&E), Michiel Firet (PRW), Monique van den Dungen (GSP) and David Kooistra (Province of Groningen).

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In the Dutch Ems-Dollard region a discrepancy was identified between legislative-oriented monitoring for obtaining a permit and ecosystem-oriented monitoring for describing status and trends. The elementary question was raised how available money can best be spent; what kind of monitoring programme yields a system understanding and at the same time yields sufficient knowledge to be used in licence procedures.

This question was addressed in a study by the Wadden Academy, jointly carried out with the project partners E&E, PRW, GSP and the Province of Groningen. The request was:
- To provide conceptual models for monitoring the estuary.
- To provide an overview of current monitoring programmes and their relationship with conceptual models.
- To provide a blueprint for an bilateral integrated monitoring programme that serves a) the general national requirements, b) the EU requirements and c) the license-driven monitoring goals.

In this study conceptual models for understanding the Ems estuary ecosystem were given. Based on this conceptual understanding the main components of an integrated monitoring program were worked out. These include the physical, physico-chemical and biological systems of the estuary including its ecotopes, and the socio-economic system. In the socio-economic system human activities determine drivers and pressures and the system receives benefits (ecosystem services) and yields a management response resulting in legislation and regulation.

Subsequently, long-term monitoring programmes were classified into three main categories:

**Type I:** Broad, coarse-scale, long-term programmes leading to assessments of status and trends.

**Type II:** Mandatory monitoring programmes designed to determine the effect of an activity or intervention on the status of the system required in permitting procedures.

**Type III:** Question-driven monitoring to obtain a mechanistic system understanding, which is guided by a conceptual understanding of the system and a rigorous study design.

An overview of current monitoring programmes and their relationship with conceptual models was given. Monitoring programmes of Type I stem from international conventions, directives and agreements and are carried out under the responsibility of governments. This study listed and compared programmes in The Netherlands and Germany. For Type II monitoring programmes, four initiatives for large projects in the Ems estuary were used as case studies. A comparison was made between the Type II monitoring requirements with existing Type I monitoring programmes. With regard to Type III monitoring programmes no long-term question-driven monitoring carried out in the Ems estuary, financed by scientific institutions, could be identified.

From the comparison of Type II effect monitoring with Type I status and trend monitoring we concluded that the set-up of the majority of the monitoring programmes was narrowed down to a juridical rationale. This prohibits a satisfactory increase in ecosystem understanding. We developed a COMPASS of criteria for the set-up of an effective monitoring programme:

**CONCEPTUAL:** based on a conceptual system understanding.

**OBJECTIVES:** setting quantifiable objectives with scientifically tractable research questions.

**MANDATED:** quality controlled and mandated by an independent monitoring authority.

**PROTOCOLS:** applying measurement protocols for consistency in sampling.

**ADAPTIVE:** adapt iteratively as new information emerges and research questions change.

**SCALES:** addressing multiple spatial and temporal scales considering the system’s heterogeneity and dynamics.

**STATISTICS:** rigorous statistical design of the sampling scheme.

On the basis of the assembled information, a blueprint is given for a bilateral integrated monitoring programme that serves license-driven monitoring goals. This blueprint gives recommendations on the monitoring design of the physical system, the physico-chemical system, the biological system and the socio-economic system. The integrated monitoring programme for the Ems estuary has the ambition to become a combination of Type I, II and III monitoring:

*A long-term monitoring programme leading to assessments of the functioning of the ecosystem, guided by a conceptual model and rigorous study design and yielding appropriate insight into effects of human activities.*
Recommendations are given for streamlining the monitoring programmes leading to a cost-efficient execution. We recommend to study the applicability of multiple hydroacoustic sensors on survey vessels. The use of satellite and aerial remote sensing gives ample opportunities for estuary-wide mapping of litoral substrates, shellfish cover, primary production in the water column and on the tidal flats, suspended sediment concentrations and ecotope mapping. New sensor technology opens up the possibility for high-frequency measurements on hydrodynamics, fine sediment transport, primary production and suspended sediment. We recommend to study the set-up of an aquatic sensor network on fixed stations, survey vessels and ships of opportunity. At the same time, maybe old-fashioned, but reliable sediment sampling and water sampling are still necessary, not only when remote techniques are insufficient but also to validate remote measurements. Last but not least, observations and sampling of biota fills the information needs on the status of the estuarine system.

In addition to a monitoring programme and its sampling scheme it is important also to have a publicly accessible data portal with current and historic data, and an internationally agreed upon management and organisation structure, including financial arrangements. For the Dutch Wadden Sea these topics are addressed in the WaLTER project (www.walterwaddenmonitor.org). For the Ems estuary in particular these have to be worked out as a next step.
The Wadden Academy has accepted an invitation from the programme E&E, PRW, Groningen Seaports and the Province of Groningen to write a report on monitoring of the international Ems estuary. The writing was guided by a committee from these organisations. The request was:

- To provide conceptual models for monitoring the estuary.
- To provide an overview of current monitoring programmes and their relationship with conceptual models.
- To provide a blueprint for an bilateral integrated monitoring programme that serves a) the general national requirements, b) the EU requirements and c) the license-driven monitoring goals.

The blueprint should give guidance on the design of a comprehensive status monitoring programme such that less effort in further effect monitoring is needed. Furthermore, the blueprint should advice on the improvement of the integration of legislative monitoring with the status monitoring network by streamlining their monitoring protocols.

The blueprint for the bilateral integrated monitoring programme is based on abiotic and biotic ecosystem components that do not only determine status and follow trends, but also give insight in processes and functions, and that adhere to legislative driven demands for effect monitoring. Recommendations are made on monitoring topics that deserve an in-depth redesign of the existing sampling scheme.

During the study regular meetings have been held with the project partners to discuss draft products. On 29 October 2014 a workshop has been held in Bad Nieuweschans, The Netherlands. About 30 participants discussed monitoring in the Ems estuary and gave suggestions for an improved monitoring network. A draft version of this report has been externally reviewed by three independent reviewers and the draft report has been discussed at a follow-up workshop on 23 April 2015.
2. STUDY AREA AND METHODS

2.1 The Ems estuary

The estuary of the River Ems is located at the border between the north-eastern part of The Netherlands and the north-western part of Germany. The most upstream boundary of the Ems estuary is fixed by the man-made weir at the German village Herbrum, which stops the tidal influence on the river. The downstream boundary is generally defined by the seaward barrier islands Borkum and Rotterumeroog. The length of the Ems estuary, including the tidal river, is approximately 100 km and the surface area is, excluding the ebb delta seaward of the island of Borkum, approximately 460 km² (De Jonge et al., 2014). The Ems-Dollard is a subsystem of the Ems estuary that starts at the German village Pogum where the Ems river widens into the semi-enclosed Dollard basin and extends to the barrier islands.

The Ems estuary forms an important navigation route. There are three harbours for sea-going vessels being Eemshaven, Delfzijl and Emden. An important river town is Papenburg with one of the world’s biggest shipyards for ocean cruisers, the Meyer Werft. These cruisers are built in covered docks that belong to the biggest in the world. Navigating these large ships (so far with a length to 330 m) to sea via the shallow and narrow Ems River became an ever-bigger challenge. In a carefully planned operation called “Emsüberführung”, the ships are towed to sea. To overcome the problem of shallow water depth, the Ems Sperrwerk (a barrier) at Gandersum is closed at high tide to dam up the river water so that a navigable depth of 8.5 m is reached. If necessary, water is brought in from the tributaries and or by pumping. This storm surge barrier was constructed between 1998 and 2002. For the purpose of navigation it is allowed to close the barrier only during winter months for a maximum of 104 hours per year and a maximum water level of 2.70 m above sea level.

The navigation channels to the harbours have been deepened a number of times in the past decades. Various papers in scientific journals have been describing physical changes due to channel deepening of the Ems estuary (e.g. De Jonge, 1983, 2000; DeGroodt and De Jonge, 1990; Schuttelaars et al., 2013; De Jonge et al., 2014). Moreover, various reports and literature overviews have provided insight in the chain of physical process reactions that have led to an increase in turbidity in the Ems (e.g. De Jonge, 1983; Talke and De Swart, 2006; De Jonge et al., 2014b; Van Maren et al. 2015). The effects related to the dredging activities (capital dredging and maintenance dredging) can be separated in two different parts being: a) the dredging operations in the main estuary between Emden and the North Sea coastal zone and b) the different deepening activities of the tidal river Ems since 1984.

A series of measures has been proposed to restore the ecological quality of the Ems estuary. For the Dutch-German Integrated Management Plan for the Ems estuary (IBP Ems) 54 measures were identified (Fachbeitragsgruppe 1 Natura 2000, 2014). For the Dutch research-programme Meerjaren Programma Infrastructuur Ruimte en Transport (MIRT) another 38 measures were proposed. This resulted in 92 measures that have been summarised in factsheets by Slijkerman et al. (2014). In The Netherlands, proposed measures focus on the realisation of a future target on:

1. Hydromorphological integrity. A complete and coherent hydromorphological system that offers the boundary conditions for estuarine processes, habitats and species.
2. Estuarine connectivity. Estuarine habitats are connected via gradients between land-sea and fresh water – salt water.
3. Primary productivity. There is sufficient productivity at the base of the food web.

Figure 1. Map of the study area with topographic names used in this report.
The Netherlands are considering measures to remove fine sediment in order to reduce the suspended matter concentration in the water column to increase primary production. Other measures aim at improvement of ecological connectivity and restoration of estuarine habitats and conditions. Last but not least, in 2015 the Masterplan Ems 2050 was signed, which lists the following measures (Masterplan Ems 2050, 2015):

1. Tide management on the tidal Ems river with the use of the Ems barrier
2. Tide management on the tidal Ems river with the installation of an inflatable weir at the Ems barrier.
3. Tide management on the tidal Ems river with a storage reservoir.
4. Restoration of 730 ha of river floodplain habitat and bird habitat.
5. Restoration of tidel habitat at Coldemünjtje.
6. Improvement of the ecological connectivity at the sluices of Knock, Oldersum and Herbrum.

2.2 Classification of monitoring efforts

In their review of the science and application of ecological monitoring, Lindenmayer and Likens (2010) give a practical and operational definition of long-term monitoring: “Repeated field-based empirical measurements are collected continuously and then analyzed for at least 10 years.” Lindenmayer and Likens (2010) show that the most effective monitoring programmes are those focused on well-crafted questions resulting in a study design, a set of attributes and an implementation approach that will be different in each monitoring program. They state that there is clearly not a one-size-fits-all approach to monitoring. Moreover, they propose to apply an Adaptive Monitoring framework (Lindenmayer and Likens, 2009) that evolves and develops in response to new information or new questions. Lindenmayer and Likens (2010) classify monitoring programs into three broad categories, being (I) curiosity driven or passive monitoring, which is devoid of specified questions or underlying study design and has limited rationale other than curiosity, (II) mandated monitoring where environmental data are gathered as a stipulated requirement of government legislation or a political directive with a focus to identify trends, and (III) question-driven monitoring, which is guided by a conceptual model and by a rigorous design that will typically result in a priori predictions that can be tested. We use an adaptation of this classification, where we do not recognise the category “passive monitoring”. Alternatively, we distinguish two subcategories for “mandated monitoring” in the Wadden Sea. We indeed distinguish broad, coarse-scale, long-term programmes leading to assessments of status and trends. In addition, we distinguish mandatory monitoring programmes designed to determine the effect of an activity or intervention on the status of the system required in permitting procedures. This is another type of monitoring that is mostly local, fine-scale and short-term, except for activities that show effects on large spatio-temporal scales, such as gas mining. Our third type of monitoring equals the question-driven monitoring to obtain a mechanistic system understanding, which is guided by a conceptual understanding of the system and a rigorous study design leading to fine-scale and often process-based measurements. In line with Lindenmayer and Likens (2010) we apply the core principles of the Adaptive Monitoring framework to be relevant to all types of monitoring – from very simple to very complex programs as well as from mandated monitoring programs usually conducted at a coarse-scale to site- or landscape-level, and curiosity-driven monitoring programs.

In this paper, we give an overview of presently running monitoring programs within the area including analyses of which programme falls within which category. There is, however, no Type III long-term question-driven monitoring carried out in the Ems estuary financed by scientific institutions.

2.3 Outline of this report

First, we provide a conceptual understanding of the functioning of Ems estuary, for which we elaborate on a division into subregions. Then we discuss a conceptual categorisation of long-term monitoring programmes. Third, we give an inventory of legally obliged monitoring programmes related to national, European and trilateral legal frameworks. Within the Ems estuary a suite of monitoring programs is or has been deployed, which often strongly vary in their aims, approach and the way the data and information is made available to others. Because the Ems estuary is a cross-bordering estuary, we make a comparison between the Dutch and German monitoring efforts. Fourth, we compare these efforts with a case study on mandated monitoring for Natura2000 permits. This involves the monitoring requirements for the permitting procedures in four initiatives, i.e. the realisation of a multiful fuel power plant by Nuon, a coal fuelled power plant by RWE, an LNG-terminal by Vopak Essent and the extension and deepening of the Eemshaven by Groningen Seaports. Fifth, we will, from a scientific point of view and against the background of ‘ecosystem based management’, make suggestions for further improving the current monitoring programmes so that we are able to assess the condition, state or health of the system. These results in a blueprint for a bilateral integrated monitoring approach in the Ems estuary.
3.1. Conceptual model description

The Ems estuary is a funnel-shaped alluvial estuary. Alluvial estuaries are estuaries that have movable beds, consisting of sediments of both riverine and marine origin, in which there is a measurable influence of fresh water inflow. The water moving in the estuary can either erode the estuary bed leading to deepening or widening or it can deposit sediments and make the estuary narrower or shallower. Hence, the shape of an alluvial estuary is directly related to the hydraulics of the estuary, which is extensively described by Savenije (2012). Alluvial estuaries have converging banks that can be described by an exponential function, Figure 2.

The Ems estuary, however, has an atypical planform. Following a number of storm surges in the 15th century and a major flooding on 26 September 1509, an unusually large water body evolved: the Dollard. Palaeographic maps of the Ems estuary show exponentially converging banks in 1250, the open water body of the Dollard in 1550, and the reclaimed lands in 2000 (Vos and Knol, 2013).

In an estuary fresh water from the river mixes with salt water from the sea. Generally, a distinction is made in three mixing types, i.e. a stratified type, a partially mixed type and a well-mixed type. The salt intrusion is generally regarded as well mixed when the stratification (the difference between the salinity at the water surface and the salinity near the bottom divided by their average) is less than 10% (Savenije, 2012), Figure 4.

