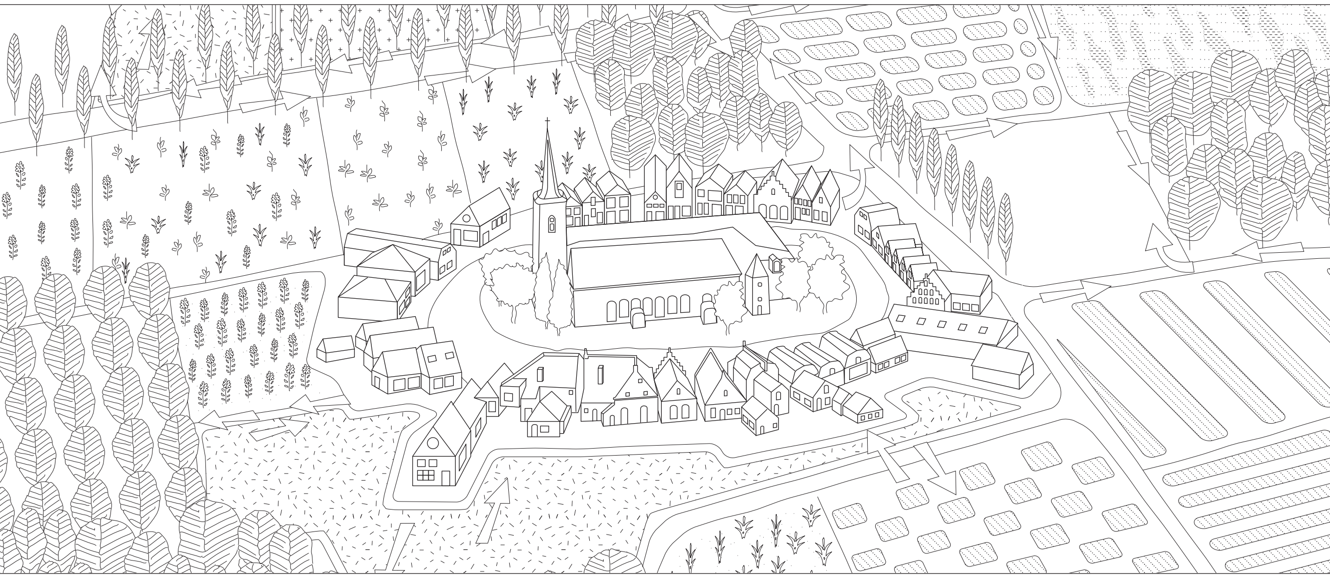
a non-straightforward archipelago

speculative strategies for enriching the ecological and cultural landscapes of the Dutch Southwest Delta



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speculative strategies for enriching the ecological and cultural landscapes of the Dutch Southwest Delta

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North Sea – Landscapes of Coexistence
Transitional Spaces, Infrastructure and Power

Tutors: Taneha Kuzniecow Bacchin, Hamed Khosravi

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Assistant Professor Urban Design Theory & Methods

Second mentor: Dr Evert J. Meijers
OTB - Research for the Built Environment

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Delft, the Netherlands

Note: Unless otherwise indicated, all images and drawings are by the author

preface and acknowledgements

This report documents the results of thematic and design explorations undertaken as part of a multidisciplinary research studio looking at the natural and socio-economic dynamics shaping the North Sea territorial landscapes. Of particular focus was mechanisms for climate change adaptation and the notion of dealing with extremes across four broad studio themes, namely:

- ***Imagination:*** inhabiting space and time, temporalities
- ***Re-Nature:*** design with nature and performative design
- ***The limits of the city:*** from cities to urban systems and territorialism
- ***Ecologies of power:*** political ecology of urban form, economies of scale

The thesis has been an opportunity to explore subjects and notions that I have been interested in for some time but was unable to satisfactorily cover in my professional experience. I am therefore thankful that the Delta Interventions Studio provided such a challenging and comprehensive venue for these explorations with theoretical input from such interesting external academics and practitioners.

I am also grateful for the considered and ever-present contribution of my mentors and tutors Taneha Kuzniecow Bacchin, Evert Meijers and Hamed Khosravi.

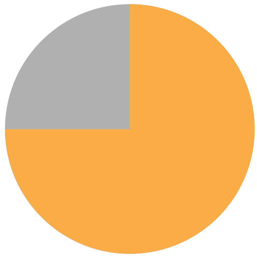
abstract

A possible consequence of the contemporary re-evaluation of Dutch flood and water management strategies could be a return to more naturalistic estuarine conditions within the Southwest Delta. This has the potential to re-animate natural systems and habitats as well as bolster cultural connections to, and across, this landscape.

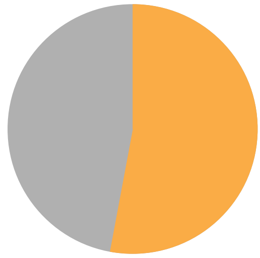
But how could this re-naturalisation benefit the urban landscapes and economies that negotiate the transition between one of Europe's densest urban, industrial and logistics corridors (from Brussels and Antwerp to Rotterdam) and the equally congested territory of the southern portion of the North Sea?

Could a new spatial typology of augmented ecologies prompt a re-orientation of both naturalistic and urban ecosystems within the delta towards greater social, economic and ecological efficacy and resilience?

contents



25% of Earth's ice-free landmass unoccupied or substantially unused by man in 2000



55% of Earth's population living in urban areas in 2016

1.1 introduction

Our relationship with the natural world that sustains both us and our cultural and economic practices, has historically been of constant concern (to scientists, artists, religious leaders, farmers, shepherds, fishermen etc.). It is only relatively recently that the relationships between natural systems (between the biota and its environment) have begun to be formally studied as ecosystem ecology and our interactions with these systems also quantified[1].

It perhaps follows then, that the realisation of our fundamental impacts upon natural ecosystems has coincided with our current ability to alter these systems on a planetary scale (the dawn of the age of the Anthropocene). As our population continues to expand, to develop and urbanise, these planetary impacts are becoming stark and undeniable (see the IPCC assessment reports on global climate change). The protection of these natural systems - and by extension of ourselves - is therefore paramount, yet only a quarter of the Earth's ice-free landmass was unoccupied or substantially unused by man in 2000 and as Ellis has suggested,

'In the Anthropocene, there is no possibility of removing human influence from ecosystems: anthropogenic transformation of the terrestrial biosphere is essentially complete and permanent.'[2]

The above infers that there remain few natural systems we do not have an impact upon and as almost 55% of our populations live in urban areas[3], from an anthropocentric point of view, it is at the junctions between natural and urban systems where the impacts might be most apparent and where (as neither system holds sway) interventions might have the most impact...as such, this is perhaps where we should be concentrating our efforts.
Identifying this point of interaction though may be difficult because, as Alberti suggests, we can no longer view these as independant systems and that 'urban landscape patterns are hybrid phenomena emerging from the interplay of human and ecological processes acting on multiple temporal and spatial scales'[4]

This multi-scalar nature of the interactions between urban and natural systems and processes also poses difficulties in the identification of a geographic site, and indeed scale, upon which to intervene. If the consequences of local actions can have systemic and planetary impacts then how do we approach design at the local scale? Alternatively, this is perhaps a point of liberation enabled by the recognition of the Anthropocene. Local interventions can have global as well as regional benefits and so an interconnected world might empower local actions to aspire to planetary changes.

1. Reed & Lister, 2014 (see references)

2. Elllis, 2013. P. 180

3. Population statistics, World Bank website (see sources)

4. Alberti, 2008. P. 13

5. McGlade, 2002

6. North Sea key facts, Safety at Sea website

7. Barry et. al., 2006

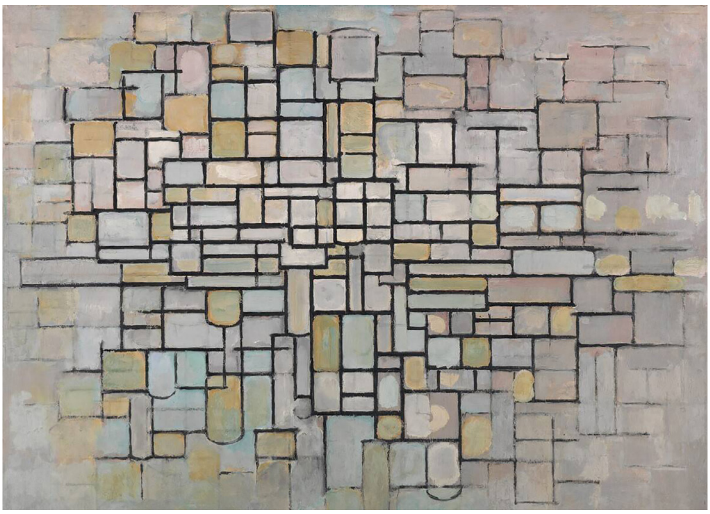
‘In de maand Juli’, Paul Joseph Constantin Gabriël (1889), Rijksmuseum 2018. Author’s photo

1.2 cultural interactions

So at a time when our populations are increasingly urban - and likely suffer eroding historic cultural connections to the landscape - the fundamental interconnectedness of human (urban) and natural systems is becoming clear. While this urban eco-systemic view concentrates on shared or conjoined infrastructures, processes and patterns or states, the interconnectedness of human cultures and their landscape contexts is no less significant and no less complex. Indeed, while this realisation of systemic reliance and influence is somewhat belated, the cultural influence that a landscape has on its population has never been in question. The Netherlands is one of the strongest examples of a country where this fundamental cultural influence runs in both directions and has manifested in a culture's physical shaping of a landscape.

There is no doubt that the Dutch relationship to landscape is fairly particular and although all cultures have had an impact on, and are impacted by, their physical geographical contexts, the timelines and relative positions (whether urban or natural processes held the upper hand) in a centuries long power struggle played out in the Netherlands are uniquely muddled. The physical construction and ordering of the Dutch landscape in response to the ever present threat of inundation likely had as much impact on the cultural psyche as it did on the deltaic groundplane[1].
As is generally the case, this is most apparent in the art that initially sought to celebrate the polder landscapes of horizontals and verticals under the ever-present sky (see Paul Gabriël's 'In de maand Juli' opposite) and then to deconstruct them (see Mondriaan's abstraction of trees, buildings and their reflections in the River 't Gein below).

'Compositie no II', Piet Mondriaan (1913)[2].



1. As discussed by Adriaan Geuze in his 2008 essay, Flatness

2. Image source, Kroller Muller Museum

This complex series of interactions and influence between culture and landscape (alongside the more pragmatic interactions of process and infrastructures) is one of the principal themes that guides the explorations within this thesis. The impacts that human cultures have on their environmental contexts are no less dramatic than the psychological and behavioural impacts that these contexts exert over the occupying communities.

While today the balance of power is perhaps weighted towards culture in the Netherlands (particularly when compared to a country such as Australia for example), the fact that the landscape itself is a cultural construct perhaps also engenders a certain complacency (as also suggested by Aadrian Geuze). The other side of this coin is that the elements that come together to compose the unique visual and cultural character of the Dutch landscape might be replicable or at least employed again in different ways to address today's environmental and existential threats.

Key A crowded territory
Territorial boundaries
Cables and pipelines
Shipping lanes
Bird migration routes

n 0 200 400km

Source: Cables, www.noordzeeloket.nl. Shipping lanes, Di studio group analysis work

Figure, 01: North Sea territory

1.3 *territorial interactions*

The inherent, causal links between global and local systems and impacts (physycal, environmental, urban and cultural) now clearly runs in both directions: local changes have global impacts as well as the other way round. This perhaps infers that any local project should have an eye towards its regional and territorial contexts...as the subject of this North Sea design studio suggests.

The North Sea represents an arena where natural and cultural forces have coincided and defined one another for centuries. Along with the Mediterranean, it is likely one of the most contested bodies of water on the planet. Today, the seven countries with coastlines along the North Sea all exercise their territorial rights (12 nautical miles from their coast), enjoy some controls over their respective contiguous zones (a further 12 nautical miles from the coast) and enjoy exploration and extraction rights over natural resources and other economic practices within their alloted Exclusive Economic Zones (extending up to 2oo nautical miles from their coast).

This neat parcellation of the water body belies the complex, overlapping and sometimes contested web of submarine cables and pipelines (oil, gas, power, data etc), shipping lanes (amongst the busiest in the world), ferry routes, flight paths, windfarm and resource extraction fields, conservation areas, fishing grounds, sand extraction activities etc. This artificial complexity is matched by the complex movement and exchange of sediments and nutrients driven by the winds and currents of this shallow sea and it is these conditions that help to sustain the phytoplankton that supports a rich variety of wildlife and fish species.