In the Ems estuary mixing usually is strong, leading to a well-mixed type. The salinity gradient reaches until the river Ems confluences with the river Leda, just south of Leer, and is dependent on the river discharge. Figure 5 shows measurements of the salinity and suspended matter concentrations carried out for the BOEDE-project in the 1970s and reported in De Jonge and Brauer (2006).
In Figure 5 a maximum turbidity zone is depicted. This zone is also known as the Estuarine Turbidity Maximum (ETM). The difference in longitudinal salinity (the gradient) from the river to the sea can cause the tidally-averaged currents to flow landward along the bottom and seaward along the surface (the gravitational or estuarine circulation). The null zone is the region in the estuary where the residual, near-bottom, landward current reverses and flows in the seaward direction as a result of river inflow. In many estuaries, the null zone contains an estuarine turbidity maximum (ETM) where turbidity is largest. Although an ETM is a natural phenomenon in estuaries, the Ems estuary has become hyperturbid in the 1990s (van Maren et al., 2015) with concentrations up to 200 kg/m$^3$ (Papenmeier et al., 2013). The breakdown of organic matter in the fluid mud leads to a strong decline in dissolved oxygen levels (< 2 mg l$^{-1}$) in summer (Talke et al., 2009), which is detrimental to marine fauna.

In an ETM the primary production of phytoplankton is low due to light limitation. In the ETM region, therefore, the food web is largely dependent on allochthonous organic matter, i.e. imported from external sources. These sources drive secondary production in the form of mesozooplankton (mostly copepods), Figure 7.
An estuarine food web contains many more species and species interactions than shown in Figure 7. The most basic life forms are bacteria that decompose organic carbon. New carbon is produced from light and nutrients by primary producers such as phytoplankton, microphytobenthos and macrophytes. Their productivity feeds (functional groups of) benthos, zooplankton, fish, birds and sea mammals. A quantitative approach to study food web interactions is an ecological network analysis (ENA). Figure 8 presents an ENA for an intertidal system in the Wadden Sea (Baird et al., 2004).

In the lower–trophic level food web there are strong interactions between bacteria, primary and secondary producers and cycling of nutrients, detritus and atmospheric substances. Figure 9 shows these interactions for the European Regional Sea Ecosystem Model (ERSEM), which is a generic model for simulation of ecological fluxes throughout the seasonal cycle and across eutrophic to oligotrophic gradients (Baretta et al., 1995). When the lower–trophic food web of Figure 9 is extended to higher trophic levels and detailed with respect to vertical spheres, Figure 10 shows a conceptual diagram of food web components in an estuarine ecosystem for the anoxic sediment, oxygenated sediment, benthic-pelagic interface, pelagic zone and atmospheric zone.

Figure 8. Food web of Sylt-Rømø Bight, showing 59 compartments aggregated into an 18 compartments model. Numbers in bold face: aggregation numbers; numbers in brackets: original compartment numbers; thin arrows: interactions between compartments; thick arrows: pelagic interactions. Figure from Baird et al. (2004).
Figure 9. Conceptual diagram of the lower-trophic food web in the benthic, pelagic and atmospheric sphere. Figure from Allen et al. (2012).

Figure 10. Conceptual diagram of food web components in an estuarine ecosystem for the anoxic sediment (grey), oxygenated sediment (light brown), benthic-pelagic interface (green), pelagic zone (blue) and atmospheric zone (light blue).
The benthic-pelagic ecosystem is spatially distributed over the estuary and dependent on physico-chemical gradients in salinity, pH, suspended matter, depth, temperature, oxygen, pollutants and nutrients. These are partly governed by internal ecological processes and partly by external boundary conditions for irradiation, wind, tides, fresh water inflow, etc. Figure 11 shows an example of a conceptual coupled physical-ecosystem model for the Proudman Oceanographic Laboratory Coastal Ocean Modeling System (POLCOMS) in which ERSEM is coupled to the POL3DB hydrodynamic model (Allen et al., 2001; Holt and James, 2001).

Species of the higher-trophic level food web (i.e. fish, birds, mammals) are spatially distributed over the estuary landscape. Their life cycles are dependent on available habitats for foraging, spawning, breeding, resting etc. Furthermore, these species show active behaviour and they migrate through water and air or over land. A useful concept to describe habitat variety in a landscape are ecotopes (Klijn and Udo de Haes, 1994). The ecotope concept originates from Arthur Tansley, a British ecologist who also originated the ecosystem concept (Tansley, 1935). He defined an ecotope as a particular portion of an ecosystem by joining the term eco- (from the Greek “oikos” meaning home) with –tope (from the Greek “topos” meaning place) (Tansley, 1939, p. 228). A present day definition of an estuarine ecotope is a geographical unit homogeneous within limits for the most important hydraulic, morphological, and physico-chemical environmental factors that are relevant for biota (Dankers et al., 2012). Often the terms habitat and ecotope are used equivalent to each other, although habitat should be used as a species’ environment and ecotope as the full range of environmental and biotic variables affecting a species (Whittaker et al., 1973). An ecotope system for coastal and transitional waters with applicability for the Ems estuary has been developed by Rijkswaterstaat (Bouma et al., 2006), Figure 12.

On a high spatial aggregation level, the Ems estuary can be subdivided in a limited number of subregions reflecting the major spatial variation in structuring physical variables. An elaboration on the definition of these subregions is worked out in the next section.

Last but not least, human impacts and their management actions need to be included in the conceptual understanding of the Ems estuary. In 2000, Dutch Nobel Prize-winning chemist Paul Crutzen stated that humans have had such profound and far-reaching impacts on the earth’s ecosystems that we have ushered into a new geologic era – the Anthropocene. We now live in a human centered era where humans act as a force of nature. Living in the Anthropocene means that we have to deal with systems that emerge not only from an initial interplay of climate and geological processes, but also from dynamic interactions of society with nature. A human influence on the Wadden Sea has been present for centuries and has been greatly responsible for the present-day functioning (Lotze et al., 2005). Figure 13 presents the conceptual changes in the food web structure between more than 1,000 years ago and today.
Figure 12. Schematic ecotope classification for coastal and transitional waters. Figure after Kers et al. (2013). Each coloured section in the right table represents an ecotope classified by salinity, hydrodynamics, current velocity, emergence time, depth and mud content.

Figure 13. Conceptual changes in food web structure between more than 1,000 years ago (a) and today (b). The size and line code of boxes and arrows indicate the direction and magnitude of change. Arrows extending to the second or third trophic level (e.g., predatory fish or humans feeding on filter feeders) are not displayed. Figure from Lotze et al. (2005).
To describe the human influence on the coastal and estuarine landscape and related ecosystem functioning, the ecotope concept has a suitable spatial scale. Figure 14 shows a coupling of habitat to human functions as applied to the estuarine and coastal environment. Note that instead of the term habitat, we would prefer the term ecotope in this respect.

A conceptual integral description in which human factors of the economic system are coupled to natural factors of the ecological system is given by De Jonge et al. (2012)(de Jonge et al., 2012). Based on their integral framework De Jonge et al. (2012) recommend applying the DPSIR scoping framework for assessing causes, consequences, and responses to changes in the integral ecological-economic system, Figure 15.

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Based on the conceptual understanding of the Ems estuary we can work-out the components of an integrated monitoring program. Such a programme should cover natural as well as anthropogenic factors. Conform Vugtveen et al. (2014) we use the term ‘benefits’ instead of ‘impacts’ in the DPSIR framework. Main components of the program are:

1. The physical, physico-chemical and biological systems of the estuary including its ecotopes.
2. The socio-economic system in which human activities determine drivers and pressures (for instance underwater noise). The socio-economic system receives benefits (ecosystem services) and yields a management response resulting in legislation and regulation.

Figure 14. Description of potential habitat related properties and designated human activities to indicate the suitability of the habitat or ecotope level as the possible ecological and economic integration level. Figure from De Jonge et al. (2012).
Figure 15. Diagram representing the general structure of an integral ecological-economic system for influences of natural factors, indicated by dashed arrows, and of anthropogenic factors, indicated by solid arrows. D = driver, P = pressure to system, S = state change of system, I = impact to humans and R = the supposed human response. Figure adapted from De Jonge et al. (2012).

Figure 16. Conceptual diagram on the main components of an integrated estuarine monitoring program.
3.2. A definition of the main subregions in the Ems estuary

In long-term monitoring of a heterogeneous estuarine region such as the Ems estuary it is helpful to distinguish between subregions, reflecting the major spatial variation in structuring variables. This is important for the spatial distribution of monitoring stations. Moreover, when there is a lack of consistent boundaries between units, reaches or compartments it is difficult to analyse, interpret and compare data and trends for differing units. In this section an overview of different existing definitions for reaches and compartments is given in combination with their underlying motivations. Based on these results, we propose a subdivision that will guide the set-up of an integrated monitoring programme for the Ems estuary.

In scientific studies the Ems estuary is subdivided into a various number of reaches or compartments. Colijn (1982) for example distinguished nine compartments in the Ems-Dollard to measure light adsorption. Baretta and Ruardij (1988) distinguished five compartments for their ecosystem simulation model (Figure 17) and the BOEDE project applied a subdivision in three compartments “Outer”, “Middle” and “Dollard” (BOEDE, 1985).

An often used subdivision in Ems-Dollard studies was published in De Jonge & Van Beusekom (1992). They distinguish between three main areas, i.e. ‘Dollard’, ‘middle reaches’ and ‘lower reaches’, Figure 18. The boundary between Dollard and middle reaches is a virtual cross-section perpendicular to the main current close to the end of the Geise-Leitdamm to the base of Punt van Reide. The boundary between the middle reaches and lower reaches is formed by a virtual cross-section starting near the entrance of the Bocht van Watum at Nieuwstad, extending through a (former) channel that cuts the Hond-shallow in two, and continuing in a straight line towards Germany. The lower reach is defined by the tidal divides to Borkum and Rottumeroog and a virtual cross-section between these islands. In later studies a fourth main area was added, i.e. the upper estuary or the tidal river Ems (De Jonge et al., 2014; Schuttelaars et al., 2013).

The literature review of Spiteri et al. (2011) applied a subdivision into an ‘inner estuary’ and an ‘outer estuary’ that resemble the lower reaches and middle reaches respectively. The inner estuary is funnel-shaped, shallow, with one main channel and a secondary channel that has degenerated. The outer estuary is wave exposed (although all of the estuary is sensitive to wind and waves, see De Jonge and Van Beusekom, (1995)), has open boundaries with coastal waters and many small and large channels. Spiteri et al., (2011) place the border between the two on an arbitrary cross-section between Eemshaven and Greetsiel, locating it more seaward then De Jonge & Van Beusekom (1992) did.
Coumans et al. (2006) applied a subdivision into six compartments based on both physical barriers and boundaries from the Water Framework Directive (WFD), Figure 19. They distinguished 1. Unter Ems between Hebrum and Leer, 2. Unter Ems between Leer and Pogum, 3. Dollard south of the Geise-Leittdam, 4. From Pogum to the cross-section Delfzijl-Rysum, 5. From Delfzijl-Rysum to the seaward boundary of the transitional water, i.e. the cross-section Eemshaven-Pilsum as defined by the WFD, 6. From Eemshaven-Pilsum into the coastal water as defined by the WFD out to 1 nautical mile from the territorial baseline.

Figure 19. Six compartments in the Ems estuary based on physical barriers and WFD boundaries. Map from Coumans et al. (2006).
Compared to the final map of the Integrated River Basin Management Plan for the Ems, Figure 20, it seems that the seaward boundary of compartment 6 was chosen too far offshore by Coumans et al. (2006). Furthermore, the cross-section Delfzijl-Rysum was chosen rather arbitrarily south of Hond-Paap in order to include these flats entirely in compartment 5, but it should have been located more to the south to accomplish this.

The Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz (NLWKN) has made a subdivision of the Ems estuary for the Dutch–German Integrated Management Plan (IMP) Ems estuary. They distinguished four Natura 2000 zones, primarily based on salinity, i.e. polyhaline, mesohaline, oligohaline and limnic, Figure 21. The zones were chosen such that individual Natura 2000-areas within the zones were not cut in two. This zonation has led to deviations from the boundaries that were chosen for the water bodies and salinity zones under the WFD.

The differences between the boundaries of the official WFD water body typology and the boundaries of the four NLWKN Natura 2000 zones of the IMP Ems estuary are depicted in Figure 22. The outer estuary of the Ems is of the polyhaline coastal water type. It is delineated by two partly overlapping WFD coastal water bodies, a Dutch Eems-Dollard Kustwater (green with white boundaries) and a German Küstengewässer des Ems-Ästuars (blue with black boundaries). The disputed territory has a green colour. The Dutch Eems-Dollard Kustwater extends into the Waddenkust (blue with yellow boundaries), the Waddenzee vastelandskust (green with green boundaries) and the Waddenzee in between (green with yellow, green and white boundaries). The German Küstengewässer des Ems-Ästuars extends into the Wattenmeer der Ems (blue with light blue boundaries).