Historically, one of the greatest sources of nation conflict has been the trade of, and the right to exploit, these highly productive fishing grounds. Annually, approximately 2.5million tonnes of fish and shellfish are caught every year and this represents between a quarter and a third of all the available biomass. While there have been 224 species of fish and shellfish recorded in the North Sea, around 95% of the catch is made up of a small number of species (34 fish and 14 crustacean species) and these stocks are heavily exploited such that species numbers are considered to be outside their safe Biological Limits or below their Minimum Biologically Acceptable level.[1]

In physical terms, the North Sea is a large, semi-enclosed continental sea approximately 960km by 580km and stretches over 750,000km^2. It is relatively shallow and ranges from less than 30m deep at its southern extents, to depths of around 200m as one moves further north. The drainage catchment of the North Sea is home to over 180 million people and the cumulative annual freshwater discharge from this catchment is over 300km^3.[2]

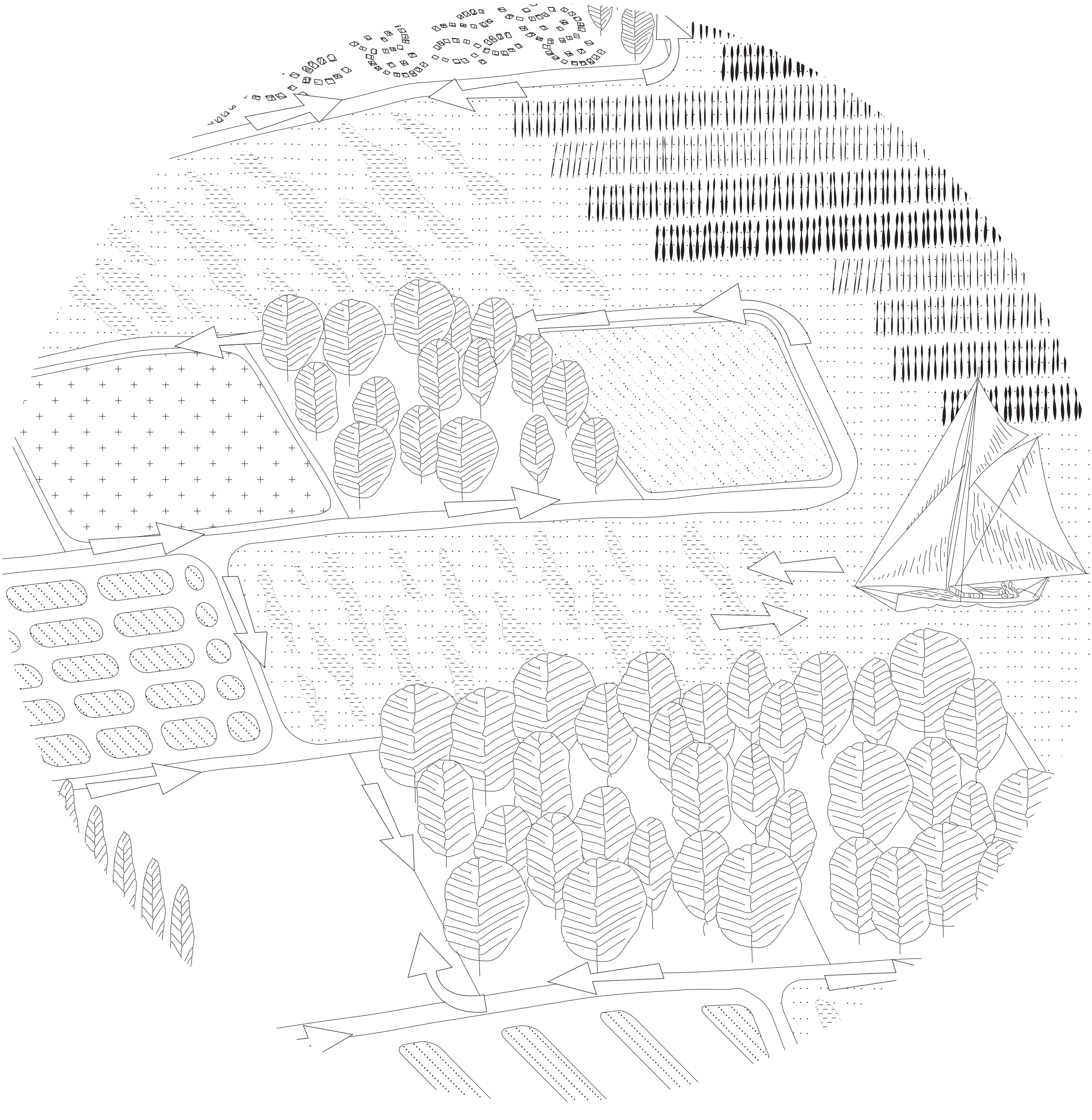
This interaction between terrestrial and marine interests, processes and practices, all driven by the distinct cultural contexts of the nations that border the sea, is a key point. There can be no separation of land and water as the exchange is continuous, multi-scalar, complex and multi-faceted. Indeed, the North Sea Conference (a gathering of nations towards protection of the North Sea environment) marks its “area of interest” as the whole of the North Sea catchment and Dutch spatial planning practices emphasise this conjunction of oceanic and terrestrial territories[3].

At the territorial scale then, it is predominantly this strong connection between cultural, economic and settlement practices over land and water that is of interest within this thesis. The interplay of anthropomorphic and natural processes that (perhaps in the North Sea as nowhere else) span and confound binary divisions of national borders as well as of distinctions between land and water, natural and cultural, near and far.

1. McGlade, 2002

2. North Sea key facts, Safety at Sea website (see sources)

3. Barry et. al., 2006



Figure, 02: Speculative edge condition

1.4 theoretical framework

This interrelation between infrastructural (both natural and urban) and cultural forces and mechanisms is a personal fascination but is also the result of a literature review that forms the theoretical framework for this thesis. This review (see appendix) tracks an historical and evolving approach to natural and urban systems, from being seen as essentially independent layers with discreet interactions, to being viewed as simultaneous processes that evolved together and exert continuous influence over each other.

Traditional reductionist mapping, partly borne of a need to equate natural, engineering, social, economic and urban processes into the same value system, strives towards an optimal state or solution...the masterplan.[1] Marina Alberti's thesis is that these systems and processes cannot be separated but that we should view them as one overarching urban ecosystem whose complexities and interactions cannot be quantified and mapped in the traditional sense.[2]

A contemporary shift in practice suggests that less rational but more revealing forms of mapping and representation are required to not only visualise the complex systems at work in urban landscapes, but also to elicit new and multiple functional associations, systemic mechanisms and cultural meaning ascribed to that landscape.[3] These techniques – perhaps incorporating scenario planning to account for the inherent uncertainties of complex systems – are intended to reveal, superimpose and suggest characteristics, relationships and synergies inherent to (or lying as potentials within) urban and landscape, systems and infrastructures.

The inference then, is that today's urban planning and design project should also concern itself with the visualisation and mapping of process and relationships within urban ecosystems (in a holistic sense). With the overlaying, decomposing and reconstructing, abstracting and personalising, diagramming and flowcharting of urban systems and interactions across spatial and temporal scales. Not with a view towards a single planning outcome or even a comprehensive representation of the landscape in question, but towards establishing potentially unexpected associations and synergies between social, ecological, infrastructural and economic systems that combine to make up the urban landscape.

1. McHarg, 1971
2. Alberti, 2008
3. Belanger, 2013

As well as informing the broad approach of this thesis, these notions inferred a relational mapping exercise be conducted. A visual representation of potentials rather than patterns and an evocative echo of the processes playing out within our urban systems that might nevertheless, propose new (conjoined) urban and natural infrastructures at the scale of the landscape. To relate natural, urban, infrastructural and social processes in order to understand, uncover and represent relationships and synergies (existing or potential) between system components through spatial and temporal scales. Rather than making distinctions between infrastructures (natural / human) or seeking one optimal state or condition, the goal was to explore the capacity of these relationships and synergies to form new complex, interrelated natural and urban infrastructures and component mechanisms that can improve the resilience of the urban ecosystem.

		SCALE			
Process	*Tools*	*Territorial*	*Regional*	*Meso*	*Micro*
Territorial orientation					
group analysis & thematic exploration (natural, social, physical, economic & political components & systems, historical review)	masterclasses (perception & representation), expert input, site visit	North Sea coasts - UK, Netherlands, Germany & Belgium			
Thematic & site analysis					
desk analysis & thematic exploration (delta processes & urbanism responses, demographic, landuse & spatial components & systems, historical urban devt.)	masterclasses (3x3x3 mapping), expert input, GIS, literature & informational review, problem field preparation, projective model, manifesto & image)	North Sea Dutch coast	Dutch South-west delta		
theoretical & narrative frameworks	literature review & theory essay				
problem statements & research questions	conclusions of initial analysis process				
relational mapping exercise (social processes, augmented ecologies & interactions)	abstract process, systemic & relational collage, plotting & layering (incl. temporal character)	North Sea	Dutch South-west delta	island scale	systems interface from polder to molecular scale
regional analysis & site selection (suitability for change in landuse by spatial unit)	mapping overlay of social, infrastructural, natural, functional & spatial characteristics		Dutch South-west delta	island scale	
Design application					
sub-regional analysis & spatial / landuse character (terrestrial & estuarine)	mapping overlay of social & infrastructural, polder & bathymetry makeup			island scale	urban/ polder/ estuary edge
themed design scenario (spatial implications of processes & augmented landuses)	site plan & sections, 3D modelling, functional requirements & precedent studies			island scale	urban/ polder/ estuary edge
design scenario testing & refinement at the sub-regional scale	scenario extents, evolution & goal mapping			island scale	
reflection (relevance, stakeholder input, territorial implications, cultural outputs & shortcomings)		North Sea	Dutch South-west delta		

Figure, 03: Methodology

1.5 methodological framework

The preceding pages serve to introduce the topics that I am interested in and the broad remit of the design studio within which this exploration has been conducted. This thesis is intended to be just that...an exploration of natural, urban and cultural interactions over a number of scales with a view to suggesting possible interventions at the local scale that might nevertheless have broader benefits and address a number of local, regional and territorial concerns.

This initial broad thematic setting (in this case through the Delta interventions studio format) of “re-naturing”, “landscape as infrastructure” and focusing on “where the sea meets the land” being established, the initial stages of the project followed those of a traditional urban or territorial design project, namely:

- Territorial analysis and thematic exploration - in this case through group work - a series of masterclasses on perception, mapping and presentation techniques, a site visit and expert input.

- Analysis and exploration of the problem field at the regional scale including the mapping of social/ economic/ ecological/ physical/ infrastructural components, trends and patterns.

- Summation of problem statements that will inform the formulation of appropriate research questions and narrative framework.

The second phase of the project constituted the relating of territorial and regional themes and system characteristics via a relational mapping exercise in order to distill certain operable landuse and ecological processes that might be applied to a spatial strategy.

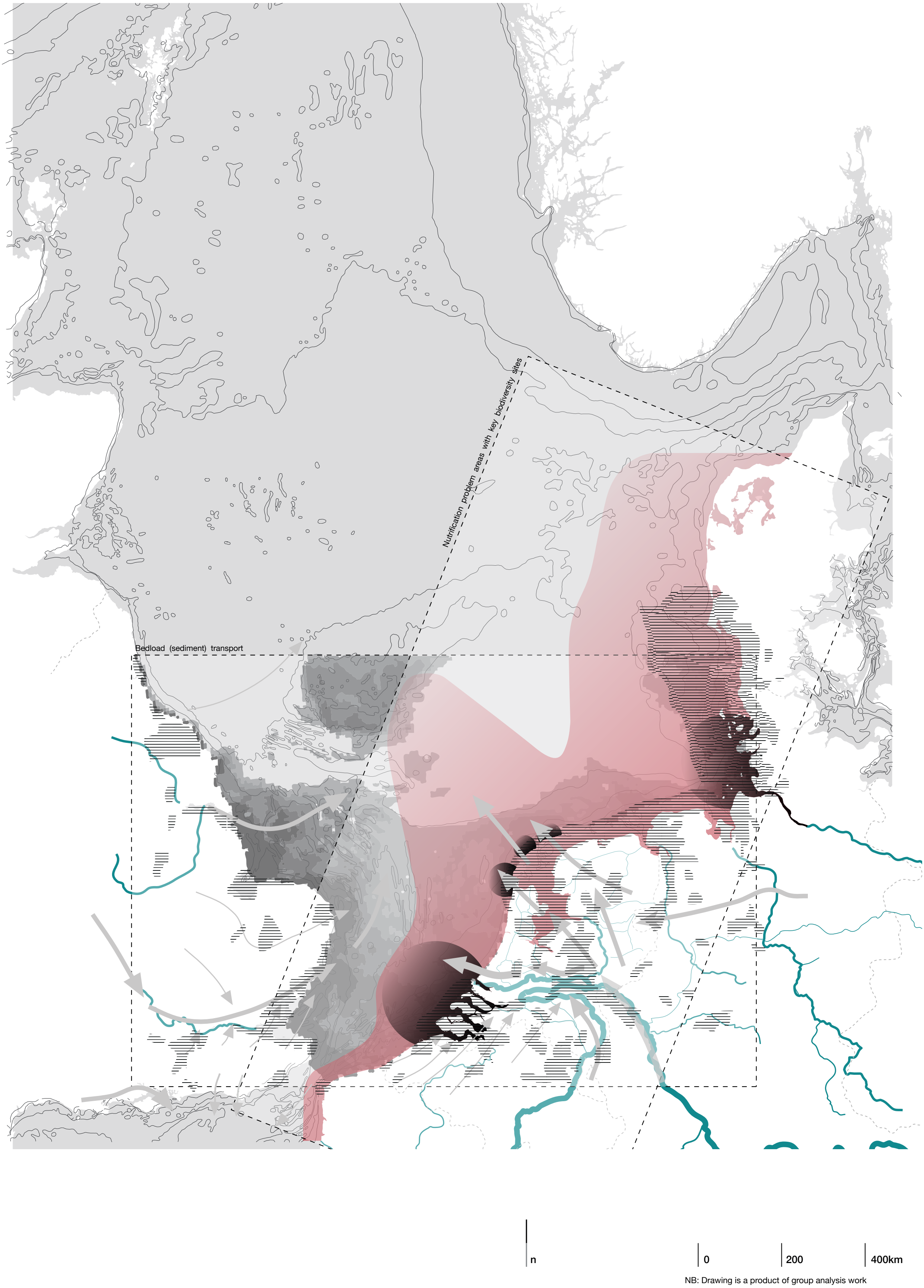
The scale at which these new landuses and processes will be applied is determined by an additional round of regional analysis. This time focusing on the spatial unit of the polder and the characteristics that might suggest if a particular area could be a candidate for the application of these new ecological infrastructures.