The brackish part of the Ems river is delineated by two partly overlapping transitional water bodies, a Dutch Eems-Dollard Overgangswater (yellow with white boundaries) and a German Übergangsgewässer Ems (yellow with black boundaries). The disputed territory has a brighter yellow colour. The transitional water ends in the Ems river just upstream from Leer at the confluence with the Leda, from whereon the river turns into a tidal fresh water river up to Herbrum. The tidal fresh water river forms the limnic zone (white with black boundaries) of the four salinity zones for Natura 2000. The oligohaline zone (light blue with black boundaries) runs from Leer to Pogum and is wider than the WFD transitional water body. The mesohaline zone (orange boundaries) runs from Pogum to a virtual transect between the harbour entrance to Delfzijl and the Knock sluice. The polyhaline zone (red boundaries) runs downstream to the extrapolated boundary of the Dutch designated Natura 2000 area under the Birds Directive 79/409/EEC. The Dutch Ems is proposed as habitat type 1130 under the Habitats Directive 92/43/EEC, but not officially designated yet.
Differences between the Natura 2000 zonation and the WFD water body zonation are:

1. The river floodplains are included in the Natura 2000 zonation, but not as WFD water body. Not all of the floodplains are designated as EU Natura 2000-area.
2. All saltmarshes on the German coast (including Dollard) are EU Natura 2000-area, but not included as WFD water body, whereas on the Dutch side the Dollard saltmarshes are part of both.
3. The Polder Breebaart in The Netherlands is EU Natura 2000-area, but not part of the WFD.
4. The Eemshaven and the harbour of Delfzijl are included as WFD water body, the harbour of Emden is excluded as WFD water body. They are all not included in the Natura 2000-area.
5. The Natura 2000 zonation boundary between the limnic and the oligohaline zones is delineated 1.2 km south of the boundary between the WFD fresh water and transitional water bodies.
6. The Natura 2000 zonation boundary between the oligohaline and the mesohaline zones is differing from the subdivision of the WFD transitional water body at Pogum.
7. The Natura 2000 zonation boundary between the mesohaline and the polyhaline zones is subdividing the WFD transitional water body at the harbour entrance of Delfzijl to Knock. Note that not all of the Ems marine waters is designated as Natura2000 area.
8. The Natura 2000 zonation boundary at the polyhaline end near Eemshaven differs from the boundary with the WFD coastal water body.
To define a final compartmentalisation into subregions, a number of considerations has been made. There is no discussion on the weir at Herbrum as the beginning of the Ems estuary. In accordance to the NLWKN Natura2000 zonation we have decided to include the floodplains of the tidal Ems river. The boundary between the freshwater and the brackish part is chosen in accordance with the transitional water boundary of the WFD. The boundary between the tidal Ems river and the Dollard is generally defined at Pogum, where the widening begins. We have chosen for the transect perpendicular to the river, similar to the subdivision of the WFD transitional water body at Pogum. The Dollard is defined as the region south of the Geiseleitdamm. Since this dam is permeable, there is exchange of water and sediment between the Emden Fahrwasser and the Dollard (De Jonge, 1992). This implies that the Dollard region can also be defined as a larger area including the Emden Fahrwasser.
However, the character of the Dollard south of the dam is significantly different, consisting mainly of intertidal areas. The decision then remains whether the Emden Fahrrwasser north of the dam should be seen as part of (an extension of) the tidal Ems river or as part of the inner estuary. Since there are no floodplains we have decided to make it part of the inner estuary. The boundary of the inner estuary with the outer estuary was chosen in agreement with the Natura2000 boundary, not the WFD coastal water boundary so that the Eemshaven becomes part of the outer estuary. The boundaries of the outer estuary with the Wadden Sea are located on the tidal divides and a cross-section between Rottumeroog and Borkum, in accordance to De Jonge and Van Beusekom (1992). This is not in agreement with the WFD boundaries, but fits better to hydromorphological characteristics.
Therefore, based on the WFD boundaries, the NLW-KN Natura2000 zonation boundaries, and in adherence to De Jonge and Van Beusekom (1992), we propose the following five subregions in the Ems estuary:

1. The tidal freshwater part of the river tidal Ems river, including floodplains, from the weir at Herbrum downstream to the boundary of the WFD transitional water located at the confluence with the Leda.
2. The tidal brackish part of the river tidal Ems river, including floodplains, downstream to Pogum at the subdivision of the WFD transitional water body at Pogum.
3. The Dollard south of the Geiseleitdam, including saltmarshes, delineated by a cross-section from the end of the Geiseleitdam southward to the base of the Punt van Reide at Fiemel.
4. The inner Ems estuary, from Pogum including the Emden Fahrwasser north of the Geiseleitdamm to the boundary between the mesohaline and polyhaline zone of NLWKN, i.e. the extrapolated cross-section for the Dutch designated Natura 2000 area under the Birds Directive.
5. The outer Ems estuary, from the extrapolated cross-section for the Dutch designated Natura 2000 area into the German WFD coastal water body of the Ems estuary and into the Dutch WFD transitional water body. The boundaries are defined by the tidal divides to Borkum and Rottumerooog and a virtual cross-section between these islands differing from the WFD boundaries.

Finally this leads to a division into five main subregions as depicted in Figure 24. It must be noted that transitional areas behind the dike such as brackish polders and nature areas, are also part of the Ems estuary. The outer boundaries should therefore be seen more fuzzy than crisp.

Figure 24. Conceptual division into five main subregions for the Ems estuary.
4. CLASSIFICATION OF MONITORING PROGRAMMES

4.1. Type I: Monitoring to assess status and trends

Type I monitoring focuses on determining the status and trends of the ecosystem. This type of monitoring typically includes long-term measurements of various (biological, physical, chemical) components. The spatial resolution is usually coarse (e.g., one station for weather conditions and water quality within a tidal basin), the temporal scale is long-term (over 10 years).

Type I monitoring provides the framework for a minimum package of measurements the Netherlands is compulsory to carry out under national or European legislation or treaties. There are four important European Directives that determine the monitoring of the Ems estuary. First and second, the Birds Directive (BD) and the Habitats Directive (HD), combined into Natura 2000 legislation, require a monitoring programme (e.g. Lengyel et al., 2008). Third, the Water Framework Directive (WFD) has monitoring and reporting obligations (e.g. Allan et al., 2006; de Jonge et al., 2006; Ferreira et al. 2007). And fourth, the Marine Strategy Framework Directive (MSFD) has monitoring requirements (e.g. Zampoulas et al., 2012). In addition to EU Directives, the Convention for the Protection of the Marine Environment of the North-East Atlantic (the ‘OSPAR Convention’) contains a general obligation to collaborate in regular monitoring and assessment of the state of the marine environment in the maritime area (e.g. Stagg, 1998; van Franeker et al., 2011). Last, but not least, the Trilateral Monitoring and Assessment Programme (TMAP), the common monitoring programme for the international Wadden Sea, combines the requirements of the European Directives and other relevant agreements (http://www.waddensea-secretariat.org/monitoring-tmap).

Natura 2000, Birds Directive (BD) & Habitats Directive (HD)

In accordance with Article 6 (1) of the Habitats Directive 92/43/EEC, for special areas of conservation, Member States shall establish the necessary conservation measures involving, if need be, appropriate management plans. Article 11 requires Member States to undertake surveillance of the conservation status of the natural habitats and species. Article 17 requires that every six years Member States shall draw up a report on the implementation of the measures taken under this Directive. This report shall include in particular information concerning the conservation measures referred to in Article 6 (1) as well as evaluation of the impact of those measures on the conservation status of the natural habitat types of Annex I and the species in Annex II and the main results of the surveillance referred to in Article 11. In the Netherlands it has been decided that a monitoring plan is part of the management plan for the Natura 2000-area Wadden Sea (Rijkswaterstaat, 2014a).

The objectives of the Natura 2000-monitoring are twofold, namely (1) Monitoring to evaluate the conservation status, and (2) Monitoring to evaluate the implementation and impact of conservation measures in and around the Natura 2000-area.

In addition, the information provided by the monitoring programme can be of major importance for the authorization of new activities in the Natura 2000-area, for instance for use in an appropriate assessment. However, it must be noted that the requirements of the monitoring programme are basically targeted to the conservation goals of the management plan. A dedicated monitoring plan might be necessary to measure the effect of an activity on Natura 2000-areas.

The monitoring programme for Natura 2000 focuses on protected habitats and species. The responsible authority for the monitoring programme of Natura 2000-area Wadden Sea is the Ministry of Infrastructure and the Environment. The monitoring plan for the Wadden Sea has not been established yet, the latest
The designation of the Dutch part of the Ems estuary as Special Protection Area under the Habitats Directive is not completed. Large regions in the German part of the Ems estuary are already designated (NLWKN, 2008).

**Water Framework Directive (WFD)**

In accordance with Article 8(1) WFD; 2000/60/EC, Member States have to establish monitoring programmes for the assessment of the status of surface water and of groundwater in order to establish a coherent and comprehensive overview of water status within each river basin district. The WFD specifies three types of monitoring, i.e. surveillance monitoring, operational monitoring and investigative monitoring (Ferreira et al., 2007). Of these, the long-term based surveillance monitoring provides a broad understanding of the health of water bodies and tracks slow changes in trends such as those resulting from climate change. The essential biological parameters in the monitoring programmes include phytoplankton, larger water plants, bottom-living invertebrate animals and fish. According to the WFD, its monitoring programme was operational by 22 December 2006 at the latest.

**Marine Strategy Framework Directive (MSFD)**

Only recently the Marine Strategy Framework Directive (MSFD; Directive 2008/56/EC) came into play in the Ems estuary. The MSFD applies to all marine waters extending from the territorial baseline to the outmost reach of the area where a Member State has and/or exercises jurisdictional rights. The territorial baseline is the line from which the breadth of territorial waters is measured. Information on the delimitation of maritime boundaries is found at the deposits of UNCLOS, the United Nations Convention on the Law Of the Sea (Liquete et al., 2010). Marine waters under the MSFD also include the “coastal waters” as defined under the Water Framework Directive. Coastal waters are defined as “surface waters on the landward side of a line, every point of which is at a distance of one nautical mile on the seaward side from the nearest point of the baseline from which the breadth of territorial waters is measured, extending where appropriate up to the outer limit of transitional waters”. Transitional waters do not fall under the MSFD unless for those parts that extend seaward beyond the European 1 nautical mile line (Liquete et al., 2010).

Germany and Denmark have defined and established a landward limit for the implementation of the MSFD (Wadden Sea Board, 2012). The limit has been set at the mean high water (MTHW = mean tidal high water) and thus includes the Wadden Sea. In the Danish marine strategy it has been decided to implement the MSFD in the Wadden Sea conservation area in overlap with the WFD. Where there is an overlap between the two directives, the Water Framework Directive applies, while the Marine Strategy Framework Directive applies to all descriptors that are not covered by the Water Framework Directive, e.g. marine litter and noise. Germany also applies all eleven descriptors of the MSFD within the Wadden Sea (blue with light blue boundaries in Figure 22). Transitional water bodies of the WFD are excluded from the scope of MSFD within Germany (Wadden Sea Board, 2012). This means that the MSFD does not apply to the Ems estuary inwards from the line Eemshaven to Pilsum that forms the boundary between the transitional water body and the coastal water body (at the difference between blue and yellow in Figure 22). The Dutch government question if there is a need for establishing an MSFD landward limit (Wadden Sea Board, 2012). Based on UNCLOS and Dutch legislation implementing UNCLOS, the waters of the Wadden Sea are internal waters. The MSFD does not apply to internal waters as defined under UNCLOS since these internal waters are situated on the landward side of the baseline of the territorial sea. This means that the MSFD does not apply to the Dutch Wadden Sea, but does apply to the Dutch WFD Waddenkust Sea (blue with yellow boundaries in Figure 22). The MSFD includes a requirement to adopt specific and standardized methods for monitoring and assessment (Borja et al., 2010). All blue parts in Figure 22 fall under the MSFD.

**OSPAR**

The 1992 OSPAR Convention contains a general obligation to collaborate in regular monitoring and assessment of the state of the marine environment in the maritime area. The Convention provides for cooperation in monitoring programmes, joint quality assurance arrangements, the development of scientific assessment tools, such as modelling, remote sensing and risk assessment strategies, and the preparation of assessments. Environmental assessment and monitoring related work is implemented for each of OSPAR’s five thematic strategies (the Biodiversity and Ecosystem Strategy, the Eutrophication Strategy, the Hazardous Substances Strategy, the Offshore Industry Strategy and the Radioactive Substances Strategy). A sixth strategy is a Joint Assessment and Monitoring Programme (JAMP). The JAMP assesses the status of the marine environment, checks on progress with the implementation of the strategies, and evaluates the resulting benefits to the marine environment (Johnson, 2008).

In 2010 the Ministerial Meeting of the OSPAR Commission adopted a renewed Strategy for the Joint Assessment and Monitoring Programme (JAMP) for the period 2010 to 2014. This provides a framework for
work to develop OSPAR’s monitoring and assessment programmes, with a particular focus on supporting the work to implement the EU Marine Strategy Framework Directive. The core marine environmental monitoring activity under the JAMP is the OSPAR Coordinated Environmental Monitoring Programme (CEMP). The CEMP is currently focussed on monitoring of the concentrations and effects of selected contaminants and nutrients in the marine environment (OSPAR, n.d.).

**TMAP**

The Trilateral Monitoring and Assessment Programme (TMAP) is the common monitoring programme for the Wadden Sea carried out by The Netherlands, Germany and Denmark (http://www.waddensea-secretariat.org/monitoring-tmap). The programme covers the entire Wadden Sea area including islands and offshore areas and spans a broad range, from physiological processes over population development to changes in landscape and morphology. The TMAP common package was implemented based on a decision at the Ministerial Conference in Stade, 1997. In 2012, a long term TMAP strategy and a TMAP vision was issued (TMAP, 2012).

**4.2. Type II: Monitoring as part of effect studies for activities or interventions**

Type II monitoring is part of (often legally-forced) effect studies that are set up to examine the impacts of human activities that are potentially harmful (e.g., fisheries, dredging) or beneficial (e.g., restoration programs) for natural values of an estuary such as the Ems.

For the design and set-up of Type II monitoring, it is important to know the precision, or statistical significance, one wants to demonstrate an effect with. Usually this leads to an increase in the density and frequency of measurements compared to Type I monitoring. This type of monitoring is usually temporary and short-term (<10 years) although monitoring periods of longer than 10 years can be prescribed. Ideally, the additional measurements follow a similar protocol as Type I monitoring, or should at least made comparable and connectable.

The conceptual description of the ecosystem along which the monitoring is designed in Type II monitoring is given by the juridical description of protected species, conservation goals and environmental objectives. Conceptually, a hypothesis is tested that a proposed activity will, or will not, harm the objectives set by legislation.

**Natura2000**

Natura2000 provides conservation objectives for certain habitats and species. In accordance to Article 6(3) “Any plan or project not directly connected with or necessary to the management of the site but likely to have a significant effect thereon, either individually or in combination with other plans or projects, shall be subject to appropriate assessment of its implications for the site in view of the site’s conservation objectives.” The competent authority that provides the permit may impose surveillance requirements to monitor the trends and developments in habitats and species associated to the plan or project. For example, an extensive monitoring scheme was set up for gas mining underneath the Wadden Sea. Gas mining without ecological damage was deemed possible. However, as an extra security it was advised to employ the “hand on the tap” principle: monitoring the status and trends in sensitive species and habitats. In the case of unwanted effects, the minister could then stop mining (Runhaar and van Nieuwaal, 2010).

**Water Framework Directive (WFD)**

In WFD terminology, Type II monitoring is best described by operational monitoring. Operational monitoring focuses on water bodies that do not meet good status, and on the main pressures they face. Operational monitoring aims at providing additional and essential data on water bodies at risk or failing environmental objectives of the WFD (Allan et al., 2006). Operational monitoring has an emphasis on the relationship between drivers, pressure, state and response (Ferreira et al., 2007).

Figure 26. Measurements of the effect of an activity or intervention on the status of the system focusing on a local increase in density and frequency of measurements for various ecosystem components. Colours can be seen as examples for measurement stations for hydrography (blue), benthos (yellow) and salt marshes (green).
4.3. Type III: Monitoring for mechanistic system understanding

Type III monitoring is characterised by a large effort in space and time, i.e. many stations in high frequency and over a long-term period. This type of monitoring also requires new components to be determined in specialized sampling lay-outs. Furthermore, it is essential to measure in a larger area while also taking boundary conditions into account.

Whereas Type II monitoring establishes the status of the ecosystem, type III focuses on processes and system understanding (e.g. Philippart et al., 2000). Knowledge of the processes and causal relationships in ecosystems is a prerequisite for explanation of observed changes in status. This monitoring will reveal the underlying causes for change and obtains a better insight into the autonomous developments and the effectiveness of measures. This helps in decision-making on management and protection of the estuary.

This type of measurements often requires a higher spatiotemporal resolution, for instance to intentionally seek a gradient in values or between extreme values. This also requires measures that are aimed at validating model parameters. It involves a wider set of measured parameters, including fluxes of matter and energy, exchange rates, population dynamics, etc.

Water Framework Directive (WFD)

In WFD terminology, Type III monitoring is best described by investigative monitoring. WFD investigative monitoring is interpreted as applied research (J G Ferreira et al., 2007). Member States undertake investigative monitoring when they need further information about surface water bodies that cannot be obtained via operational monitoring, including information on accidents.
5. Monitoring Programmes to Assess Status and Trends – Type I

5.1 Legal obligations for monitoring

The Dutch and German Type I monitoring programmes of the Ems estuary obey the following conventions, directives and agreements (Table 195 of Fachbeitragsgruppe 1 Natura 2000 (2014))

- **KRW**: Kaderrichtlijn Water / WRRL: Wasserrahmenrichtlinie. Monitoring requirements for the EU Water Framework Directive on hydrology, morphology (substrate and bathymetry), chemical substances and physical-chemical status, toxic substances in sediment, as well as the biotic components seagrass distribution and cover (eulittoral and sublittoral), macrozoobenthos and fish.

- **HR**: Habitatrichtlijn / FFH-RL: Fauna-Flora-Habitat-Richtlinie. Monitoring requirements for the EU Habitats Directive on morphology (substrate and bathymetry for habitat typology) and assessment of the state of European habitats, including quality elements such as seagrass (eulittoral and sublittoral), macrozoobenthos, musselbeds and fish.

- **OSPAR**: Oslo and Paris convention. Monitoring requirements on hydrology, chemical substances in water and sediment, seagrass (eulittoral and sublittoral), macrozoobenthos, musselbeds, and fish. The Convention has been signed and ratified by 15 European nations and the European Community.

- **TMAP**: Trilateral Monitoring and Assessment Program. Monitoring requirements on hydrology, morphology (substrate and bathymetry), chemical status, toxic substances in sediment, assessment of the state of habitat types, seagrass (eulittoral and sublittoral), macrozoobenthos, musselbeds, breeding birds, contaminants in eggs, and non-breeding birds. The TMAP is carried out by national and regional authorities of Denmark, Germany, Schleswig-Holstein, Hamburg, Lower Saxony and The Netherlands.


- **ASCOBANS**: Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas. No monitoring requirements were listed, but monitoring contributes to the protection of marine mammals. In 2015, ASCOBANS has 10 European parties that signed the agreement (http://www.ascobans.org/en/parties-range-states).

- **Trilateral agreement on the Conservation of Seals in the Wadden Sea**: Under the umbrella of the Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention) a trilateral Seal Agreement has been concluded between Denmark, Germany, and the Netherlands. The policy and management of common and grey seals and porpoises in and around the Wadden Sea is set in the five-year Seal Management Plan (SMP), which was prepared by the Trilateral Seal Expert Group (TSEG) and approved by the responsible Ministers the three Wadden Sea countries.

- **AEWA**: Agreement on the Conservation of African-Eurasian Migratory Waterbirds. Monitoring requirements on breeding birds and non-breeding birds. AEWA has 26 African and 39 Eurasian parties and is focussing on 255 species of waterfowl.

- **Schelpdierwaterrichtlijn / Schelpewasserrichtlinie**: The EU Shellfish Directive concerns the quality of shellfish waters and applies to those coastal and brackish waters designated by the Member States as needing protection or improvement in order to support shellfish (bivalve and gastropod molluscs) life and growth and thus to contribute to the high quality of shellfish products directly edible by man.

- **Zwemwaterrichtlijn / Badegewässerrichtlinie**: The EU Bathing Water Directive enables water monitoring and management measures to be improved, and information to be made available to the public, about any element of surface water where the national authorities of a Member State expect a large number of people to bathe or have not imposed a permanent bathing prohibition, or issued permanent advice against bathing.
5.2 Current monitoring programmes in Germany and The Netherlands

The monitoring programmes in the Ems estuary that provide data for the above mentioned conventions, directives and agreements are all Type I programmes. They are carried out by different institutions:

5.2.1. Germany

1. The “Gewässerüberwachungssystems Niedersachsen” (GÜN) is carried out by the Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz (NLWKN). Since 1980, this monitoring network supplies data on the quantity and quality of precipitation, groundwater, surface waters and coastal waters of Niedersachsen. With regard to coastal waters, this programme is primarily focusing on the requirements for the WFD and is also providing data for the OSPAR Coordinated Environmental Monitoring Program as well as TMAP (NLWKN, 2013).

2. The “Erfassungsprogramme im Naturschutz” is a continuous, systematic, long-term monitoring programme in Niedersachsen on flora, fauna and biotopes. The NLWKN is co-ordinating four acquisition series on species and biotopes in which more than 3000 volunteers operate: vegetation, birds, biotopes and all other species. Vegetation maps of coastal biotopes are worked-out following the EU habitat typology (Drachenfels, 2014).

3. The “Kooperationsprogramm Naturschutz” is carried out under the responsibility of the Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz (NMUEK). The programme is financing voluntary measures for nature conservation mainly in Natura-2000 areas of Niedersachsen and is divided in four sections: agricultural land, special habitat types, permanent grassland and northern wintering and migratory birds. The programme results in maps of agricultural buffer strips, conservation areas and biotopes for specific species and habitat types, including those that lie at the border of the Ems estuary (NMUEK, 2014).

4. The “Niedersächsische Meeresüberwachung” is operated by NLWKN and the National Park Administration Wadden Sea. It is part of the federal / state-wide monitoring programme for the North and Baltic Sea named “Bund-/ Länder-übergreifende Messeprogramme für die Nord- und Ostsee” (BLMP). Following the requirements of relevant marine directives and agreements, the BLMP is coordinating on monitoring concepts and the allocation of work to the specialized services provided by the federal and local governments. The BLMP was founded on 17 April 1997 at the 34th Conference of Environmental Ministers of northern Germany and reorganized in its basic structure in 2007. The programme is based on the requirements of the EC Water Framework Directive, Marine Strategy Framework Directive, Habitats and Birds Directives, and the marine protection conventions (OSPAR, HELCOM, TMAP) and other regulations. Hence, the seafloor and coastal waters are investigated on biological parameters, physico-chemical parameters, sediment texture, and the contamination of sediments and organisms. These tasks are carried out in individual monitoring programmes of the partners. Detailed information can be found in the BLMP Monitoring Manual (BSH, 2014) or http://www.blmp-online.de/.

5. The “Niedersächsischer Landesamtes für Verbraucherschutz und Lebensmittelsicherheit (LAVES)” is responsible for monitoring fish fauna for the WFD. Measurements take place every two years in three locations in the Ems, i.e. at Krummhörn, Oterdum and Terborg with the use of stow nets (NLWKN, 2010). The actual fishing is carried out by a subcontractor, Bioconsult. LAVES is also responsible for seal counts in the Ems estuary.

6. The “Wasser- und Schifffahrtsamt Emden” is responsible for the development and maintenance as well as for the order and security of shipping traffic on the waterway between Papenburg and Emden and further out to the islands of Borkum to Spiekeroog. Navigational depth in the Ems estuary is measured at least once a year with echosounding. Several fixed water level measurement stations are maintained in the Ems estuary.

7. The “Bundesamt für Seeschifffahrt und Hydrographie (BSH)” is responsible for monitoring physical quantities in the North and Baltic Sea. This is done with permanently installed monitoring networks for temperature, salinity, direction and speed of currents and water levels. The BSH is also determining the (physico-chemical) quality of surface waters and sediment for the BLMP.

8. The “Bundesministerium für Ernährung und Landwirtschaft (BMEL), Johann Heinrich von Thünen-Institut (Bundesforschungsinstitut für Ländliche Räume, Wald und Fischerei)” is responsible for monitoring and sustainable management of fish, crustaceans and molluscs. The Thünen-Institut also deals with questions concerning the conservation and protection of marine mammals and birds, the distribution and effects of pollutants in the sea, and the impact of aquaculture on the aquatic environment.
5.2.2. The Netherlands

The monitoring programmes in The Netherlands that provide data for the above mentioned conventions, directives and agreements are carried out or coordinated by different institutions:

1. The "Monitoring Waterstaatkundige Toestand des Lands" (MWTL) is carried out under the responsibility of Rijkswaterstaat (RWS), which is part of the Ministry of Infrastructure and the Environment. It is a national environmental monitoring programme for hydrochemistry, hydrobiology and geomorphology. In marine waters it focuses on height (lidar) and bathymetry, contaminants in fish, shellfish and bird eggs, chemical parameters in surface water and sediment, phytoplankton, macrozoobenthos, seagrass and birds (Rijkswaterstaat, 2014b).

2. The "Landelijk Meetnet Water" (LMW) is carried out under the responsibility of Rijkswaterstaat. LMW is a facility that is responsible for the acquisition, storage and distribution of abiotic water data. In over 400 locations measurements are made of discharge, water level, wave height and direction, flow velocity and direction and water temperature.

3. The "Netwerk Ecologische Monitoring" (NEM) is a partnership between government (Ministry of Economic Affairs, Ministry of Infrastructure and the Environment (Rijkswaterstaat and PBL), provinces and the Central Bureau for Statistics (CBS). The major part of the collection of data is carried out by volunteers, under coordination of Private Data Management Organisations (PGOs). The NEM focuses on flora and fauna such as terrestrial mammals, bats, birds, fish, reptiles, amphibians, butterflies, dragonflies, beetles, marine invertebrates, plants, lichens and mushrooms.

4. The "Wettelijke Onderzoeks Taken" (WOT) is carried out under the responsibility of the Ministry of Economic Affairs. Two programme units are relevant for marine waters. The "WOT Natuur & Milieu" ensures the implementation of legal monitoring tasks for Nature & Environment. Since 2014 the unit it is coordinating NEM. The "Centrum voor Visserij Onderzoek (CVO)" provides management advice on fisheries and collection of data on fishing and fish stocks. WOT measurements in the Dutch Wadden Sea focus on seals, demersal fish, macrozoobenthos in particular shellfish, and salt marshes and are deployed by IMARES Wageningen UR.

In The Netherlands there is also the “Subsidy system Nature and Landscape” (SNL), which are provincial subsidies. Owners and nature management organisations receive subsidies for management and nature development of natural and cultural landscapes. Subsidies are also available for monitoring as well and data contributes to Natura2000 monitoring requirements. The focus is on terrestrial ecotopes, but salt marshes are included. There are no long-term records yet that derive from SNL, therefore this monitoring is not included here.
5.3 Monitoring in The Netherlands and Germany compared

An overview and comparison of monitoring that is relevant for the Ems estuary is given below. The programmes listed here are all embedded in legal frameworks except for the SIBES programme of NIOZ. The SIBES programme is financed by NIOZ and the Nederlandse Aardolie Maatschappij BV (NAM). However, for completeness this programme is listed as well.

**NETHERLANDS**

**Hydrography**
In the LMW programme several hydrographical parameters (water levels, current velocities, wave heights) are measured from fixed measurement poles or wave buoys.

Fixed water level stations in the Ems estuary are located at Nieuwe Statenzijl (subregion 3), Delfzijl (subregion 4) and Eemshaven (subregion 5). Wave buoys are all located in subregion 5: Oude Westereems Zuid, Oude Westereems Noord, and Ranzelgat Noord.

**Hydrochemistry**
In the MWTL programme several hydrochemical parameters (suspended matter, nutrients, oxygen, toxic constituents) are determined from samples from surface waters and sediment. In 2014 there were 10 measurement stations existing in the entire Dutch Wadden Sea. Sampling frequency varies from 12 to 19 times per year for surface water. The Ems estuary has four measurement stations that are sampled 19 times annually, Table 2. Sediment is sampled twice in a 3-yearly cycle. In 2014 the sediment has been sampled (Rijkswaterstaat, 2014b). In the 1970s and 1980s there were 33 sample locations in the Ems-Dollard, but since the 1990s the number of measurement stations has been declining (de Jonge et al., 2006b; Jager et al., 2009).

**Pollutants**
Pollutants in water and sediment are monitored in the hydrochemistry programme of MWTL in four stations, Table 1. Rijkswaterstaat is also responsible for measuring pollutants in bird eggs of Oystercatcher or Common tern for TMAP. The analysis of chemical contaminants is carried out by the

**GERMANY**

**Hydrography**
The Wasser- und Schifffahrtsamt Emden measures water levels in the Ems estuary at 24 locations.

The hydrographical Station Ems of MAR-NET (Marines Umweltmessnetz in Nord- und Ostsee of the BSH) is located far offshore (54°10’N, 06°21’E).

**Hydrochemistry**
Four stations in Ems estuary: 1 in I, 2 in II and 1 in V. Analysis of nitrite+nitrate, ammonium, ortho-phosphate, silicate, DOC, TP, and TN. Sampling frequency differs between weekly, 2-weekly or once per quarter.

**Pollutants**
Three (combined) stations for pollutants in sediment: one in subarea I (Herbrum Schleuse Unterwasser), one (three combined) in subarea III (Ems-Dollart Sediment A B C) and one (three combined) in subarea V (Borkum Sediment A B C). Two stations for pollutants in water: one in II (Terborg Pegel), one in IV.
Institut für Vogelforschung (IfV) in Wilhelmshaven. In the entire Dutch Wadden Sea there are five measurement locations of which one is located in the Ems estuary at the shipping channel of the port of Delfzijl.

**Bathymetry**
The bathymetry of the Dutch Wadden Sea is determined by singlebeam depth soundings every six years in the MWTL programme. The transect width is 200 m. Each year a subarea of the Wadden Sea is surveyed, the Ems-Dollard was covered in 1985, 1990, 1995-1997, 2001-2002, 2008 (Grasmeijer and Pasmans, 2013) and the latest bathymetric survey of the Ems-Dollard took place in 2014. A next survey is planned for 2020. The height of coastal dunes and beaches is determined yearly by a combination of lidar and depth soundings.

**Substrate**
In the SIBES research and monitoring programme sediment is sampled annually on a regular grid of 500 x 500 m in the intertidal areas of the Dutch Wadden Sea. The substrate composition in the subtidal parts of the Dutch Wadden Sea are determined twice per year in a 3-yearly cycle in the MWTL programme, see the paragraph on hydrochemistry.

NLWKN is measuring pollutants in bird eggs for TMAP in sampling station Dollart. Pollutants in Blue Mussel are monitored at Borkum.

**Bathymetry**
Singlebeam and multibeam echosound depth soundings in the sublittoral zone - terrestrial and laser scan surveying in the eulittoral zone. If possible combined with side-scan-sonar investigations.

A full bathymetric map of the Ems estuary was made by the WSA Ems every five years in 2005, 2010 and 2015.