This application should conform with the stated design goals and, whilst proposals are to benefit the territorial scale, they will be concentrated at the regional and local scales as a spatial model for the combination of landuse, settlement, social, economic, infrastructural and ecological infrastructures (all embodied in these new landuses).

The characteristics of these idealised scenarios are then tested at the sub-regional scale so as to better understand their spatial, functional and economic implications for the urban and cultural landscapes of the Southwest Delta and of their extrapolation through the scales.

The structure of this thesis will also broadly follow the chronological progression of this structural and thematic analysis at the territorial then regional scales as the basis for the research question, design goals and narrative framework. The thesis will then make a step change into the sub-regional scale with specific design proposals and their broader urban implications.

a territorial overview



Figure, 04: North Sea analysis conclusions

2.1 North Sea environment and nutrient exchange

As mentioned in the introduction, the North Sea is a complex web of contemporary interactions, habitats, political and maritime demarcations as well as the venue for centuries of conflict and trade, recreation and sustenance. While this body of water has played a pivotal role in the formation and maintenance of the various nations and cultures that encircle it, it is the influence of these cultures on the North Sea itself that this short territorial analysis will focus on, concentrating on impacts towards the southern, shallower end of the sea.

This area is a microcosm that nevertheless suffers the same environmental issues identified for the whole by the North Sea Sustainable Development Framework[1] including:

- **Ocean warming and acidification** caused by climate change (potentially altering species distributions and the availability of plankton as the base of the food chain)
- **Sea level rise and more frequent extreme weather events** (Deltares suggests that sea levels could rise in the Netherlands by up to 2m by 2100)[2]
- **Impacts of and on coastal landuse** (environmental and economic viability of coastal populations as well as the nature of flood defence practices)
- **Seabed integrity** (this has a huge impact on the biotic productivity of the North Sea yet is extensively disturbed and dredged)
- **Eutrophication** (largely from nutrient rich runoff via river discharge that feeds algal growth which in turn causes oxygen depletion, fish and crustacean deaths, impacting fisheries and recreation)
- **Biodiversity** (as Alberti notes, 'ecosystem function in the ability of Earth's processes to sustain life over a long period of time. Biodiversity is essential for the functioning and sustainability of an ecosystem.')[3]

As well as accommodating a concentration of human population and activity (this area is home to four of the top 25 largest container ports in the world by volume as well as the four largest in Europe[4]), the character of the south-eastern edge of the North Sea is dictated by the interplay of ocean, riverine and delta processes. Of sediment erosion, movement and deposition along the coast (enabled by the shallow waters) alongside those sediments delivered by rivers (see fig. 5). As McGlade notes,

'The movement of sediments in the North Sea, particularly fine sediments, and the transport of dissolved and suspended particulate matter are major elements in the land-sea interaction and play key roles in determining biological productivity.'[5]

Alongside the deposition of nutrient rich sediments in shallow coastal waters, these river processes also alter the salinity and nutrient composition of this quarter of the sea, contributing to the higher biotic productivity along the coastal fringes (see fig. 7). This availability of nutrients though is a double edged sword. On the one hand the salinity gradients (see fig. 6) and increased nutrient availability closer to shore provide habitat and sustenance to innumerous plant, animal, fish and bird species as well as to the phytoplankton that ultimately supports the food chain. Too many nutrients though and these algal communities can explode (as mentioned previously) and damage both plant and animal (through oxygen depletion or damage to inshore foraging areas) as well as human communities.

Nutrient levels as oceanic carbons in marine sediments are the product of plant and animal decomposition but are also a product of anthropogenic activities and pollution (such as agricultural runoff, chemical and other organic wastewater). As such, total organic carbon levels present in ocean sediments are an indication of environmental health and productivity as well as being used as an indication of contamination[6].

1. Summary of environmental issues, Forum for the Future website

2. Projected sea level rise, Deltares website

3. Alberti, 2008. P. 70

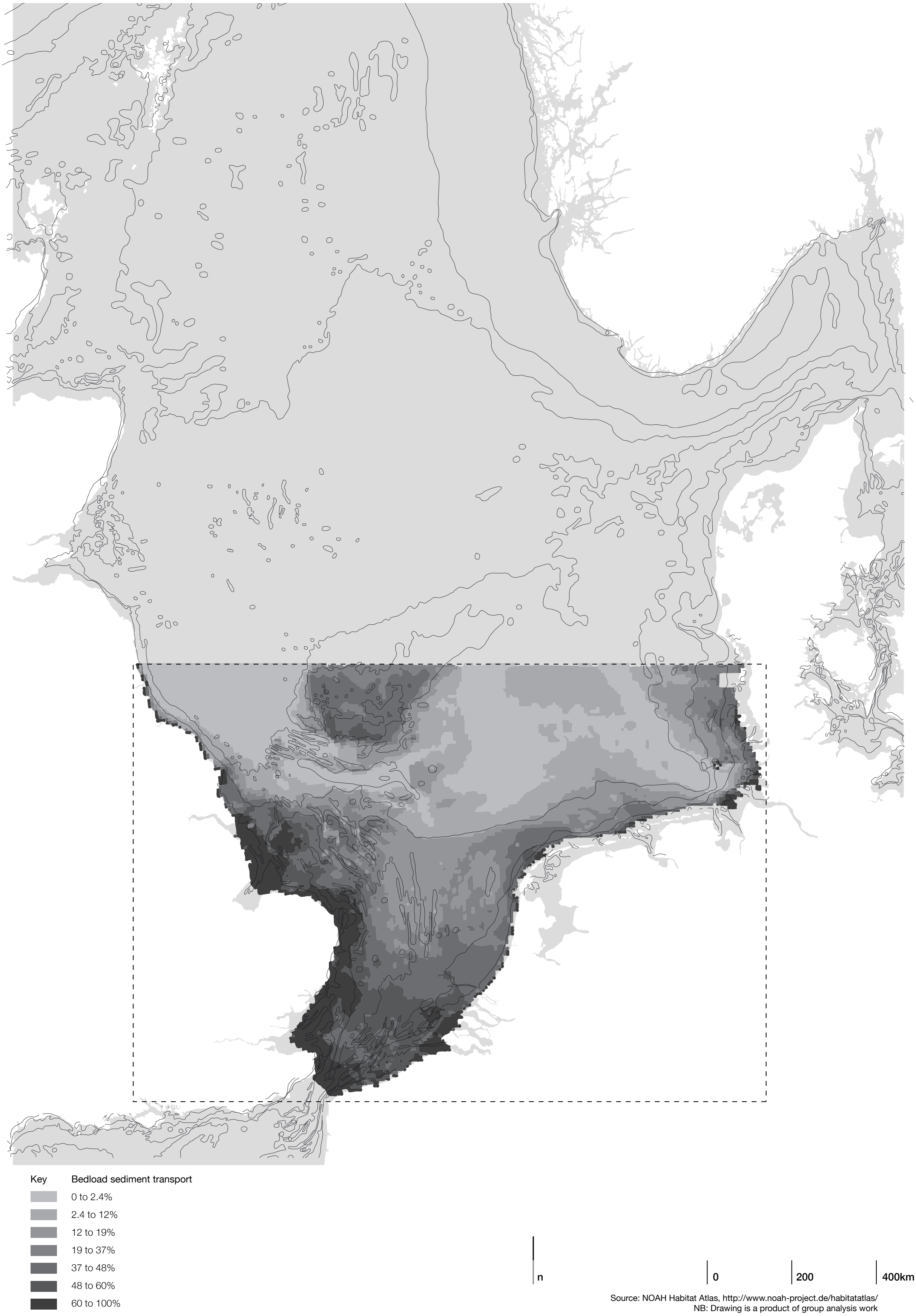
4. Port statistics, World Shipping website

5. McGlade, 2002. P. 347

6. Avramidis et. al., 2015

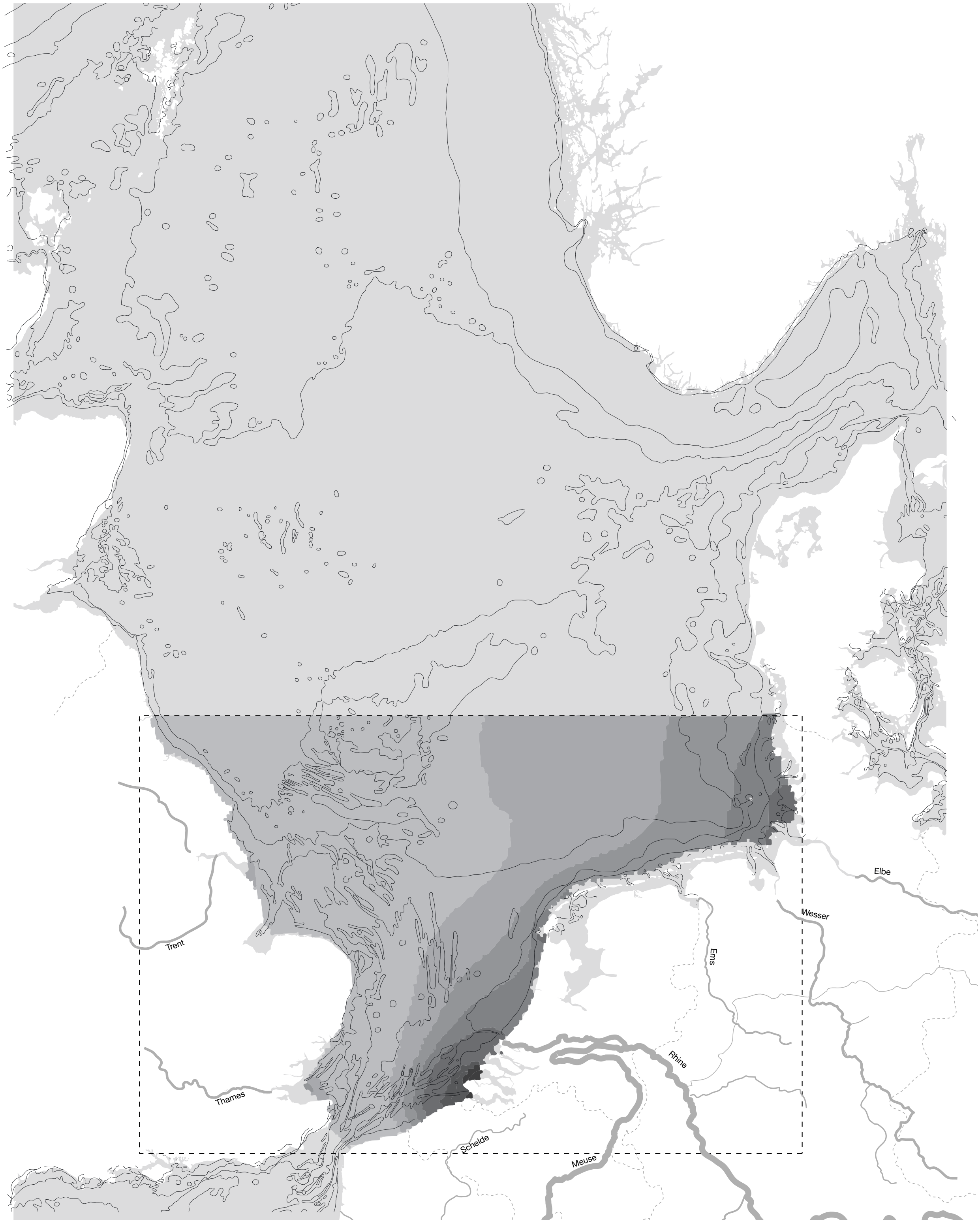
‘The movement of sediments in the North Sea, particularly fine sediments, and the transport of dissolved and suspended particulate matter are major elements in the land-sea interaction and play key roles in determining biological productivity.’[1]

1. McGlade, 2002. P. 347



Source: NOAH Habitat Atlas, http://www.noah-project.de/habitatatlas/
NB: Drawing is a product of group analysis work