**Substrate**
Sediment is appraised/designated firstly as a supporting parameter in the context of the investigation of benthic biotic communities using grabs, sediment cores and samples taken by divers/dip sampling. Secondly, whole water bodies are mapped with what is practically an area-wide approach using hydroacoustic and remote sensing procedures, as well as targeted in situ sampling.

At present, the surveillance monitoring of substrates in the coastal and transitional waters of Germany’s river basin districts does not comply with the prescribed minimum cycles of six years (BSH, 2014).

Both organogenic and clastic components, seabed-physical parameters such as roughness (surface structure) and hardness (density, compaction), the rheological properties of the substrates and, sometimes, suspended load are investigated during the monitoring of the seabed’s structure, the substrate and, in transitional waters, the quantity of the substrate.
Benthos

**Benthos survey Wadden Sea and Ems-Dollard – MWTL.** Benthic survey on 9 littoral transects and 3 sublittoral transects in the Wadden Sea, since 1991. Sampling in spring and autumn. Frequency is once every three years, annually in Dollard. Per transect 10-20 samples.

Phytoplankton

**Phytoplankton** is determined in the water samples of the MWTL hydrochemical programme, see the paragraph on hydrochemistry. The Ems estuary has four measurement stations, Table 2. Chlorophyll-a concentrations are determined 19 times each year. Phytoplankton counts are determined 14 times per year in summer using flow cytometry and microscopic inspections.

Seagrass

Monitoring of seagrass in the Wadden Sea is part of the MWTL programme of Rijkswaterstaat since 1991. Since 2005, the monitoring consists of a combination of aerial and field surveys. Since 2011 the field survey changed from an area approach to a transect approach, without the aid of aerial photo interpretation. Potential seagrass habitats are systematically monitored in August or September by walking transects of several kilometres. In each 20x20 m grid cell the cover of seagrass is estimated, and this information is used to construct a distribution and cover map of different seagrass species. As from 2011, Rijkswaterstaat reduced the monitoring frequency for benthic invertebrates under the WFD is three years, yearly is recommended.

Seagrass

Comprehensive surveying by means of overflights (aerial survey) in combination with field mapping every six years. The flights are carried out three times a year in summer (if possible in June, July and August) in order to ensure that the maximum seagrass and macroalgae coverage is surveyed in the course of the year to be used for assessment. The aircraft flies at an altitude of 300 to 500 m. During the flight, three independent observers enter the corresponding populations on Wadden Sea maps. Annual sampling of selected seagrass meadows (permanent monitoring units) to validate aerial data, and surveying the annual variability of the seagrass within the six-year period and characteristic supporting parameters (including species composition, density, quantity of epiphytic algae, biomass). Two stations for seagrass and macroalgae are located on the Hond-Paap.

Phytoplankton

**Phytoplankton** is determined in the water samples of the MWTL hydrochemical programme, see the paragraph on hydrochemistry. The Ems estuary has four measurement stations, Table 2. Chlorophyll-a concentrations are determined 19 times each year. Phytoplankton counts are determined 14 times per year in summer using flow cytometry and microscopic inspections. For these reasons, and in accordance with the current state of knowledge, it does not appear expedient to monitor the ecological status of a type 1 transitional water area using phytoplankton. (ARGE Elbe, 2005 and Ad-hoc-Working Group on Nutrients & Phytoplankton).

Benthos

**Benthos** survey Wadden Sea and Ems-Dollard – MWTL. Benthic survey on 9 littoral transects and 3 sublittoral transects in the Wadden Sea, since 1991. Sampling in spring and autumn. Frequency is once every three years, annually in Dollard. Per transect 10-20 samples.

Phytoplankton

One station in Ems estuary: in V. Phytoplankton is quantified microscopically in sedimentation chambers and Petri dishes (Phaeocystis colonies). Chlorophyll-a content is determined as a measure of biomass. Transitional waters are characterised by high concentrations of suspended matter and wide fluctuations in salinity, which worsen the growth conditions for phytoplankton. For these reasons, and in accordance with the current state of knowledge, it does not appear expedient to monitor the ecological status of a type 1 transitional water area using phytoplankton. (ARGE Elbe, 2005 and Ad-hoc-Working Group on Nutrients & Phytoplankton).
are taken with a hand corer. The Ems-Dollard transects are located on Heringsplaat, Dollard (subarea 3).

**Littoral shellfish survey – WOT IMARES.** Annual inventory of littoral shellfish stocks in the Dutch Wadden Sea (WOT mussel and cockle survey) running since 1990. Various sampling gears are used depending on tidal state: either a specially modified hydraulic dredge (sampling area 0.42 m²), a handheld cockle-sampling device (sampling area 0.033 m²) or at low tide with a corer (diameter 24.4 cm). All gears sample the top 10 cm, and a total surface area of ~0.8-0.1 m² is taken in each case (multiple samples per stations, depending on gear type). Samples are sieved using a 5 mm sieve, and for each species density and biomass is determined. A stratified sampling grid is used; distance between sampling points is smaller in those places where a higher density of the target species (mussels and/or cockles) is expected. Additional information, for instance on age or size classes, as well as occurrence of other species is collected.

Sampling transects are located in the Dutch parts of the Inner Ems estuary (subarea 4) and on the Dutch mudflats in the estuary mouth (Outer Ems estuary, subarea 5).

**Litoral shellfish banks – WOT IMARES.**

This survey maps the contours of littoral banks of mussels and oysters in the Dutch Wadden Sea since 1995 for the WOT-programme. Prior to the survey, an inspection flight is carried out to assess the greatest changes in extent. Then a field visit follows. Contours are recorded on foot with a handheld GPS. Coverage percentages to be visually estimated. Banks do not qualify when percent coverage is less than 5%.

A selection of banks is visited annually for detailed analysis on the structure of the banks (age distribution, morphology, vertical layers, etc.). Two or three of these banks are located south of Rottum, just within subarea 5.

The contours of all shellfish banks present are recorded from the Inner Ems estuary (subarea 4) and on the Dutch mudflats in the estuary mouth (Outer Ems estuary, subarea 5). No record is known in the Dollard.

**SIBES survey - NIOZ.** Benthic infauna is sampled on a regular grid of 500 x 500 m with

**Eulittoral: Sediment samples are taken using box corers or piston corers. Sublittoral: Van Veen grab or dredge. In future, greater use should be made of sonar systems/video techniques for supporting purposes.**
10% random locations in littoral areas since 2008, Ems-Dollard since 2009. Locations to be visited on foot or by boat. At sites visited by foot one sample per station is taken, with an area of 0.0177 m² to a depth of 25 cm. At sites visited by boat two samples per station are taken, with a total area of 0.0173 m² to a depth of 25 cm. Samples are sieved over a 1 mm sieve. Large shellfish are separated and frozen, the rest of the sample is kept in a 4% formalin solution. Sediment is sampled on a regular grid of 500 x 500 m (in 2008 1 x 1 km). A sediment core is taken from one sample for each location to a depth of 4 cm. Sampling locations in the Ems-Dollard are located in the Dutch tidal parts of the outer and inner Ems estuary (subareas 4 & 5) and Dollard (subarea 3).

**Birds**
Monitoring of breeding birds, resting birds and beached birds in the Ems estuary is carried out as part of the BLMP by the NLWKN and Nationalpark Niedersächsischen Wattenmeer. The Joint Monitoring of Breeding Birds (JMBB) as part of TMAP started in 1989. It consists of annual surveys of the colonial and rare breeding birds and annual counts in the census areas. Every six years a complete census of all selected species in the entire Wadden Sea during the breeding season is coordinated.

**Fish**
The most comprehensive monitoring programme for fish in the Dutch Wadden Sea is the Demersal Fish Survey by IMARES running since 1969. The Dutch Demersal Fish Survey (DFS) is part of an internationally co-ordinated inshore survey carried out by The Netherlands (DFS), UK (Young Fish Survey-YFS), Belgium (Demersal Young Fish Survey-DYFS) and Germany (DYFS). The DFS aims at monitoring young plaice and sole in their nursery grounds in the North Sea coastal zone, but records every species caught. The Ems estuary, including main channels in the Dollard, is sampled as DFS region 620 (ICES, 2013).
**Marine mammals**
Monitoring of seals in the Dutch Wadden Sea is carried out by IMARES. The monitoring of harbour seals and grey seals is performed by flying over the area at low tide. Surveys of the Dutch area are synchronised with those in Germany and Denmark to produce a count of the total Wadden Sea population. The counts are carried out several times per year and planned according to breeding and moulting season. The complete Ems-Dollard is surveyed.

**Salt marshes**
The salt marshes in the Dutch Wadden Sea are monitored in the VEGWAD programme of Rijkswaterstaat since the mid-1970s with a mapping frequency of once per six years. Vegetation maps are produced with a scale of 1:5,000 or 1:10,000. Input is from remote sensing (interpretation of stereo false-colour photographs) and fieldwork (ground truthing). For the classification of the vegetation a detailed typology is used (SALT97) that can easily be transformed into the TMAP typology. The salt marshes along the Dollard and Punt van Reide are part of the VEGWAD programme. The latest aerial survey took place in 2012, the next is planned for 2018. Groninger Landschap is responsible for monitoring the accretion and vegetation composition of the Dollard salt marshes since 1983. Sedimentation-erosion bars are surveyed in spring and autumn and vegetation quadrants in autumn.

**Marine mammals**
Monitoring of seals in the Lower Saxony Wadden Sea is the responsibility of LAVES since 2005. Population size is documented since 1958. The Lower Saxony Wadden Sea is subdivided in three parts between Emden, Mariensiel and Luneplate. Each aerial survey is executed with three planes simultaneously at low tide. Five simultaneous surveys are carried out in summer and synchronised with international counts.

**Salt marshes**
The foundation for the monitoring of salt marshes is provided by Sachteleben and Behrens (2010), which was drawn up at the federal level for terrestrial habitat types. The responsibility for habitat monitoring in the Ems lies at NLWKN. An area-wide survey of habitat types is carried out in the course of the six-year reporting cycle to ascertain their range and area. The survey is carried out using aerial images and the biotope mapping keys issued by the Länder and/or the TMAP typology. Selection and permanent specification of representative sample plots or transects is done for detailed surveying of characteristic vegetation structures, functions and species (BSH, 2014).
A spatial overview of long-term monitoring stations in the German and Dutch parts of the outer and inner Ems estuary and Dollard is given in Figure 28 and Figure 29.

Figure 28. Monitoring stations in the Outer Ems estuary. Squares: German monitoring stations. Circles: Dutch monitoring stations.

Figure 29. Monitoring stations in the Inner Ems estuary and Dollard. Squares: German monitoring stations. Circles: Dutch monitoring stations.
TABLE 1. German monitoring stations for contaminants (in sediment, water and Blue Mussel), macrozoobenthos, biological water quality / phytoplankton and water level. Source: Marine Environmental Data Base (MUDAB) Germany.

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### TABLE 4. Dutch LMW stations for water level.

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### TABLE 5. Dutch / German stow net stations for fish. Source: Jager et al. (2011).

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### TABLE 6. Dutch and German stations for contaminants in biota. Sources: Marine Environmental Data Base (MUDAB) Germany, Rijkswaterstaat (2014b), TMAP.

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<thead>
<tr>
<th>AREA</th>
<th>STATION NAME</th>
<th>CODE</th>
<th>TYPE</th>
<th>LON.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer estuary</td>
<td>Bork_Myt_1</td>
<td>DE, cont. mussel</td>
<td>6.78000</td>
<td></td>
</tr>
<tr>
<td>Inner estuary</td>
<td>Bocht van Watum</td>
<td>BOCHTVWTM</td>
<td>NL, cont. mussel</td>
<td>6.90000</td>
</tr>
<tr>
<td>Inner estuary</td>
<td>Paap Groote Gat Reiderplaat</td>
<td>NL, cont. Flounder</td>
<td>6.90000</td>
<td></td>
</tr>
<tr>
<td>Inner estuary</td>
<td>Delfzijl zeehavenkanaal</td>
<td>DELFZZHVKNL</td>
<td>NL, bird egg</td>
<td>6.90000</td>
</tr>
<tr>
<td>Dollard</td>
<td>Dollart</td>
<td>DE, bird egg</td>
<td>6.90000</td>
<td></td>
</tr>
</tbody>
</table>
6. COMPARING NATURA2000 MONITORING REQUIREMENTS WITH STATUS AND TREND MONITORING

6.1 Introduction

In the Ems estuary some large scale interventions were planned that were accompanied by monitoring programmes. These programmes were commissioned by the competent authority that provides the permit for the proposed activity. According to the Dutch Nature Conservation Act the authority may impose surveillance requirements to monitor the trends and developments in habitats and species associated to the plan or project. These programmes are examples of Type II monitoring. An elaboration and comparison with Type I monitoring is given below.

6.2 Description of case studies

Recently there were four initiatives for large projects in the Ems estuary in or nearby Eemshaven. These are the realisation of a multifuel power plant by Nuon, a coal fuelled power plant by RWE, an LNG-terminal by Vopak Essent and the extension and deepening of the Eemshaven by Groningen Seaports (GSP). A common plan was made to compensate for the significant negative effects on the protected natural values of the Ems estuary. Since the realisation of both power stations had overlapping monitoring requirements, an overall monitoring programme was set-up (Wymenga et al., 2009). Additionally, various company-specific monitoring plans have been made, such as those for RWE and GSP (RWE Power, 2009; Van Kessel, 2010). All monitoring was planned for the period 2009–2014.

Wymenga et al. (2009) have defined the overall monitoring requirements for the two power stations. The objectives were to monitor the effects of the initiatives on the natural values, to monitor the effectiveness of the compensation measures, and to monitor as an early warning system for adaptive execution of the proposed activities. The monitoring was concerned with breeding, wintering and migratory birds, numbers and diet of seals, migration of harbour porpoises, vegetation mapping and macrozoobenthos. Detailed monitoring methods have been worked out that adhere to existing long-term monitoring programmes and data as good as possible. An emphasis was put on comparison with existing standardised data as a reference (T0) situation where the T0 situation is the situation as it is just before the new action or intervention.
6.3 Comparison

In Table 7, Table 8 and Table 9 a comparison is made between the Type II monitoring requirements with existing Type I monitoring programmes. The comparison is relevant for two reasons:

When a plan or project in a Natura2000 area is licenced, the competent authority that provides the permit may impose monitoring of the trends and developments in habitats and species. It is relevant to have an understanding of ongoing long-term monitoring programmes since these might fill in, partly or in whole, the required monitoring demand. If the question does not match the demand, an additional Type II monitoring effort is necessary.

To make a judgement on trends and developments in habitats and species with respect to a proposed activity, it is necessary to be able to refer to existing time series as reference situation. Long-term monitoring programmes provide data for a T0-comparison.