Figure, 05: Bedload sediment transport

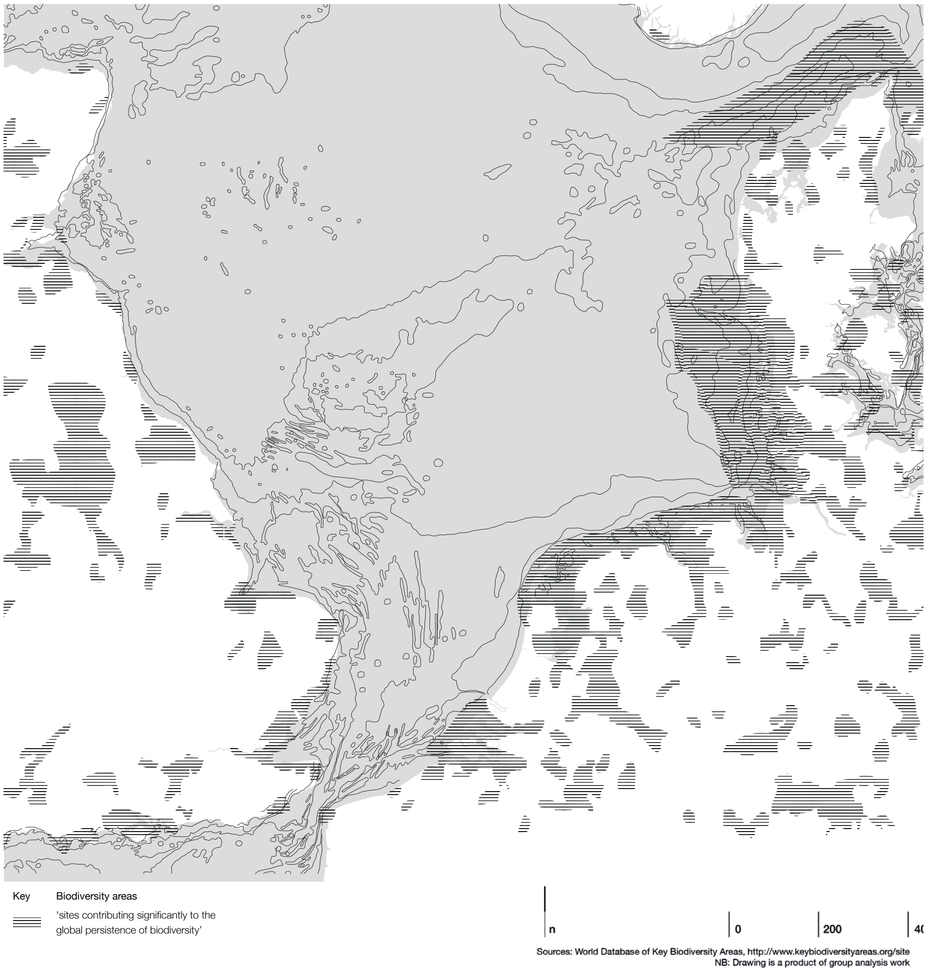


Key	Salinity (bottom) with major rivers
	34.7 to 35.5%
	34.1 to 34.7%
	33.4 to 34.1%
	32.5 to 33.4%
	29 to 32.5%
	24 to 29%
	15.7 to 24%

n 0 200 400km

Source: NOAH Habitat Atlas, http://www.noah-project.de/habitatatlas/
NB: Drawing is a product of group analysis work

Figure, 06: Salinity gradients



Figure, 07: Biodiversity areas

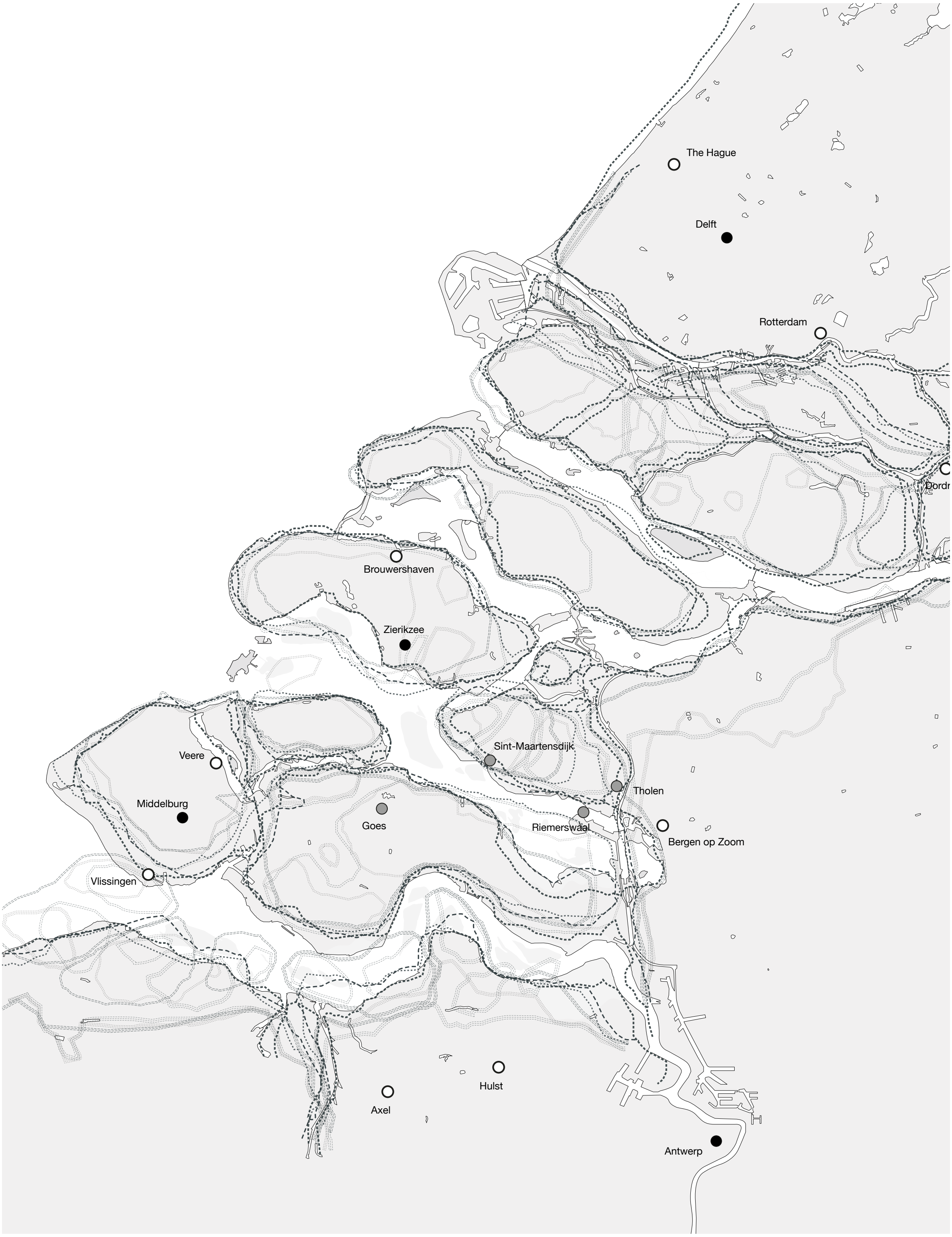
2.2 land / sea exchange

It appears clear then, that many of the processes that contribute to the environmental health of the North Sea as a whole, are heavily influenced by land borne practices, by the sediment flows and deposition within the shallows and by river flows and discharge. The geographical locations where all of these factors combine to provide highly productive terrestrial, fringe shallows and aquatic landscapes and habitats is in the river deltas such as those found along the Dutch and German coasts.

The Rhine / Meuse / Scheldt Delta has traditionally been a prime example of this exchange between land and sea and has supported significant urban populations for hundreds of years. Today though, the estuarine processes that once drove the delta's interactions with the North Sea have been curtailed. Given the significance of these processes for the environmental health of both the delta and the broader stretch of North Sea to which it is connected, measures to improve conditions in one should also aid the other.

In other words, as the focal point between two systems (in the oceanic and terrestrial) whose functioning fundamentally influences both, the delta is the location where measures introduced to benefit both systems might have the most impact and the widest influence.

regional problem field



Key — A Landscape in Flux

- Approx. extents, 12th Century
- 15th Century
- 17th Century
- 18th Century
- 19th Century
- Mid 20th Century

- Oldest settlements, pre 12th C.
- New ports, 12th to 13th C.
- Eastern Scheldt ports, 14th C.

n 0 10 20km

Sources: http://www.topotijdreis.nl. H. Hettema (1947), Grote Historisch Schoolatlas. R. Rutte (2013), Four hundred years of urban development in the Scheldt estuary.

Figure, 08: A landscape in flux

3.1 Southwest Delta, historical settlement patterns

The same forces that promote the exceptional productivity of the North Sea, the movement and deposition of sediments via ocean currents, tidal flows and riverine processes, have historically also played an enormous role in the shaping of the Rhine / Meuse / Scheldt Delta. Initially, the oceanic deposition of sediments moving along the coast from south-west to north-east dominated to create a series of barrier dunes with alluvial wetlands behind. These were sparsely settled but around the 11th century, extreme weather events punctured this barrier, created new sea outlets for the Rhine River and improved conditions for urbanisation.[1]

Settlements within this landscape of salt marshes and tidal flats began to consolidate on areas of higher ground, particularly on creek ridges and often centred on a church.[2] As flood protection dikes improved and expanded, an archipelago of islands developed with their cores fixed by rings of dikes and the fringes of the islands made up of mud flats and salt marshes (Walcheren was likely surrounded by a dike ring by the year 1025).[3] As such, settlement was naturally concentrated within these areas protected from the vagaries of the estuarine forces as well as along the road links between cores that acted as infrastructural spines within the island landscape.

At this time, the leading European ports of Brugges and Ghent were serviced by a number of smaller harbour towns along the North Flanders coast but as their waterways began to silt up, the opportunity arose for new Dutch port towns, located within the delta, to become important transhipment points and trading centres in their own right. So by the 14th century, the Southwest archipelago was settled by a number of older, local centres servicing each of the individual islands (such as Zierikzee and Middelburg) and by a number of newer port towns strategically located along principal trading routes (such as Vlissingen, Veere and Brouwershaven).

As trading patterns changed and the provinces of Brabant and Holland became more important, new harbour towns were established in the Eastern Scheldt (such as Goes and Tholen) along new trading routes as the existing port towns continued to prosper. As much as these centres benefitted from trade, the shifting economies and national fortunes saw the gradual relegation of the Southwest Delta port towns until the whole province fell into decline from the 18th century.

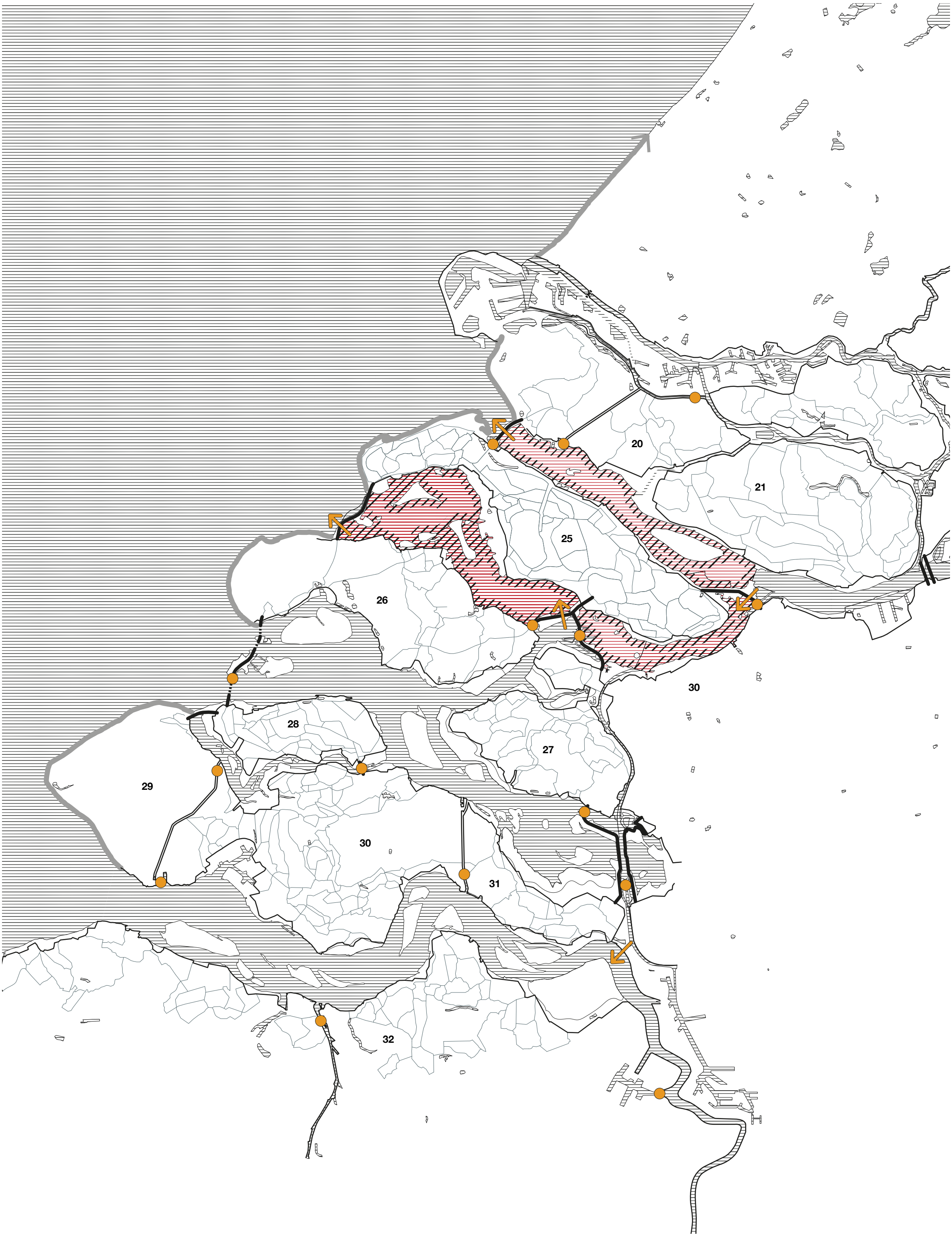
Cultural identities within these towns likely focused on their position as an island centre, on their direct connection to the estuarine waterways and to the North Sea from which they drew their livelihood (through trade, fishing or privateering). Vlissingen in particular enjoyed prime position to control the gateway to the Western Scheldt and to Antwerp, was the centre of the Herring trade in the 15th century and a focus for privateering activities. Indeed, during the 18th century the Spanish term for privateers was “Ditselingos”, meaning “men from Flushing”[4]

The estuarine location of these harbour towns also informed their urban development as sedimentation around the dike rings gradually expanded the encircling areas of dry land and allowed the expansion of the dike rings outward. This process was repeated and as the islands gradually expanded, canals had to be dug to maintain the connection between the original harbour town and the shifting navigable waterways.