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Table 7. Comparison of Type II monitoring requirements in the overall monitoring plan (Wymenga et al., 2009) for two power stations with Type I monitoring programmes (see paragraph 3.3).

<table>
<thead>
<tr>
<th>TYPE II MONITORING REQUIREMENTS CITING WYMENGA ET AL. (2009)</th>
<th>TYPE I MONITORING PROGRAMMES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Breeding birds</strong>&lt;br&gt;Six counts per breeding season in three study areas (“impact area”, “compensation area” and “salt marsh restoration area”) will be carried out in accordance to SOVON standards. at high-tide roosts. Specific programmes in the Ems-Dollard region exist that have focal species such as Common tern and Arctic tern and are coordinated by other parties such as the Vogeltrekstation.</td>
<td><strong>Breeding birds</strong>&lt;br&gt;Long-term monitoring of breeding birds is carried out in the Wadden Sea coordinated by SOVON since 1991. A T0-comparison is possible. the census areas. Every six years a complete census of all selected species in the entire Wadden Sea during the breeding season is coordinated.</td>
</tr>
<tr>
<td><strong>Wintering and migratory birds</strong>&lt;br&gt;Monthly counts of resting birds on high water refuge sites in four study areas will be carried out in accordance to standardised survey methods.</td>
<td><strong>Wintering and migratory birds</strong>&lt;br&gt;Long-term monitoring of wintering and migratory birds in high water refuge sites is carried out monthly in the Dollard and quarterly along the Ems since 1974 and coordinated by SOVON. A T0-comparison is possible.</td>
</tr>
</tbody>
</table>
**Sea mammals**
Aerial counts of seals will be executed in addition to the 10-13 existing surveys in the long-term monitoring programme by IMARES. Three existing surveys will be extended into the Ems estuary. An additional 4-5 surveys will be executed in winter and spring.

Migration patterns of seals will be studied with GPS-tags.

The presence and number of porpoises will be recorded with passive acoustic C-Pods.

The diet of seals will be studied to determine the significance of the Dollard as foraging site, which is indicative for their migration behaviour. Scats of seals will be sampled on haulouts.

As an early warning system for unexpected changes in the number of (juvenile) seals or their behaviour, camera observations of the haulout on Hond-Paap will be carried out.

**Vegetation mapping**
The vegetation cover and diversity of nature compensation areas (salt marsh and freshwater marsh) will be determined.

**Macrozoobenthos**
The density and biomass of sublittoral macrozoobenthos in the Dollard (Kerkeriet) will be sampled twice a year.

**Breeding birds**
Long-term monitoring of the number of seals is carried out by IMARES since 1995 and the proposed monitoring makes use of these. A T0-comparison is possible.

Seal tagging is not part of existing long-term programmes. A T0-comparison is not possible.

Passive acoustic monitoring of sea mammals is not part of existing long-term programmes. A T0-comparison is not possible.

Diet of seals is not part of existing long-term programmes, but is carried out in some scientific studies. A T0-comparison is partly possible.

Camera observations of seals are not part of existing long-term programmes. A T0-comparison is not possible.

**Vegetation mapping**
Vegetation mapping of salt marshes is carried out as part of existing long-term programmes by Rijkswaterstaat and IMARES. A T0-comparison of salt marshes is possible.

**Macrozoobenthos**
Only a limited number of stations in present long-term monitoring programmes on macrobenthos in the Wadden Sea are in the subtidal zone. A T0-comparison is insufficiently possible.
Table 8. Comparison of Type II monitoring requirements in the company-specific monitoring plan for Groningen Seaports with Type I monitoring programmes (see paragraph 4.3).

<table>
<thead>
<tr>
<th>TYPE II MONITORING REQUIREMENTS CITING VAN KESSEL (2010)</th>
<th>TYPE I MONITORING PROGRAMMES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Underwater noise</strong>&lt;br&gt;Measurements of underwater noise levels.</td>
<td><strong>Underwater noise</strong>&lt;br&gt;There is no monitoring of underwater noise in long-term programmes. A T0-comparison is not possible.</td>
</tr>
<tr>
<td><strong>Turbidity and primary production</strong>&lt;br&gt;The turbidity in dredging plumes will be measured with ADCP, CTD and OBS. Grain size characteristics of sediment samples will be determined. The changes in bed height will be determined. Volumes of dredged and dumped material will be determined. Monitoring of primary production was considered not useful by the authors.</td>
<td><strong>Turbidity and primary production</strong>&lt;br&gt;There are few stations for turbidity. Bed grain size composition in subtidal areas is not determined. The bed height is surveyed every six years. Dredged and dumped volumes are recorded as an industry standard. A T0-comparison is insufficiently possible.</td>
</tr>
<tr>
<td><strong>Turbidity and macrozoobenthos</strong>&lt;br&gt;The length and ashfree dry weight of mussels (Mytilus edulis) will be determined at two impact sites and one reference site.</td>
<td><strong>Turbidity and macrozoobenthos</strong>&lt;br&gt;Age and size classes of mussels are monitored in the littoral shellfish survey for WOT. A T0-comparison is possible.</td>
</tr>
<tr>
<td><strong>Presence and migration of sea mammals</strong>&lt;br&gt;Seals will be tagged to follow their migration patterns. C-pods will be placed to monitor presence of Harbour porpoise (Phocoena phocoena).</td>
<td><strong>Presence and migration of sea mammals</strong>&lt;br&gt;There is no long-term monitoring on the migration patterns of seals and porpoises. A T0-comparison is not possible.</td>
</tr>
<tr>
<td><strong>Behaviour of seals during construction</strong>&lt;br&gt;A video camera will monitor resting behaviour of seals.</td>
<td><strong>Behaviour of seals during construction</strong>&lt;br&gt;There is no long-term monitoring of the behaviour of seals. A T0-comparison is not possible.</td>
</tr>
<tr>
<td><strong>Foraging Eider ducks</strong>&lt;br&gt;The presence of mussel beds based on the existing long-term monitoring programmes will be used as an indicator for foraging possibilities.</td>
<td><strong>Foraging Eider ducks</strong>&lt;br&gt;Location of mussel beds is monitored for WOT and will be applied in the proposed monitoring effort.</td>
</tr>
<tr>
<td><strong>Macrozoobenthos</strong>&lt;br&gt;The present long-term monitoring of twelve transects of macrozoobenthos will be reported as baseline.</td>
<td><strong>Macrozoobenthos</strong>&lt;br&gt;Twelve transects of macrozoobenthos biomass are monitored for MWTL will be applied in the proposed monitoring effort.</td>
</tr>
</tbody>
</table>
TYPE II MONITORING REQUIREMENTS
CITING RWE POWER (2009)

<table>
<thead>
<tr>
<th>Intake and discharge of cooling water</th>
<th>Intake and discharge of cooling water</th>
</tr>
</thead>
<tbody>
<tr>
<td>A measurement and registration system will be set-up for cooling water.</td>
<td>This is a location and activity specific requirement. Long-term monitoring of water temperature is part of a limited number of stations of MWTL.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Entrainment of fish</th>
<th>Entrainment of fish</th>
</tr>
</thead>
<tbody>
<tr>
<td>The quantity of entrained fish will be monitored in spring and autumn. The significance with respect to population size will be determined.</td>
<td>There is monitoring of demersal fish in the Wadden Sea and Ems since the 70s. There is no similar programme for pelagic fish, which are susceptible for impingement. A T0-comparison is insufficiently possible.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Light emission</th>
<th>Light emission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurements to check conformity to light emission standards will be carried out.</td>
<td>There is no monitoring of light emission in long-term programmes. A T0-comparison is not possible.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Emission of substances to water</th>
<th>Emission of substances to water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substances in the discharged water will be monitored, i.e. pH, BOD, COD, suspended matter, N, P, heavy metals and organic micro pollutants.</td>
<td>Long-term chemical monitoring is carried out in 4 measurement stations in the Ems. A T0-comparison with background levels is possible.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Emission of substances to air</th>
<th>Emission of substances to air</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substances in the emitted air will be monitored, i.e. SO₂, NOₓ, dust, HCl, metals, dioxins, carbons and NH₃.</td>
<td>Long-term monitoring of air quality is carried out, but is not part of this analysis.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Noise above ground</th>
<th>Noise above ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise measurements during construction will be carried out to check conformity to standards.</td>
<td>There is no monitoring of noise in long-term programmes. A T0-comparison is not possible.</td>
</tr>
</tbody>
</table>
6.4 Evaluation

For most topics within the Type II monitoring programmes the choice of monitoring locations was not based on an underlying conceptual model of the ecosystem, but was based on juridical rationale instead. For example, the selected sites for the monitoring of breeding birds were the “impacted area”, “compensation area” and “salt marsh restoration area”. Apparently there was no interest in monitoring the status and trends in breeding success over the Ems estuary as a whole. The interest was in the areas that were directly affected by the proposed activity and the accompanying compensation and restoration measures. Another example is the monitoring of turbidity and primary production that was prescribed in the licence. Although the authors of the monitoring plan stress the importance of primary production in the ecosystem and state that only in spring and summer an increase in turbidity could lead to effects on production, it was decided not to measure primary production, but only turbidity, and only in the winter season. Monitoring locations were placed directly around the dredged sites and sediment disposal sites. Sampling locations therefore directly relate to the activities, and are not based on a system’s understanding of suspended sediment transport throughout the estuary, nor on the effects of an increased turbidity on the primary production in the estuary. A third example is the monitoring of sublittoral macrozoobenthos. These were measured only in the tidal channel Kerkeriet that was to be closed for shrimp fisheries. Although there is a major lack in subtidal monitoring for benthos, no other tidal channels have been selected for monitoring. As a reference, monitoring data were chosen that were obtained in 2008 in the navigation channel to Eemshaven, located in the outer estuary. It can be questioned in how far these data can serve as reference and if it wouldn’t be possible to determine a more appropriate reference.

As shown in section 3.2, Type II effect monitoring leads to a local intensification of monitoring efforts. However, the sampling strategy is based on the juridical description of protected species, conservation goals and environmental objectives instead of ecosystem understanding. The consequence is that the data that are gathered will not, or hardly, help in obtaining a system’s understanding. In the above described case study, the exception is formed by the measurements on seals and porpoises. A comprehensive monitoring programme was set-up and executed, which delivered valuable data on the spatio-temporal distribution and behaviour of sea mammals in the Ems estuary.

6.5 Conclusion

In this chapter we compared effect monitoring for Natura 2000 with status and trend monitoring. We conclude that the set-up of the majority of the monitoring programmes was narrowed down to a juridical rationale, which prohibits a satisfactory increase in ecosystem understanding. If the set-up of the programmes would have involved more criteria, such as those given by Lindenmayer and Likens (2010, 2009), the results of the measurements would have been more valuable.

Undoubtedly one of the objectives of effect monitoring is to yield appropriate insight into the ecosystem effects of a proposed activity in terms of protected species and conservation goals. A favourable effect monitoring programme, however, would involve multiple objectives that are made quantifiable and scientifically tractable. The formulation of objectives should at least be based on hypotheses on the conceptual understanding of ecosystem functioning. It should result in measurement objectives on multiple spatial and temporal scales, considering the system’s heterogeneity and dynamics. Moreover, a rigorous statistical design of the sampling scheme should follow, founded on the quantified objectives, so that the expected precision of the results is known beforehand. When carrying out the actual monitoring, it is of utmost importance to formulate and apply measurement protocols for consistency in sampling. Surely, new information will emerge and research questions may change in the course of the monitoring programme. The programme should therefore be made adaptive, with regular feedback loops in which the results are evaluated. We propose to install an independent monitoring authority that carries out quality control in all phases of a monitoring programme, from set-up to adaptive evaluation. Based on these requirements, we developed a COMPASS of criteria for the set-up of an effective monitoring programme:

**CONCEPTUAL:** based on a conceptual system understanding.

**OBJECTIVES:** setting quantifiable objectives with scientifically tractable research questions.

**MANDATED:** quality controlled and mandated by an independent monitoring authority.

**PROTOCOLS:** applying measurement protocols for consistency in sampling.

**ADAPTIVE:** adapt iteratively as new information emerges and research questions change.

**SCALES:** addressing multiple spatial and temporal scales considering the system’s heterogeneity and dynamics.

**STATISTICS:** rigorous statistical design of the sampling scheme.
7. TOWARDS A BILATERAL INTEGRATED MONITORING PROGRAMME

7.1. Introduction

Monitoring an estuarine ecosystem involves measurements of physical parameters (hydrodynamics, morphodynamics) that are fundamental for bottom-up ecosystem control, chemical parameters (nutrients, contaminants) that determine boundary conditions leading to inhibition or enlargement of biomass productivity, and biological parameters to determine biomass, density, diversity and population dynamics of flora and fauna. Additionally, it is paramount to measure human use in the form of drivers, pressures and management responses. It should be noted that in order to understand ecosystem changes in the Ems estuary it is important to have an understanding of a much wider area, including the Wadden Sea and North Sea. This requires a database with ecological data on large-scale patterns and long-term changes (Vandepitte et al., 2010).

Determining which parameters should be monitored is a crucial step in designing a monitoring programme. Relevant parameters do not only determine status and follow trends, but should also give insight in processes and functions of ecosystem components. Furthermore it is of high importance to design a sampling scheme that is both effective and cost-efficient. Many textbooks (e.g. De Gruijter et al., 2006) and scientific papers have been written on sampling design. For the purpose of this study it goes too far to give detailed sampling designs, but we will make recommendations on monitoring topics that deserve an in-depth redesign of the existing sampling scheme. Last but not least, we hereby again stress the importance of consistent methods for sampling throughout the whole estuary, which must be laid down in measurement protocols.

In this study we compared monitoring questions that follow from effect studies with available long-term monitoring programmes. This yielded a number of ‘shortcomings’, i.e. a demand for effect monitoring that is not fulfilled by the present supply of long-term programmes. Effect monitoring in the Ems estuary focused on a large number of topics, i.e. underwater and above-ground noise, emission of light, emission of substances to water and air, turbidity, primary production, macrozoobenthos, the impingement of fish in power stations, breeding, wintering and migratory birds, foraging Eider ducks, numbers and migration of seals and harbour porpoises, diet of seals, behaviour of seals, vegetation mapping and deposition of nitrogen on sensitive vegetation. When designing a bilateral integrated monitoring programme these shortcomings can be addressed. However, when new activities are proposed, this might lead to new monitoring demands. The basic question is what ecosystem components need to be monitored with what precision and resolution to answer future questions on licensing. The integrated monitoring programme for the Ems estuary has the ambition to become a combination of Types I, II and III monitoring:

“A long-term monitoring programme leading to assessments of the functioning of the ecosystem, guided by a conceptual model and rigorous study design and yielding appropriate insight into effects of human activities.”