As much then, as their locations in the delta determined the cultural identity and economic prosperity of these towns, so too did it determine their physical urban patterns. By the same token, land reclamation and flood protection practices over the centuries absolutely determined the shape and functioning of the delta itself (more on this later).

The constant though over these centuries of spatial and economic ebb and flow, has been change. Of the physical processes that ultimately promoted and then threatened urban expansion and of the shifting trading routes and commodities that could be exploited by ocean going communities and harbours at strategic locations. For hundreds of years, shifting fortunes and flows of waters as well as the sediments they carry determined the location, prosperity, identity and urban form of these communities...until flood protection technology improved and gained the upper hand over natural processes.

1. Meyer, Nijhuis et. al., 2014
2. Rutte, 2013
3. Meyer, Bobbink and Nijhuis, 2010
4. Vissier, 1996



Key

A Landscape Fixed

- Shipping lock
- Coastal defences, dunes
- Dams with
- Storm surge barrier
- Dikes
- Polder structure
- Outlet sluice
- Areas of sand starvation
- Grevelingen, anoxic bottom conditions
- Volkerak-Zoommeer, algal blooms
- Haringvliet, polluted fine sediment
- **21** Dike ring

n 0 10 20km

Sources: H. Meyer Et. Al. (2015), New perspectives on urbanizing deltas. LOLA/ Rijkswaterstaat (2007), Dutch Dikes. Deltares (2012), Sustainable scenarios for the Southwest Delta.

Figure, 09: A landscape fixed

3.2 Deltaworks as a fixed landscape

From the 11th century, this same landscape of flux encouraged the repeated expansion of dikes and flood defences that changed the extents of the islands such that historical townships lost their immediate connection with the sea. At the same time, the sedimentation that had relegated the Flanders ports threatened the accessibility of Zeeland harbours and the sea-going trade that had been their lifeblood shifted to Rotterdam and Amsterdam (only Vlissingen remained viable located as it was, adjacent to the deep water channel access to Antwerp).

With national unification in the 19th century came concerns that the peripheries of the Netherlands were stagnating and the country's economic activities were becoming too centralised. Plans to relocate port activities to Vlissingen and build a rail link to the German industrial areas did not eventuate as an engineered solution was found to the silting up of Rotterdam harbour. The reclamation of the Haarlemmermeer also cemented Amsterdam's dominance and continued the delta's relegation towards the economic periphery.[1] The solution to sediment build-up in the harbour of Rotterdam was the construction of the Nieuwe Waterweg in the early 1870s. This new channel concentrated river discharge at speeds greater than would allow sediments to settle but also effectively bypassed the freshwater discharge role of the Southwest Delta.[2]

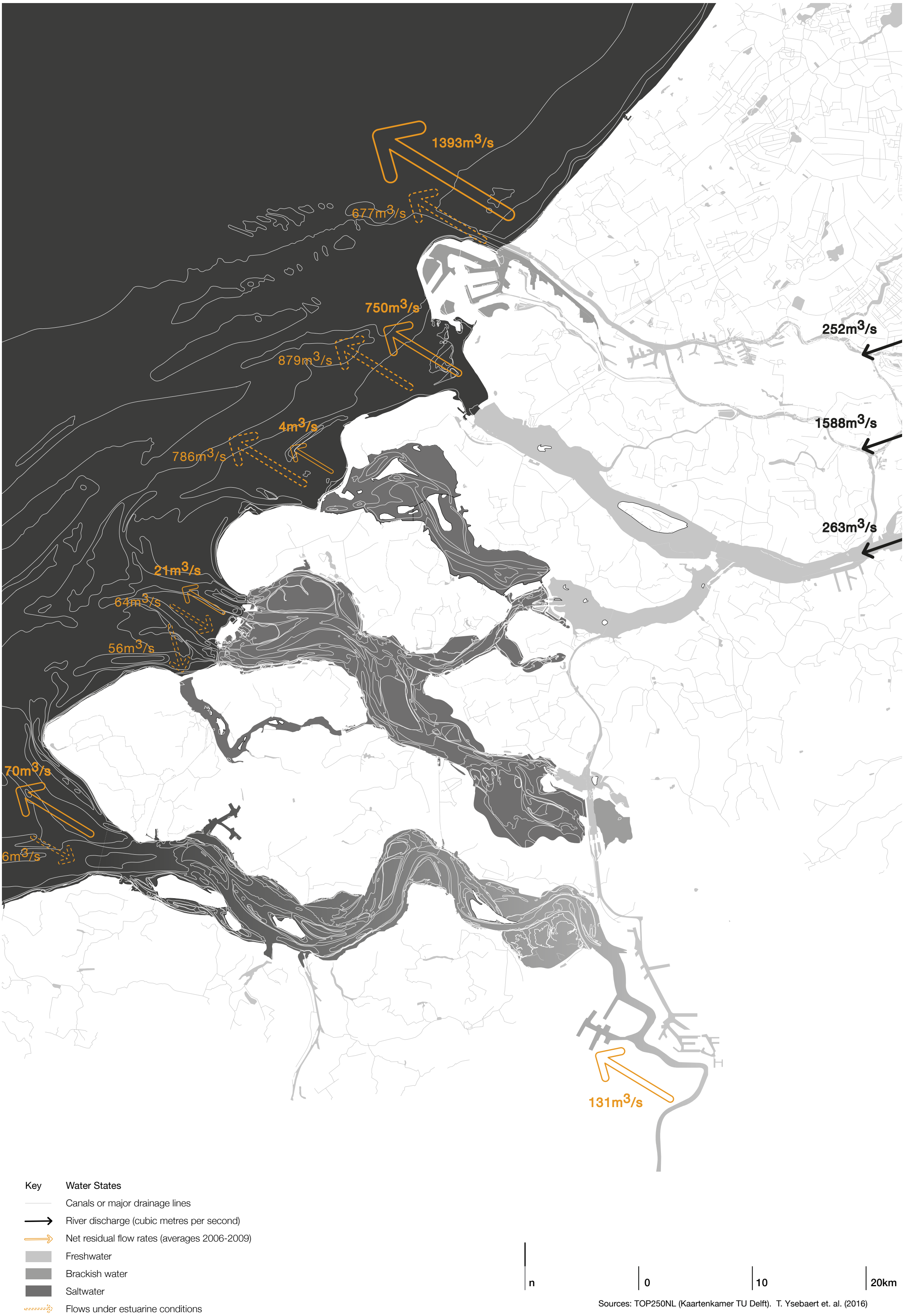
This ability to shape and direct riverine flow was one of the consequences of improvements in flood defence and engineering technology that centralised water management practices in the Rijkswaterstaat and began to promote these as expressions of national identity and prowess.[1&3] The 1953 flood was clearly a watershed in the cultural relationship with the ocean and the monumental engineered flood protection measures implemented (The Deltaworks) certainly aligned with this type of thinking. The Deltaworks shielded deltaic communities from extreme weather events by closing the coastline and curtailing riverine outlets to the North Sea with a number of monumental dam and sluice structures but it also improved road transport links between islands and enabled expansion of the tourism and recreation industries.

The creation of a number of different water bodies from a previously inter-connected estuarine system also provided freshwater reserves that facilitated an expansion of agricultural and industrial practices but these distinct water bodies also each began to exhibit their own characteristics and problems (see fig. 10 and opposite). These issues include '…the degradation of ecological quality and ecosystem functioning, disruption of fish migration routes, and water and sediment quality problems.', largely caused by '…the impact of [these] infrastructural measures on the natural processes, such as an imbalance between geometry (e.g., depth, surface area), water flows and its constituents, a disrupted sediment balance and a lack of connectivity.[4]'

Essentially the estuarine processes that created both the water salinity gradients (gradual transitions between salt and freshwater that allow for a multitude of habitats) and the tidal mudflats and salt marshes have been curtailed with a corresponding reduction of habitat extent, and therefore, of biodiversity.[4&5] Indeed, Paalvast suggests that 'In 2011, less than 7% of the total area of the Rhine-Meuse estuary was left, relative to the 1950 situation.'[6] and the Delta Commission's 2008 report concluded that without additional artificial (beach nourishment) or natural (estuarine and sedimentation processes) sand replenishment, the tidal flat habitats in the Eastern Scheldt could disappear by 2050.[7] The Netherlands Environmental Assessment Agency (PBL) also estimates that overall, in the hundred years to 2000, the diversity and health of natural ecosystems has declined by over a third to just 18% on their Natural Capital Index. This infers that, on average, the number of species found in an ecosystem is just 18% of what would be expected for the natural state of that ecosystem.[8] At the same time, the landuses that initially benefitted from the draining of the polders and the securing of freshwater supplies, broad field agriculture, are becoming threatened by rising soil salinity (as salt water seeps into lowlands through the barriers) and these issues will only increase as sea levels rise.[9]

So while the fixing of the terrestrial landscape edges and the containment of estuarine processes no doubt reduced flood risks to those living in the delta and (perhaps temporarily) facilitated agriculture, the impacts on biodiversity, variety and viability of habitat, water quality and connectivity as well as fundamental estuarine processes (of waterflow, exchange, sediment transport and deposition) have been detrimental.

1. Meyer, 2014
2. Meyer, Nillesen and Zonneveld, 2012
3. Meyer, Nijhuis et. al., 2014
4. Ysebaert, 2016. P. 34
5. Troost, 2012
6. Paalvast, 2014. P. 51
7. Delta Commission, 2008
8. Biodiversity in The Netherlands, PBL website
9. Wiersma et. al., 2014



Figure, 10: Water states

3.3 water states

Clearly the Deltaworks - as the natural extension of centuries of land reclamation and flood defence practices - have substantially altered the estuarine processes within the Rhine / Meuse / Scheldt Delta and altered river flows, sediment loads and the nature of the delta's water bodies. The National Flood Risk Analysis for the Netherlands report indeed, suggests that the majority of the levee systems within the Southwest Delta are able to withstand water levels equivalent to a 1 in 4,000 year flood event (the second highest allocation behind the 1:10,000 standard).[1]

While the benefits for flood protection, vehicular access and the availability of fresh water are relatively clear, changing attitudes to water management practices in the Netherlands (as evidenced by programs such as "Room for the river" and the Delta Commissions "Working together with water") suggest a move away from the engineered approaches that the Deltaworks represent. At the same time more emphasis is being afforded - and significance attached to - natural processes and one of the key indicators of their success...levels of biodiversity.

The question is though, that with sea level rise predictions steadily increasing (currently up to 2m by 2100 as mentioned previously), what impacts will the traditional approach of heightening dikes have on settlements and lifestyle, along with continued impacts on estuarine systems. Indeed the Delta Commission recognised this untenable situation and the increasing uncertainty of sea level rise predictions in its 2008 report (that assumed a sea level rise by 2100 of 0.55 - 1.2m) along with their assessment that the Eastern Scheldt barrier will only be operable up to a 1m rise in sea level, after that 'the Committee can see good arguments for implementing such safety solutions as will restore (nearly) all the tidal dynamics of the Eastern Scheldt.'[2]

So it seems clear that the traditional approach of engineered barriers between the estuarine and oceanic water bodies has protected the archipelago from flood but have also curtailed the processes that foster environmental health in the delta (the exchange of sediments and presence of salinity gradients). Ironically it is precisely these processes that contain the mechanism by which the delta landscapes might physically accrete (increase in height) and so keep up with the rising sea levels: something that the constructed barriers are unable to do and so may fail before the end of the century.

The constant morphological changes inherent to a deltaic landscape (and those that drove the historical location and shaping of the island settlements) are driven largely by the sediment regimes facilitated by riverine (carrying sediments washed into the rivers from their terrestrial catchments) and tidal (sediments brought in from the ocean) flows. Clearly the Deltaworks interrupted these movements, ranging from a total cessation of flows (as in the case of the Grevelingen, cut off from coastal influence by the Brouwersdam and from riverine flows by the Grevelingendam) to a reduction in natural flows, as is the case with the Eastern Scheldt storm surge barrier on the estuarine dynamics of the Oosterschelde. These estuary dynamics and interactions are complex and vary from water body to water body as well as between areas in the same sea arm. The overall trend though, is that the more isolated an area is from the natural flows, the greater the impacts on (i.e. the reduction of) sediment movements. Even after the impositions of the Deltaworks, the natural processes of erosion and deposition within the estuarine water bodies still occur. If there is less sediment input from the rivers (due to changing landuse practices and riverine flow dynamics) or from the coastal areas (cut off by dams or flood barriers) then erosive forces hold sway (particularly in intertidal areas), a process known as sand starvation (in the Oosterschelde alone the costs of sand nourishment to offset its impacts are estimated as up to €40million by 2060[3]).

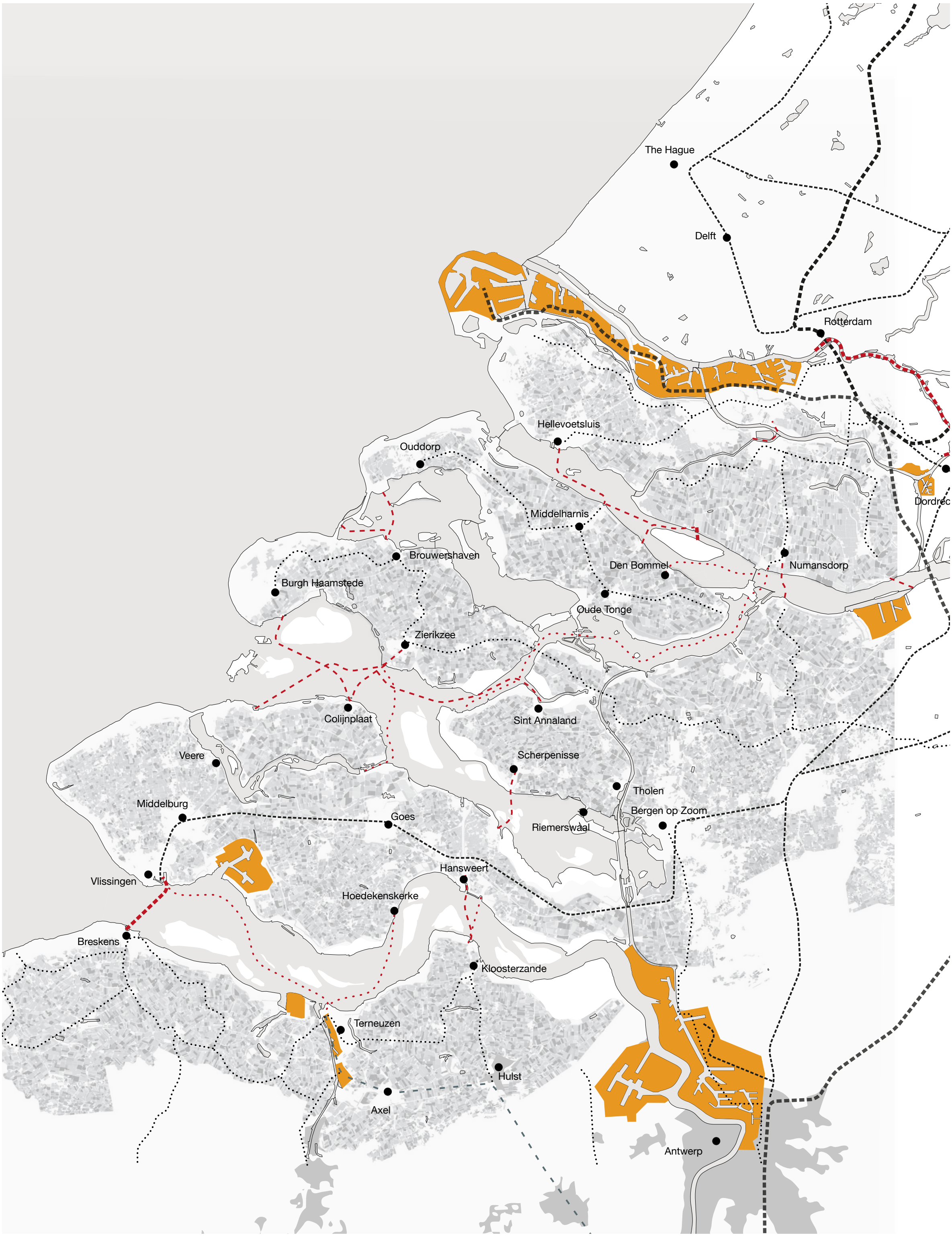
The Oosterschelde is the least affected by its respective barrier but its tidal range has still reduced by around 12%, the influence of the North Sea on the estuary has reduced by around 30% and as a whole, the Oosterschelde is less morphologically active...the very processes that (along with tidal flows) build and maintain the intertidal mudflats so crucial for habitat.[3] Sediment accretion rates by natural estuarine processes are approximately 1cm per year in the Oosterschelde[4] so in a morphological and habitat sense, movement of sediments could be seen as the infrastructural driver of both biodiversity and mechanisms to match sea level rise.

1. Flood risk in The Netherlands, Rijkwaterstaat website

2. Delta Commission, 2008. P. 57

3. Brand et. al., 2016

4. Wiersma et. al., 2014



Key   Economics and landuse

- Settlements
- Ferry routes as at 2010
- Ferry routes, summer only
- Ferry routes removed since 1950
- Passenger rail routes
- Rail routes removed since 1950
- Tram routes removed since 1950
- Port industrial areas
- Open field agricultural uses

n   0   10   20km

Sources: H. Meyer Et. Al. (2015), New perspectives on urbanizing deltas. K. Myserli from http://code.waag.org/mansholt/map/#walcheren

Figure, 11: Economy and landuse

3.4 economy and landuse

The economies and globally connected infrastructures associated with the Delta are not insignificant. In 2014, Rotterdam and Antwerp accounted for over a third of all goods passing through Europe's top 20 ports (602m of 1638m tonnes) and this throughput has been steadily growing in recent years.[1] One half of Rotterdam's, and over a third of Antwerp's cargo was liquid bulk goods such as liquefied natural gas, crude oil, oil products and others. These imports support the largest petrochemical cluster in Europe which, along with a number of large scale industrial areas reliant upon the port and logistics infrastructure, is dependant on the large supply of freshwater for industrial processes to be found within the delta's waterscapes. The continued success of these activities in the face of growing competition from Asian ports, a changing climate and changing attitudes to fossil fuel use is nevertheless in question. There is a growing realisation from the port and municipal authorities that a heavy reliance on fossil fuel based industries is neither socially, environmentally or economically sustainable. As such, there are multiple visions (from industry and the Zeeland municipality) for how these areas might navigate the energy transition and address climate change, including the establishment of a Biobased Delta to concentrate on, and attract, biotech industries but also to recalibrate the existing fossil fuel based refinery industries towards bio-refineries (extracting products, heat and fuel from woody biomass etc.).[2]

For hundreds of years, the settlement of Zeeland was indelibly connected to its landscape and the adjacent ocean, for trade and cultural identity. The centuries of land reclamation and flood protection measures as well as shifting economies of trade, transferred the area's industrial focus from the sea to the land (from fishing to agriculture) such that in 1899, only 1% of the area's population was employed in the fishing industry[3]. The fertile sediments that facilitated such productive fisheries, once deposited and de-watered, also supported the agricultural practices that became the archipelago's mainstay once trade and fisheries diminished in significance. These practices too were at the mercy of global economic forces as a previous concentration on wheat and madder crops became uneconomical and attention focused on the growing of sugar beets, potatoes and other crops.[4] The agricultural conditions did improve with the plentyful supplies of freshwater guaranteed by the Deltaworks but in 2011, agriculture and fisheries (along with associated industries) accounted for only around 9% and 1% of employment within Zeeland respectively[5].

In fact, while the area of farmed land has remained largely the same since 2000, the number of farms has halved[6]…suggesting consolidation and perhaps that less farms are being run by individual families and more being operated by larger concerns that might not be resident in Zeeland and so profits may not stay in the region. The vast majority of the delta's economy is oriented towards the service and industrial sectors, including around 9% of employment within the recreation and tourism industries[5] including the tourists (approx. 17million overnight stays a year) that visit to enjoy the ocean and very waterways the Deltaworks barriers have constrained. In spatial terms at least, this represents an imbalance as despite both contributing similarly to the Zeeland economy, agriculture's terrestrial landuse footprint (as occupying approx. 70% of available land) dwarfs that of the areas where recreation might take place (in recreation, woodland and nature areas) at around 10% of the province.[7]

The delta is one of the most sparsely settled areas in the country with most municipalities exhibiting densities of less than 200 inhabitants per km2 and over half suffering a fall in population between 2011 and 2016[7]. Despite being adjacent to the densely urbanised areas between Brussels and Amsterdam in general and the centres of Rotterdam/ The Hague, Antwerp, Bruges and Dordrecht in particular. This decline is reflected in (or perhaps partly caused by) the paucity of national trunk road connections (three only) and passenger rail lines (a single line to Vlissingen) into the delta. This was not always the case and a number of tram and ferry services have been removed since the 1950s (see opposite). The delta centres might also be suffering agglomeration shadow effects from the arc of larger and better connected centres in their vicinity, i.e. their lack of connectivity to the national networks discourages investment that may go to better connected centres but also prohibits the delta's urban areas from "borrowing", or making use of services in these better connected centres. Research suggests though, that this isolation might reduce competition for small businesses in the Delta and promote a localised economy.[8]

1. Port statistics, Eurostat website

2. Bio-based Delta website

3. Everything you should know about Zeeland, Province of Zeeland

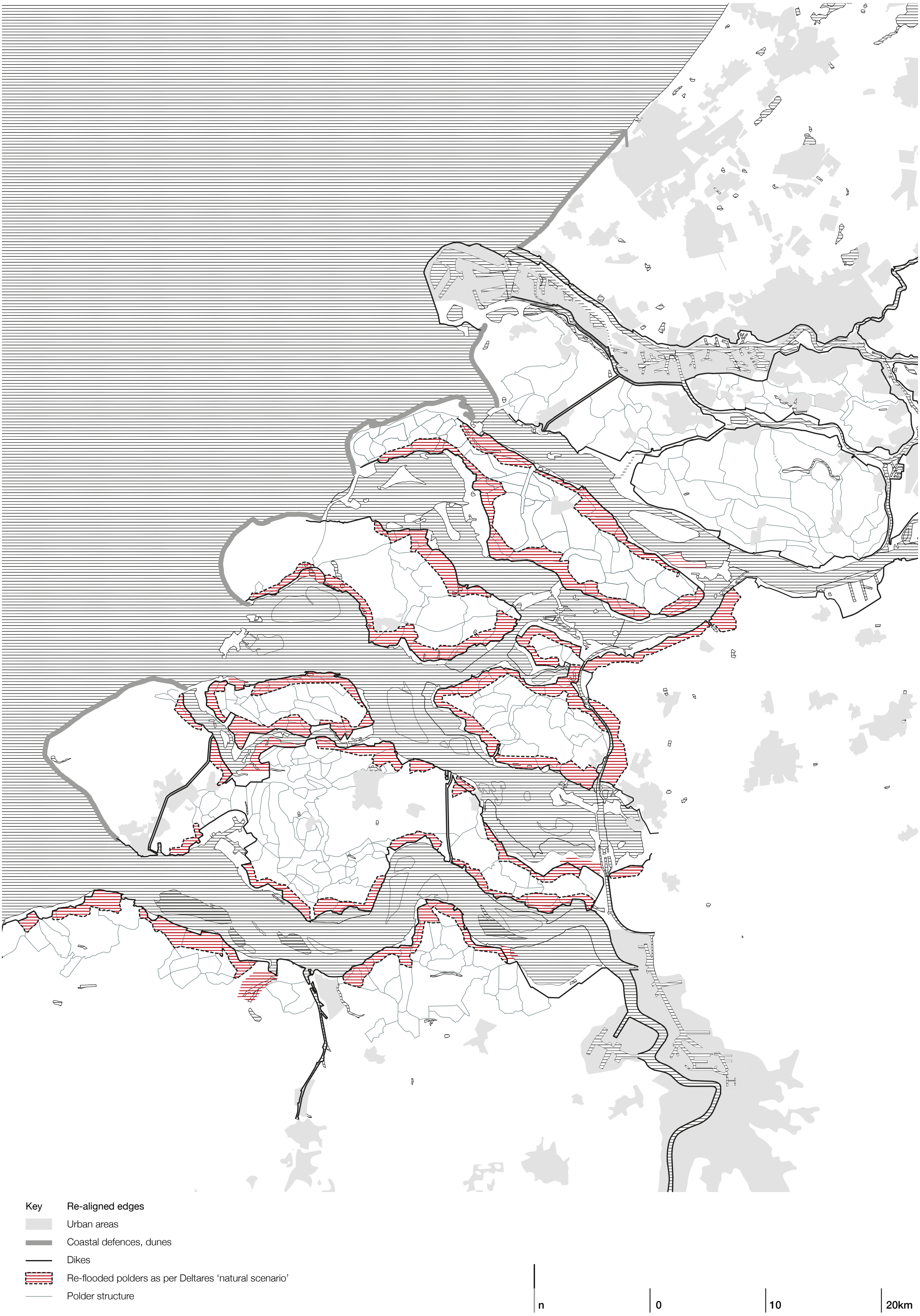
4. Meyer et. al., 2015

5. Zeeland economic agenda, Province website

6. Zeeland agriculture statistics, CBS website

7. Landuse and population growth in the Netherlands, CLO website

8. Meijers & Burger, 2016



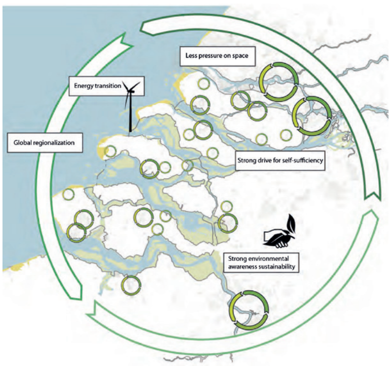
Source: Deltares (2012), Sustainable scenarios for the Southwest Delta.