Crucial for any monitoring programme is a conceptual understanding of how the system functions. Without an overarching framework, monitoring subprogrammes will be separate items with no clear relation and contribution to an overall assessment. We have described a conceptual understanding of the Ems estuary that provides an overarching framework, Figure 16. In this report we provide a blueprint for a bilateral integrated monitoring programme based on the conceptual overarching framework of the Ems estuary. We make recommendations on monitoring for different topics within this framework. The list of topics is adapted from the listing in the Bund/Länder-Messprogramm für die Meeresumwelt von Nord- und Ostsee BLMP (BSH, 2014) and is depicted in Figure 30.
On 29 October 2014 a workshop has been held in Bad Nieuweschans, The Netherlands. In this workshop suggestions for an improved monitoring network in the Ems estuary have been given. These suggestions have been used to design the integrated monitoring programme. And last, but not least, recommendations that were given by the IMP (Fachbeitragsgruppe 1 Natura 2000, 2014) are listed. The IMP (Fachbeitragsgruppe 1 Natura 2000, 2014) proposes measures for the ecological recovery of the Ems estuary. Measure number M28 is on “Creating an Ems estuary specific inventory and monitoring concept”. This measure aims at the development of a sound monitoring programme to observe the hydro-morphological and ecological developments in the Ems estuary. It describes that, where relevant, system level (e.g. widespread sub-littoral habitat mapping through sonar) measurements are to be combined with local measurements. In this way, a better insight into the autonomous developments and the effectiveness of restoration measures will be obtained. In M28, multi-modelling, statistical data analysis, ‘investigative monitoring’ and research and monitoring must be organized in close mutual co-ordination. The recommendations for the integrated monitoring programme might serve as a first step.

In addition to a monitoring programme and sampling scheme it is important also to have a publicly accessible data portal with current and historic data, and an internationally agreed upon management and organisation structure, including financial arrangements. For the Dutch Wadden Sea these topics are addressed in the WaLTER project (www.walterwaddenmonitor.org). For the Ems estuary in particular these have to be worked out later.

**Figure 30. Topics in the Ems estuary bilateral integrated monitoring programme.**

- salt marshes, (sub)littoral ecotopes
- phytoplankton, microphytobenthos and zooplankton
- seagrass
- macrozoobenthos
- fish
- birds
- mammals
- bathymetry
- sediment composition
- hydrodynamics, fine sediment transport and suspended sediment
- physical system
- physico-chemical system
- biological system
- salt marshes, (sub)littoral ecotopes
- human drivers, pressures and management responses
- socio-economic system
- phytoplankton, microphytobenthos and zooplankton
- seagrass
- macrozoobenthos
- fish
- birds
- mammals

**Figure 31. Schematic drawing of the proposed locations of fixed stations (circles), ferry transects (dashed lines) and survey transects (solid lines) for hydrodynamics, fine sediment transport and suspended sediment measurements.**
7.2. Hydrodynamics, fine sediment transport and suspended sediment

In the Ems estuary, specifically in the tidal Ems river, the ecosystem is suffering from increased suspended matter concentrations. The tidal Ems river has become hyper-turbid in the 1990s (van Maren et al., 2015) with concentrations up to 200 kg/m$^3$ (Papenmeier et al., 2013). The breakdown of organic matter in the fluid mud leads to a strong decline in dissolved oxygen levels (< 2 mg l$^{-1}$) in summer (Talke et al., 2009), which is detrimental to marine fauna. For the Ems estuary it is therefore of key importance to have an improved understanding of the hydrodynamics, fine sediment transport and suspended sediment concentrations in the system. Current measurements are too local and too scarce to understand spatial structures.

IMP Ems

The IMP (Fachbeitragsgruppe 1 Natura 2000, 2014) proposes to install additional measuring stations for water level, current velocity, discharge and freshwater flow, but it was not described where exactly.

Recommendations

An intensive measurement programme is necessary to improve system understanding and to improve (numerical) models. In terms of the monitoring categories I, II and III, a start has to be made with a Type III scientific programme. Type III monitoring is characterised by a large effort in space and time, i.e. many stations in high frequency and over a long-term period. This type of monitoring also requires new components to be determined in specialized sampling lay-outs. Furthermore it is essential to measure in a larger area while also taking boundary conditions into account. After a number of years the intensity of this programme can be reduced to a Type I monitoring, because it is very important to aim for long-term time series of data. Both lateral and longitudinal transects have to be chosen in the estuary to determine current velocities, suspended sediment concentrations, salinity, nutrients and chlorophyll. With these data fluxes of substances need to be determined. These transects will have to be monitored with a number of instruments. We propose to install a FerryBox (Grayek et al., 2011; Petersen et al., 2008) on the ferries to Borkum travelling from Emden and Eemshaven. The Eemshaven-Borkum ferry crosses the Westereems once a day in winter, and up to seven times a day in mid-summer. The Emden-Borkum ferry follows a longitudinal transect from Emden towards Eemshaven and then crosses the Westereems. The car-ferry to and from Emden travels twice a day year-round.

Dedicated surveys can be carried out with survey vessels. We suggest to study the application of the instrument AcrobatTM from Sea Sciences Inc. This is a computer controlled, towed undulating vehicle that collects geo-referenced data with various instruments. These instruments cannot only collect abiotic data on hydrodynamics and fine sediment, such as CTD, OBS and LISST laser particle size analyzer, but may also include chlorophyll fluorometers, ISUS nitrate sensor, bioluminescence photometer, etc. The AcrobatTM has been applied in shallow water depth of 3 m programmed to undulate between 0.5 m below the surface and 1 m above the seabed (Grant et al., 2008) and therefore seems suitable for Wadden Sea conditions. Suggested locations for transects are the estuary mouth between Eemshaven and Krummhörn, the Dollard channels between Punt van Reide and Geise-leitdamm, the tidal Ems river river entrance at Pogum and the longitudinal channel axis into the tidal river where turbidity is highest.

Very important is to grasp both long-term trends as well as short-term variation in currents and transport by determining turbulence statistics. With regard to spatial scale, small-scale turbulence (smaller than water depth) as well as large-eddy structures need to be understood much better. The relevant time scale for suspended sediment transport is determined by the sedimentation and erosion within a tidal cycle. To determine net fluxes of suspended sediment transport in or out of the estuary mouth it is therefore important to measure with 10 minute intervals on a seasonal scale. To achieve these high-frequency measurements fixed instruments on measurement poles or other structures are recommended. It is recommended to apply these on at least three locations, i.e. at the end of the Geise-leitdamm where the tidal Ems river enters the inner estuary, at the Eemshaven and in the offshore part of the outer estuary in between Rottumeroog and Borkum (Nolte et al., 2015). It is advised to install both abiotic and biotic sensors. The instruments should measure the complete water column because of the vertical gradients in flow and salinity in an estuary. Apart from sensor technology, water samples need to be taken to determine suspended sediment concentrations as ground-truthing and validation of instruments. Furthermore, various temporary stations (one to three months) can be set-up with landers for high frequent measurements yielding local data for model calibration.
7.3. Biological and physico-chemical water and sediment quality

The Ems estuary has seven long-term monitoring stations for biological water quality, three from the Dutch government and four from the German government. A nearby Dutch station Rottumerplaat located 3 km offshore is shown in Figure 32 as well. Typical parameters that are measured are chlorophyll, pheophytin, and number of phytoplankton cells, together with pH, salinity, temperature, transparency, nutrients and oxygen concentrations. In one Dutch station, Bocht van Watum Oost, the physico-chemical sediment quality is determined every three years on parameters such as grain size, organic carbon, and calcium carbonate.

Recommendations

Considering the heterogeneity and dynamics of the Ems estuary, we consider the number of stations to be low. We recommend to develop a joint monitoring network with automatic measuring sensors within a data-assimilating model environment and to increase the number of stations. This network must preferably be joined with the network for hydrodynamics, fine sediment transport and suspended sediment, as well as joined with the network for primary production.

As a minimum requirement we agree with the IMP (Fachbeitragsgruppe 1 Natura 2000, 2014) to install an additional measurement station between Papenburg and Herbrum in the tidal freshwater part of the tidal Ems river. We further propose to install another two additional permanent monitoring stations: At the end of the Geise-Leitdam to monitor the hydrochemical quality in the inner estuary under the direct influence of water from the tidal Ems river. Near Eemshaven to monitor the hydrochemical quality of the exchange water between the inner and the outer estuary.

7.4. Contaminants in water, sediment and biota

Contaminants in water and sediment

Contaminants in water are monitored in nine stations, three by the Dutch government (the same stations as for the biological water quality) and two by the German government. Contaminants in sediments are monitored three-yearly at ten stations by the Dutch government and yearly at three (combined) stations by the German government. The monitoring effort seems sufficient.

Contaminants in biota

The monitoring of contaminants in biota are determined in eggs of Common terns or Oystercatchers, the tissue of Blue Mussel / Pacific oyster, and in European flounder (Platichthys flesus). Contaminants in bird eggs are measured for TMAP in The Netherlands at Delfzijl zeehavenkanaal, and in Germany at the Dollard. Contaminants in Blue Mussel or Pacific oyster are monitored at a Dutch station at Bocht van Watum and a German station at Borkum. Contaminants in European flounder are determined for OSPAR CEMP-JAMP at Paap Groote Gat Reiderplaat.

Recommendation

The coal fuelled power plant in the Eemshaven is emitting mercury in air and water. Mercury is included in the analysis of muscle tissue in European flounder, in Blue Mussel and in bird eggs. We recommend to include tissue sampling of (washed ashore) sea mammals.
7.5. Bathymetry

Both The Netherlands and Germany apply a combination of echosoundings from survey vessels and lidar from airplanes to survey bathymetry (depth and height relative to sea level). Rijkswaterstaat surveys the Ems estuary including the Osterems tidal basin and excluding the tidal Ems river every six years. BSH surveys the Ems estuary excluding the tidal Ems river every six years, some parts in the outer estuary more frequent for navigation purposes. The Emden Harbour Authority surveys the navigable depth of the channels in the Ems estuary and tidal Ems river frequently.

**IMP Ems**

With regard to the bathymetry measurements the IMP (Fachbeitragsgruppe 1 Natura 2000, 2014) recommends to implement a higher inspection frequency than every 6 years due to the strong dynamics in the Ems Estuary.

**Recommendations**

We recommend to line-up the planning of Dutch and German survey programmes in the Ems estuary so that every three years a full bathymetry map becomes available.

With regard to monitoring techniques, De Groot et al. (2014) recommend to apply multibeam depth soundings of the sublittoral parts of the Wadden Sea instead of singlebeam for higher accuracy.

7.6. Sediment composition

In The Netherlands the sediment composition is investigated by bed sampling. Since the onset of the scientific- and licence-driven SIBES programme in 2009, the intertidal sediment composition is sampled yearly in a 500 x 500 m grid. Since SIBES is not officially part of the mandatory monitoring programmes, its continuation is not guaranteed. A comprehensive programme for subtidal substrate sampling is lacking. In Lower Saxony bed sampling is carried out, but not in a regular survey grid. In addition to in-situ sampling, whole water bodies are mapped with hydroacoustic and remote sensing methods in German waters.

**New technology**

In the German WIMO-project new concepts for littoral and sublittoral environmental monitoring have been developed (http://wimo-nordsee.de/?page_id=21). This project has demonstrated that not only substrate typology, but also geomorphological features and biotic reefs on a fine spatial scale can be derived from remote sensing, either from satellites, aerial flights, unmanned aerial vehicles or under water hydro-acoustics.

**Recommendations**

We recommend to develop a joint research programme for substrate mapping in the outer and inner estuary and Dollard based on a combination of in-situ and remote techniques. The use of hydro-acoustic (e.g. Bartholomä et al. 2011) and satellite remote sensing (e.g. Schmidt et al. 2012) methods, combined with groundtruthing, is a promising and cost-efficient way to spatially cover the intertidal and subtidal areas.

We recommend to simultaneously carry-out hydro-acoustics for substrate composition with echosoundings for bathymetry. Groundtruthing of sediment grain size composition can be obtained from surveys on littoral and sublittoral macrozoobenthos. For details on this type of monitoring programme reference is made to www.walterwaddenmonitor.org.

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*Figure 35. Current monitoring of sediment composition (tan) in the dense grid in The Netherlands for the SIBES programme, and proposed complete coverage with remote sensing (black).*
7.7. Phytoplankton, microphytobenthos and zooplankton

Phytoplankton biomass (expressed in cell volume) is surveyed in four stations, three from the Dutch and one from the German government. Sampling frequency (max. 19 times per year) is low compared to the growth dynamics of phytoplankton (turnover time 0.5 – 5 days). Measurements of primary production in the Ems estuary as part of a monitoring programme are absent. Monitoring of biomass and growth rate of microphytobenthos in the Ems estuary as part of a current monitoring programme is absent. Albeit its essential role in estuarine functioning, monitoring of zooplankton in the Ems estuary is absent.

New technology

Spatial coverage of microphytobenthos and phytoplankton biomass can be monitored with satellite remote sensing. The Sentinel-2 and -3 satellites that will become operational are promising. New sensor technology has been developed to determine in-situ primary production. The Fast Repetition Rate Fluorometry (FRRF) sensor measures the (variation in) production–biomass ratio and is suitable for phytoplankton and microphytobenthos. This sensor can be deployed on fixed platforms and on ships. We recommend to study the application of an FRRF on the Acrobat™ in combination with the monitoring for hydrodynamics, fine sediment transport and turbidity.

Recommendations

Recent study has shown a halving in pelagic primary production in the inner estuary between 2012-2013 and 1979–1980 due to an increase in turbidity. A halving in primary production in the outer estuary is ascribed to nutrient reduction (Brinkman et al., 2015). We recommend to install an additional station in the inner estuary near the end of the Geisse-leitdam. We recommend to install an additional station at the boundary between the inner and outer estuary since this forms the boundary between high productivity in the outer Ems and low productivity in the inner Ems. We recommend to measure not only phytoplankton biomass and species composition but also primary production. We recommend to monitor zooplankton in all phytoplankton stations with similar methods as being used in MONEOS, so by monthly samples of 50 l filtered over a 50 µm net (Meire and Maris, 2008).

We recommend to operationalise the combination of field measurements, high-frequency sensor networks and remote-sensing for planktonic and benthic primary production in the Ems estuary with specific attention to the inner and outer estuary and Dollard.

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**Figure 36.** Current (green) and proposed (black) monitoring locations for plankton, including complete coverage with remote sensing (black). Squares: German stations, circles: Dutch stations. Recommended is to measure primary production, phytoplankton and zooplankton (concentration and composition) in all stations.
7.8. Seagrass

Monitoring of seagrass in the Ems is part of the TMAP cooperation. The seagrass that is (or rather, was) present on Hond-Paap is surveyed by both the NLWKN as well as Rijkswaterstaat. NLWKN visits the Hond-Paap annually and Rijkswaterstaat every three years. Moreover, NLWKN is mapping seagrass coverage by aerial flights every six years.