Figure, 12: Depoldering in Deltares ‘natural scenario’

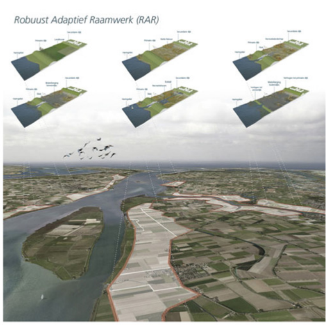
3.5 the future of the delta

The challenge then is to suggest ways in which the area's communities could re-animate a productive relationship with what has always been its greatest asset, the landscape and identity of a settled archipelago within a fertile delta. This relationship might move beyond the currently overwhelming dominance of agricultural landuses and give more priority to recreation activities and the natural landscapes in which they take place (in particular in the water and along coastal or estuarine fringes). Attention should also be paid to improving connectivity towards the enormous population centres that surround the delta.

While this is one of the goals of this thesis for proposed interventions in the Southwest Delta, most academic and professional proposals concentrate on natural and estuarine dynamics in the delta in part at least, to restore ecological values within its waterways. A number of visions for the re-naturing of polder edges and re-introduction of estuarine systems have been put forward (or compiled) by a variety of actors including NGO's such as the World Wildlife Fund[1], academics[2&5], practitioners[3] and research institutes (see the range of baseline approaches - including a "natural scenario" - expounded by Deltares[4], see opposite).



REST scenario, H+N+S



Adaptive framework, haringvliet, IPDD

WWWF proposal for the delta as a biodiversity hotspot

The constituent components and the extent to which these visions seek to return estuarine flows vary, from opening the barriers for a complete return to natural flows (as in the WWF plan intended to maximise the return of biodiversity) to variations of flows and new storm or saltwater intrusion barriers. The implications of these schemes are highly complex though as a huge number of issues coincide in the management of deltaic and riverine systems from the response of flood management to sea level rise, the maintenance of freshwater supplies for agriculture and industry, sand starvation (via reduced sediment loads and transport), water storage and retention, maintaining port access to saltwater intrusion and increased river discharges.

Given that the "business as usual" approach though, offers little promise for improved biodiversity or water quality in the Rhine / Meuse / Scheldt Delta, this thesis will assume that estuarine flow and sedimentation processes can largely be restored to the delta but that in this restoration, must lie the impetus for both an economic and cultural rennaissance of the communities within the archipelago. This is broadly based on Deltares' 'natural scenario' for the reorientation of flood defence infrastructures in the delta from the current thin lines of engineered structures (dams and dikes) to broader zones of saltmarshes or other augmented ecological engineers (such as oyster reefs etc.) to buffer against storm and flood damage, increase the elevation of the land via sediment accretion and offer new saline agricultures and natural habitats to replace existing agricultural landuses.

1. The Netherlands as a hub for biodiversity, WWF website

2. Meyer, Nillesen and Zonneveld, 2012

3. Plans by H+N+S/ Deltares in Meyer, Bobbink and Nijhuis, 2010

4. Wiersma et. al., 2014

5. Meyer et. al., 2015

6. Image sources: Delta Commission, 2008, Meyer et. al. eds., 2010

thesis and design framework

Assuming a re-opening of the Southwest Rhine/ Meuse/ Scheldt Delta and a return to a more ecologically functional model, could scenarios for new augmented ecologies inform a re-orientation of the urban ecosystems and spatial landscapes within the delta towards greater social, economic and ecological efficacy and connectivity?

4.1 research questions

In the context of urban systems combining with their environmental contexts to produce complex urban ecosystems (as described in the theoretical framework), the Southwest Delta might be seen as a prime example of one system's subjugation over the other...to the potentail detriment of both. This attempt to absolutely order and control natural systems in the name of flood protection (as evidenced in the Netherlands as a whole and in the delta in particular) is perhaps the natural extension of 20th century planning, engineering and design practices.

The recent shift towards the acceptance and harnessing of natural processes (augmenting ecologies within multi-functional landscapes) and the opportunities this might afford for the enrichment of our urban landscapes offers another approach.[1]

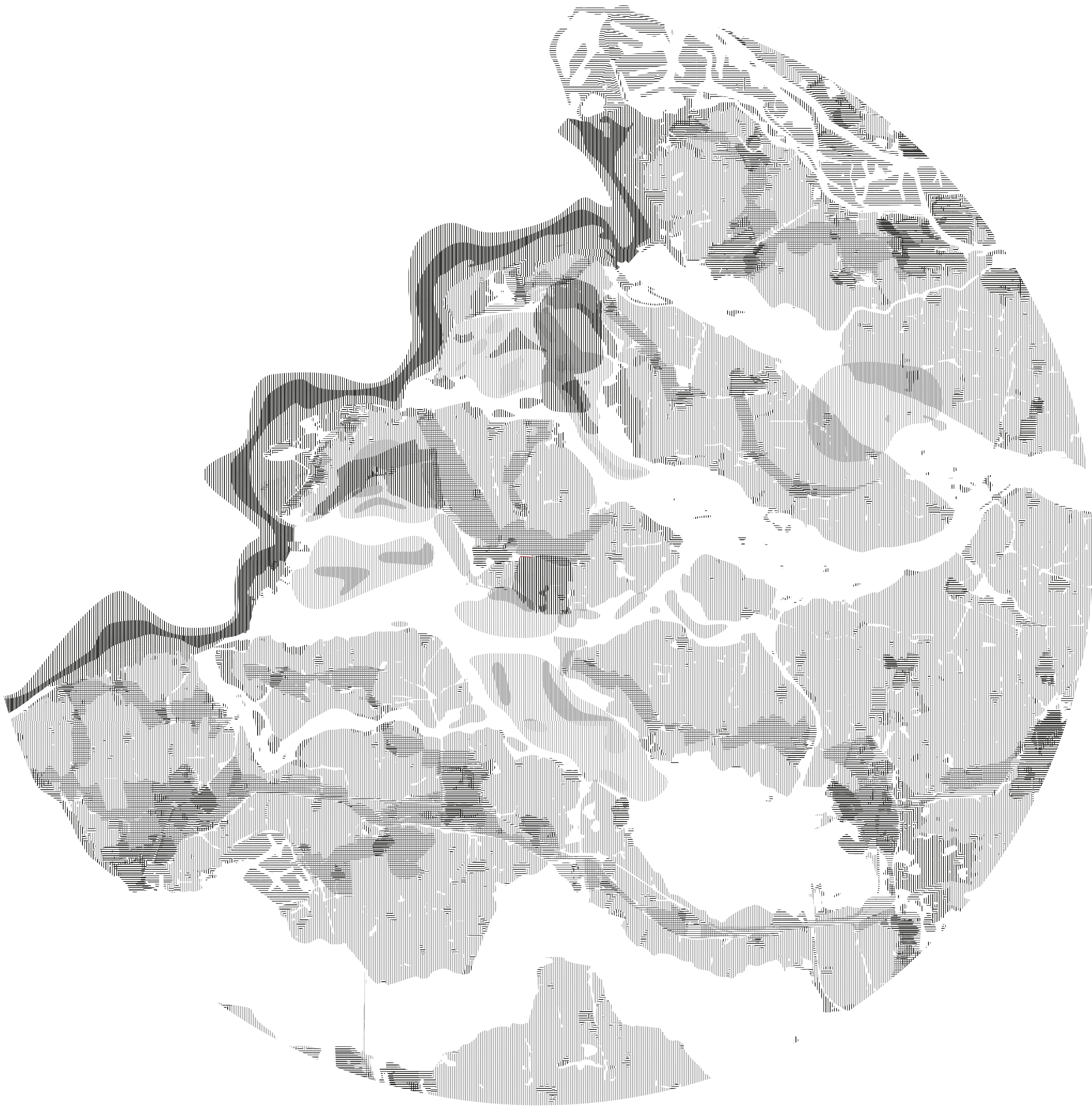
This approach recognises the ultimate social and environmental unsustainability of our current restriction and separation of natural versus urban processes (as demonstrated in the Southwest Delta) and perhaps suggests the ultimate goal of planning in our urban and rural landscapes should be maximising their resilience (particularly in the current context of quickening global climate, social and economic change). The term as used here is intended to accord with Alberti's hypothesis that 'resilience in urban ecosystems is defined by the system's ability to maintain human and ecosystem functions simultaneously.'[2]

Main research question
Assuming a re-opening of the Southwest Rhine/ Meuse/ Scheldt Delta and a return to a more ecologically functional model, could scenarios for new augmented ecologies inform a re-orientation of the urban ecosystems and spatial landscapes within the delta towards greater social, economic and ecological efficacy and connectivity?

In order to address this question, a number of related topics will be investigated (***sub-research questions***).

- What is the current social, economic and ecological character of the delta?
- What potential is there to introduce new links and synergies between these characteristics and how might we augment certain ecologies to improve efficiencies and attract multiple social, economic and ecological benefits?
- What are ecosystems services, what particular urban predicaments can they address and how might they be used to measure the benefits of new proposals?
- What specific landuse practices could be applied in the delta to bolster ecosystem services and address the design goals?
- What functional, spatial and locational principles could be used to guide the design of these multi-functional landscapes intent on providing ecosystem services?
- How might historical and current settlement patterns and relationships to landscape within the delta offer inspiration for new relationships and settlement patterns?
- How might the role of the countryside within the delta area (agriculture, polder landscapes, recreation etc.) be enriched?
- How might changing landuse practices and priorities contribute to cultural identity in the delta?
- What benefit could mechanisms grounded in the delta (ecological as well as social and economic) provide for the broader North Sea territory?

1. Waldheim, 2016
2. Alberti, 2008. P. 22



Key | Propositional landuse patterns

- Settlement, existing
- Settlement extensions
- Industrial areas
- Natural systems, existing
- Natural system extensions
- Agriculture and fisheries, existing
- Agricultures extended

Figure, 13: Speculative landuse pattern

4.2 narrative framework

Cultural explorations of the Zeeland, Belgian and Dutch coasts within this thesis have concentrated on the slippery notions of settlement, urban constancy and cultural anchors in the ever-changing landscape of the deltaic coastal conditions. It was these conditions that first characterised (likely affording both sustenance and strategic advantage) and then threatened the populations and discreet cultures of settlement in these areas.

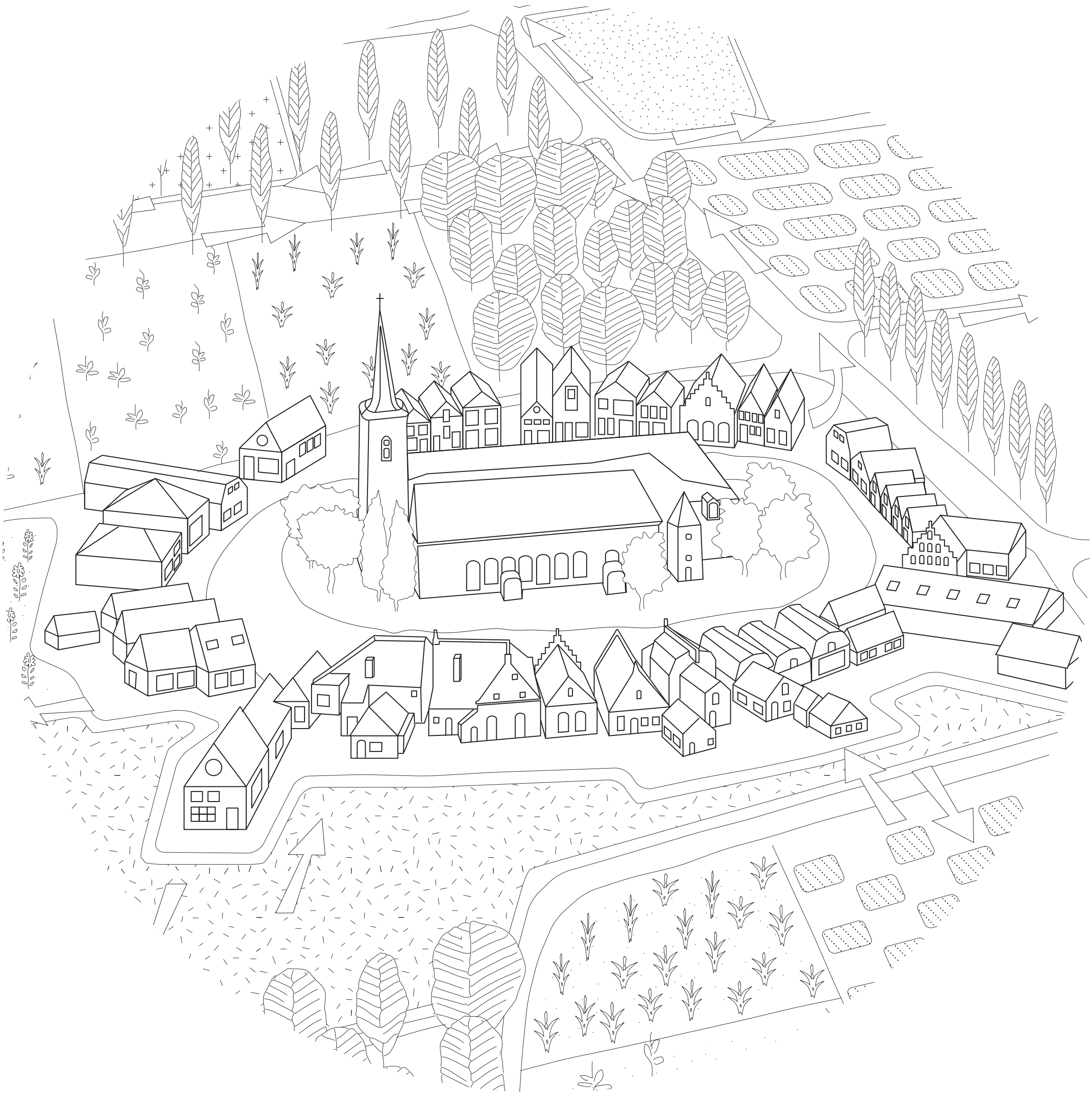
So within these fixed reference points, cultural and economic interactions between the population and the ocean have fluctuated dramatically over the centuries. A once seagoing people occupying a land that was continually shaped and re-shaped by ocean and delta processes have turned their back to the water and re-focused on the agricultural land created by their formidable flood defence systems. These defences not only placed a physical (and hence emotional and cultural) barrier between the population and the water, but they fixed island and coastal edges that were previously in constant flux.