Jager (2013) made the following detailed recommendations on monitoring seagrass and related environmental parameters:

- Monitoring locations for temperature were not optimised to represent the conditions at the seagrass site. None of the abiotic parameters measured were measured in the sediment (pore water), and there is no information on sulphide levels at all.
- Monitoring data and knowledge of the impact of herbicides on *Zostera marina* are insufficient.
- Monitoring data are insufficient on herbivores and *Labyrinthula*.
- Monitoring of qualitative indicators of plant health (ratio of above/below-ground biomass, plant length, number of spathes, seed production estimates), and of in situ conditions in the sediment pore water (sulphide, ammonium, oxygen) and water column (oxygen saturation, light, current velocity, temperature, salinity) can give better explanations of a seagrass population decrease by early warning and enhanced detection of hampered growth conditions.
- The present monitoring, by walking transects on the tidal flat, is rather limited and inaccurate. In The Netherlands, the frequency of monitoring was reduced to once every 3 years which is insufficient given the observed rapid (annual) changes in seagrass cover and area.

**Recommendations**

In general, we recommend to view the Dutch and Lower Saxony Wadden Sea as one system; the seagrass cover, density and other characteristics are similar in this area and notably different from the Schleswig-Holstein Wadden Sea. We recommend to agree on one methodology for field surveys and to carry out the monitoring by one organisation. We recommend to carry out a field survey bi-annually. A survey in late summer determines maximum biomass and a survey in winter determines whether or not a seagrass meadow is annual or perennial (with rhizomes).

![Figure 37. Current monitoring transects of the Dutch authority for seagrass cover, and two stations on Hond-Paap monitored by the German authority.](image-url)
7.9. Macrozoobenthos

Surveys for macrozoobenthos differ markedly between The Netherlands and Lower Saxony. The spatial resolution and extent of SIBES and the WOT littoral shellfish and shellfish banks surveys in the Dutch Wadden Sea are unprecedented.

What is, however, missing in both countries is sufficient, spatially explicit monitoring of density and biomass of sublittoral infauna and epifauna. Due to the lack of monitoring of sublittoral benthos there is a large knowledge gap on the total benthic biomass, biomass production, benthic filtration rates and food web dynamics.

**IMP Ems**

The IMP (Fachbeitragsgruppe 1 Natura 2000, 2014) proposes collection of sublittoral mussel bed distribution data using remote sensing (sonar). The acoustic remote sensing can be used in conjunction with video recordings, grab samples and underwater visual observations to map the distribution of sublittoral mussel beds. Finally the IMP also proposes monitoring of the stock and the proliferation of invasive species.

**Recommendations**

We recommend to extend the intensive Dutch macrobenthos monitoring surveys SIBES and WOT to the German Lower Saxony Wadden Sea. The WOT survey is especially suited for the mapping of shellfish banks that have a clustered spatial distribution, the SIBES survey is especially suited for species diversity and sediment properties.

We recommend to yearly monitor sublittoral benthos with a combination of boxcore and dredge sampling in a regular grid of 500 x 500 m. Sediment subsamples will be taken from the boxcore samples to measure sediment grain size composition.

*Figure 38. Current monitoring of macrozoobenthos (yellow) and proposed sampling grid and transects (black). Squares: German stations, circles: Dutch stations. Transects in Dollard: MWTL survey Heringsplaat. Transects in inner and outer estuary: WOT shellfish monitoring.*
7.10. Fish

The demersal fish surveys in The Netherlands and Germany are aligned with each other and coordinated internationally by ICES. The current pelagic fish sampling with stow nets also has aligned responsibility between both countries via the Arbeitsgruppe Wasserqualität (Unterarbeitsgruppe Fisch). Stow net sampling takes place only once every two years at three locations. There is no equivalent comprehensive pelagic fish survey in comparison with the current demersal fish survey.

Recommendations
We recommend continuation of the demersal fish surveys (DFS and DYFS).

We recommend to increase the sampling frequency of stow net sampling to monthly surveys to capture seasonal effects. We suggest to install an additional station in de Dollard region and at the end of the Geisse-leitdamm to monitor the swimway into the Ems tidal river.

We recommend to jointly develop an estuary-wide survey programme for pelagic fish and in particular for migratory fish. Given the protected status of migratory fish, an increased monitoring effort is recommended. An increased understanding in pelagic fish biomass numbers is a prerequisite to understand food web functioning and links with piscivorous birds and sea mammals. In the Ems-Dollard there is quite a lot of attention to providing breeding habitat for piscivorous birds such as the Arctic Tern (Sterna paradisaea) and Common Tern (S. hirundo). It is important to gain insight in their food resources. Moreover, a quantitative understanding of population sizes of fish species is important to assess the effects of impingement by power stations. This survey programme may include daily measurements with a permanent fyke or stow net station, for instance at the entrance of the estuary near Eemshaven.

Figure 39. Current monitoring of fish (orange) and proposed additional sampling stations (black). Orange circles: representation of current DFS/DYFS stations. Orange squares: current stow net sampling locations (Krummhörn/Spijk, Oterdum and Terborg).
7.11. Birds

Monitoring of bird numbers is a prime example of coordinated effort in The Netherlands and Germany between many persons (mainly volunteers but also professionals). In the Dollard region long-term series of monthly bird counts at are carried out since 1973 in both the German and Dutch parts by Jouke Prop (e.g. Prop et al., 2012). Trends in bird numbers, and breeding success, prove to be an indicator for the ecological quality of the estuary. Nevertheless, specific attention to the low-water distribution of birds is needed. There is a knowledge gap on the relation between the number of birds obtained at high-water counts, their distribution over the tidal flats at low-water and the factors that determine their distribution. The combination of low-tide bird counts with macrozoobenthos distribution clarifies important foraging areas, and raises a deeper understanding of functional relationships in the foodweb. Moreover, low-tide counts give insight in disturbance from human activities. These counts help in decision-making on management and protection of the estuary.

**IMP Ems**

The IMP (Fachbeitragsgruppe 1 Natura 2000, 2014) recommends to detect regularly used high-water rest areas and their connections to the surrounding foraging areas.

**Recommendations**

We recommend to perform low-tide counts in the form of a Type III scientific monitoring programme with a high-intensity (monthly, in conjunction with high-tide counts) for a limited period (two or three years), to obtain a deeper scientific understanding. In this scientific programme, counts can be supplemented with geotagging of birds, videomonitoring and/or bird radar.

We recommend to continue the monthly high tide counts and in addition, a Type I monitoring programme is recommended with low-tide counts twice a year, in spring (May) and late summer (September).

There is currently no calculation of the population dynamics of colony breeders in the Ems estuary possible. We recommend to increase the monitoring efforts on breeding success, with a focus on colony breeders such as terns.

7.12. Mammals

**Seals and porpoises**

Aerial seal surveys to determine population size are synchronised internationally and results are shared and discussed within the TMAP trilateral seal management group. When an occasional harbour porpoise is observed during a seal survey, it will be registered as well. Common Seals and Grey Seals are protected species in Natura 2000-area Wadden Sea. Harbour porpoise is not a protected species in the Dutch Natura 2000-area Wadden Sea, but is protected in the German Niedersächsisches Wattenmeer. Sea mammals are iconic species and receive a lot of attention in licensing procedures. A relatively large additional effort in licence-driven monitoring was needed for the case study on the large scale interventions in or nearby Eemshaven.

**New technology**

Although the horizontal resolution of satellite remote sensing is probably high enough to count seals (31 cm panchromatic Worldview 3 images), distinguishing between species is not possible, so this technique is deemed not useful. Recent advancements in geotagging of seals reveals a wealth of information on migration, foraging areas and behavioural patterns. Tagging is usually carried out as licensing requirement (Type II monitoring).

**Recommendation**

We recommend to continue the aerial counts of seals in the international Wadden Sea. We recommend to increase the aerial count effort in winter season to obtain better seasonal distribution patterns of both species that have different pupping seasons.

**Bats**

In the Wadden region both sedentary and migratory bats occur. The Wadden coastline is a migratory flyway for the Nathusius’ pipistrelle (*Pipistrellus nathusii*) (UNEP/GGRID-Arendal, 2011). Nathusius’ pipistrelles even cross the North Sea as many bats have been found on oilrigs (Lagerveld et al., 2014). The Ems estuary is used as a migratory route for Nathusius’ pipistrelle and other bat species as was shown by Jonge Poerink and Haselager (2013) on Rottumeroog. Human activities such as wind energy parks may hamper these highly protected mammals (Kunz et al., 2007). In the Ems-Dollard region many wind turbines are present and more will be built, but an overview of migratory routes, timing and number of bats is lacking. We acknowledge that bats do not play a significant role in the estuarine food web of the Ems, but since they are highly protected we need a better understanding of these animals.
**Recommendation**

We recommend to design a network of bat detectors in the Ems region to raise understanding of migratory routes, timing and number of bats and to come up with management actions such as the spatial delineation of wind turbines and mitigating measures to prevent collisions with turbines.

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**7.13. Salt marshes, littoral and sublittoral ecotopes**

Monitoring of salt marshes is carried out in both countries with similar methods and frequencies. A common systematic typology of salt marshes has been developed by TMAP (http://www.waddensea-secretariat.org/saltmarsh).

The monitoring of the status and trends of European habitats is described by Natura 2000 legislation and included in monitoring programmes. However, for ecosystem understanding the classification of the Wadden area in European habitats is too course. A more detailed ecotope distribution gives a better understanding of changes of the (sub)littoral wadden. These ecotopes are derived from a combination of height/depth, substrate type, salinity, current velocity, inundation time and geomorphological characteristics (Bouma et al., 2006). Ecotopes in the Western Scheldt are mapped regularly (in 1996, 2001, 2004, 2008, 2010, 2011 and 2012) with the use of the ZES.1 ecotope system of Bouma et al. (2006). Ecotope maps prove to be instrumental in analysing the ecological quality of the Scheldt estuary (Arcadis, 2014).

**New technology**

Satellite remote sensing with optical and radar (SAR) sensors can derive cost-efficient Wadden Sea-wide maps for topography, sediment classification and mussel beds. At the moment, Landsat 8 (optical) and Sentinel-1 (SAR) images can be obtained for free, and in the near future Sentinel-2 (optical) and -3 (optical and SAR) will have free data. New algorithms need to be developed and applied in an operational chain towards end products.

**IMP Ems**

The IMP (Fachbeitragsgruppe 1 Natura 2000, 2014) proposes each 6 years a complete spatial coverage for the assessment of H1150 (coastal lagoons) in the outer estuary with documentation of extent, severity and risk, instead of the current situation in which only selected transects are inventoried.

**Recommendations**

We recommend continuation of the TMAP salt marsh monitoring.

We recommend an increased effort in monitoring sedimentation-erosion height in salt marshes.

We recommend three-yearly mapping of ecotopes according to the ZES.1 system for the Ems estuary. Maps for depth, flow velocity, inundation, littoral sediment composition and salinity are available. It might be necessary to generate maps for geomorphological features based on aerial photography.

Monitoring of human drivers, pressures and management responses is vital to understand ecosystem changes in the Anthropocene. In many ways human activities are monitored and reported. Examples include shipping intensity on the navigation channels, locations and volumes of dredged and dumped sediment, and nature management (e.g. numbers of herbivores per ha) of salt marshes. When comparing the requirements for Type II effect monitoring, we found two topics that were addressed as knowledge gaps, i.e. noise and light.

**Underwater and above-ground noise**

Underwater and above-ground noise may hamper fish, marine mammals and birds. In licence procedures for activities that generate noise, an assessment on its effects is required.

Monitoring of above-ground noise is not part of a Wadden Sea wide programme, but in some instances microphones are set-up. An example is when the Royal Dutch Airforce is practising bombing from F-16 jetfighters on the shooting range on Vlieland.

Monitoring of underwater noise is not part of a monitoring programme either. Occasionally underwater sound measurements are carried out for research purposes. The analysis in spatial models and the interpretation of noise is complex. Due to the analytical difficulties, there is currently a lack in understanding of background levels of noise, either caused by natural (waves) or anthropogenic sources. There is no objective measure of trends in underwater noise by shipping, pile driving, or other activities in the Ems estuary and therefore a T0-comparison is not possible.

**Recommendation**

We recommend to design and install a measurement programme for underwater noise adhering to Descriptor 11: Energy incl. Underwater Noise of the Marine Strategy Framework Programme: “Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment”.

**Emission of light**

Light is a potential disturbance for (breeding) birds, and it might attract birds to dangerous objects (wind turbines, lighthouses). There are industry standards for light emission of objects, also because of the ‘horizon pollution’ in the quiet and dark Wadden area. The actual measurements of light levels on the horizon, or reflections of light in the sky, is not carried out. There is no objective measurements of trends in light pollution from Emden, Delfzijl of Eemshaven.

**Recommendation**

We recommend to design and install a measurement programme for light. Sky luminance mapping might be the best available method.
7.16. Streamlining measurements in the monitoring programme

As described above, measurements for several system components are closely related. This gives opportunities to streamline the measurements and to strive for a cost-efficient execution of the monitoring. Figure 40 shows a conceptual diagram of monitoring techniques that can be combined. With hydroacoustic methods the bathymetry can be determined together with mapping of sublitoral substrate characteristics. We recommend to study the applicability of multiple hydroacoustic sensors on survey vessels. The use of satellite and aerial remote sensing gives ample opportunities for estuary-wide mapping of litoral substrates, shellfish cover, primary production in the water column and on the tidal flats, suspended sediment concentrations and ecotope mapping. We recommend to intensify the applicability of RS techniques. New sensor technology opens up the possibility for high-frequency measurements on hydrodynamics, fine sediment transport, primary production and suspended sediment. We recommend to study the set-up of an aquatic sensor network on fixed stations, survey vessels and ships of opportunity. At the same time, maybe old-fashioned, but reliable sediment sampling and water sampling are still necessary, not only when remote techniques are insufficient but also to validate remote measurements. Last but not least, observations and sampling of biota fills the information needs on the status of the estuarine system.
ACKNOWLEDGEMENTS

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Holt, J.T., James, I.D., 2001. An s coordinate density evolving model of the northwest European continental shelf 1. Model description and density structure against both on and off the shelf, the whole of the North Sea Project sources 106, 15–34.


Masterplan Ems 2050, 2015. Vertrag „Masterplan Ems 2050“.


NMUEK, 2014. Richtlinie Agrarumweltmaßnahmen Naturschutz (NiBAUM 2014) - DRAFT.


Rijkswaterstaat, 2014b. MWTI Meetplan 2014; Monitoring Waterstaatkundige Toestand des Lands Milieumeetnet Rijkswatersen chemie en biologie.


### APPENDIX I

Participants of the Bad Nieuweschans workshops

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