The theoretical hypothesis is that, notwithstanding the fragility of these defences in the light of extreme sea level rise, this disconnection has fundamentally restricted both the natural systems they seek to contain and the potential richness of settlement in these areas. A reworking of the settlement and agricultural patterns, as well as a review of the area's physical relationship with the waters that surrounds Zeeland, could suggest conditions where natural processes could enrich, and once again provide economic and cultural sustenance for those inhabiting the territory.

As discussed previously, there have been a number of proposals for a review of water management and landuse strategies within the delta, generally intended to return some semblance of estuarine and natural processes as alternative means of flood attenuation. Some envisage this happening by selectively allowing lowland polders to be re-flooded by delta processes (temporarily or permanently depending on natural cycles).[1]

This approach typifies the intention to break the rigidity of the current dike and polder landscape structure and blur the boundary between land based and aquatic landuses so as to allow the distinction between urban and natural areas to become somewhat fuzzy (see opposite for a notional vision of this process). The implications of these actions will likely be largely limited to the estuarine areas but the same approach could be applied to the coastline (that is now a fixed physical, legal and economic edge) such that it too, might lose its rigidity as coastal erosion and deposition processes are allowed to play a greater role, requiring urban and regional planning to incorporate these processes as existential components of the urban and rural landscapes.

1. Meyer, Nijhuis et. al., 2014



Figure, 14: Speculative urban interface

4.3 project goals

The exploration of topics raised by the research questions will be conducted through the lenses of the theoretical and narrative frameworks. The intention is to focus on a reinterpretation of the landscapes within the Southwest Rhine / Meuse / Scheldt Delta at a strategic and conceptual level. To uncover synergies between the systems that operate within the delta (and, by extension, across the North Sea) and use these synergies of interrelated natural and urban processes to proffer suggestions for alternative, multi-functional landuse and settlement patterns that (through incorporation of the notion of flux) may be more economically, socially and ecologically resilient than those currently within the delta. These themes will be distilled into a strategic spatial design proposal and then tested at the sub-regional scale.

The following broad design goals are intended to guide and narrow the focus of this process:

- As notions of resilience infer an ability to absorb and **adapt to change**, new landscape strategies and scenarios will therefore incorporate change and the temporal dimension as intrinsic components of the design.

- Distinctions between landscape and settlement layers (urban / countryside, land / water, beach / ocean / sandbar, agriculture / aquaculture etc.) should be eroded such that they don't detract from, but rather bolster community, economic and cultural values by proposing landuses that might share synergies with economic activities. In other words, these **indeterminate margins** in the delta archipelago will ideally be required to perform ecological, economic and cultural functions simultaneously.

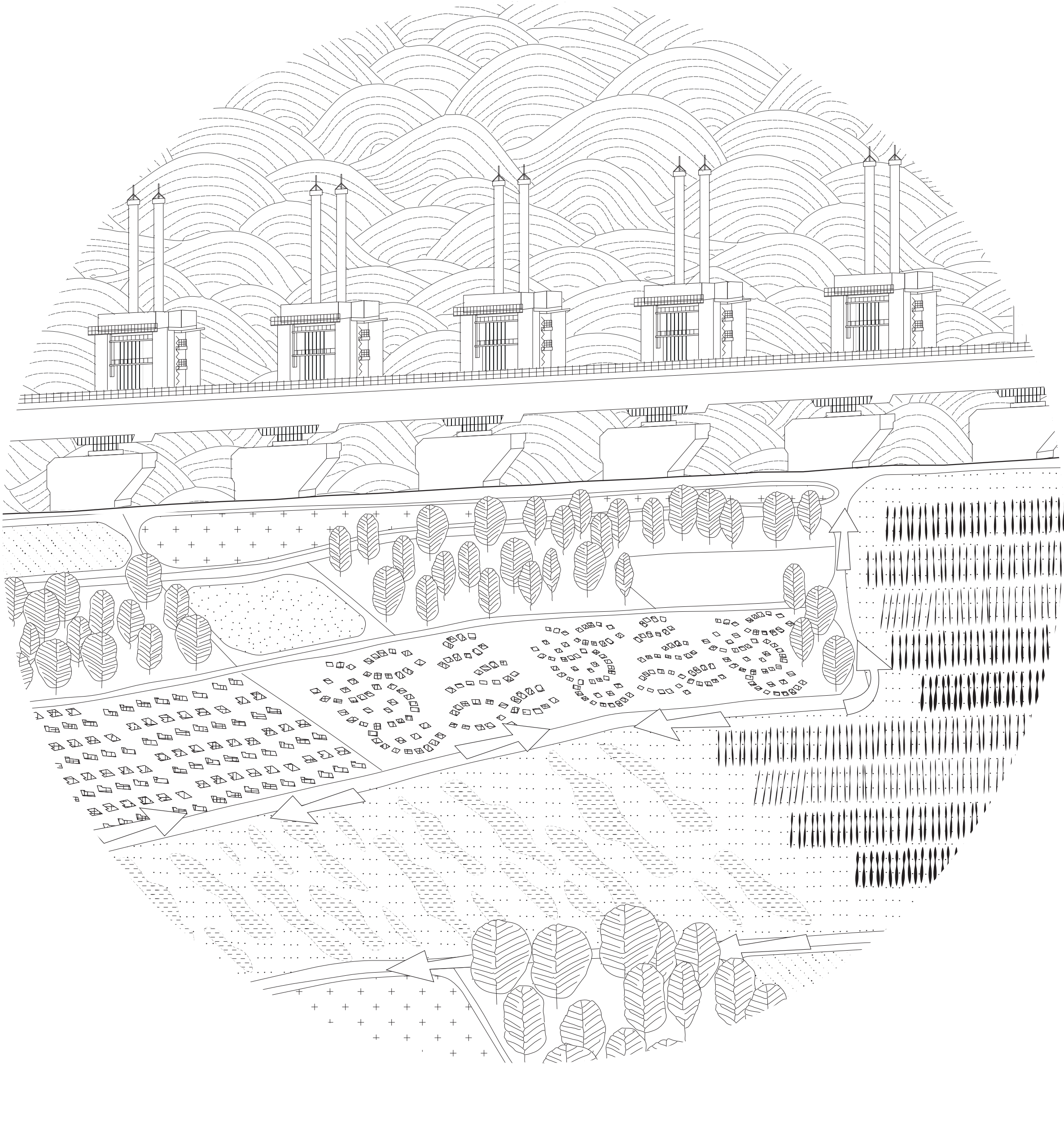
- Thematic narratives and proposals should **operate across scales** from the local, through the regional to territorial landscapes.

- Operative landuses should **address the effects of climate change in the context of the energy transition**...in other words, the functional and economic benefits of these landscapes should be oriented towards new industries (renewable energy, saline agricultures etc.) rather than fossil fuel dependant industries (this would include traditional agriculture).

- **Cultural identities** should comprise a key component of thematic and design products.

- Proposals should suggest scenarios to reconfigure settlement patterns in these indeterminate areas to accommodate different flood risk regimes.

- **Spatial configurations** of augmented landuses and their interactions with urban, cultural and infrastructural landscapes should be a focus of the design.



Figure, 15: Speculative infrastructures

4.4 *project propositions*

So in the context of fast-changing global social and trade economies, climate change impacts that will significantly impact urbanised deltas, the energy transition away from fossil fuels, threatened ecological systems (at the territorial and regional scale) and demographic disadvantages, clearly the Southwest delta is facing a watershed that will likely combine a number of existential threats. At the same time and at a systemic level, the delta is in a unique position to capitalise on its potential as a biodiversity hotspot, its status as a recreation destination, its well established agricultural base and its location adjacent to some of the most urbanised and industrialised areas in Europe.

A coordinated and regional re-orientation towards harnessing these advantages to position the delta for the coming century could clearly benefit the local communities and act as a (recreation, natural and economic) resource for adjacent urban areas but should also have broader positive territorial (and therefore global) impacts. As has been mentioned, this is already being prioritised by industry and provincial government groups (such as in the Biobased Delta plans) but this project will focus on spatial and cultural implications.

While the subsequent design products will be informed by a relational mapping exercise and functional requirements of the chosen augmented ecological landuses, a number of preliminary project propositions will provide a narrative foundation.

- The Southwest Delta is to become an **engine of biodiversity and habitat generation** at the territorial scale (maximising breeding grounds, habitat and nutrient filtration etc.).

- By the same token, the delta is to capitalise on this focus on natural systems to service the adjacent belt of cities as a **recreation hub and ecological counterpoint** to these urban landscapes.

- A proportion of currently cultivated areas behind dike and polder walls will be selectively **re-colonised by natural processes** (be they estuarine or riverine).

- Ecosystem engineering principles and practices will be incorporated to **multiply benefits** within these new fringe wetlands for example, fields of bouchots used to farm Blue Mussels (Mytilus edulis) that will make a positive spatial, economic and environmental contribution (through increasing sedimentation rates, dissapating wave energy, stabilisation of intertidal areas and habitat provision).[1]

- A **focus on saline agriculture** could also re-orient the area's agricultural focus towards a more sustainable model. Salt marshes could provide similar benefits to the shellfish reefs above but could also act as carbon sinks, could improve water quality and be used as a source of food or biomass.

- The **delta should act as a nutrient trap** that effectively filters the run-off from an enormous European catchment before it enters the North Sea. This could be done by employing macroalgae (seaweed) cultivation that in turn could also be used as a feedsource or stock of biomass and biofuels.

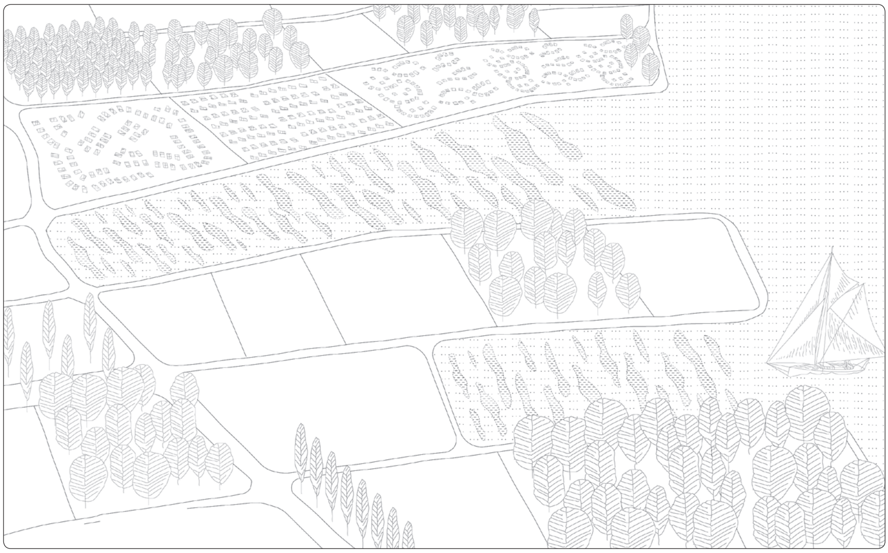
- **Settlement patterns** should potentially retreat to a connected spine of well defended urban occupation, a partial reversal of the traditional settlement trajectory.

1. Wiersma et. al., 2014

Source: Google Earth

relational mapping

Salicornia europeae, Samphire



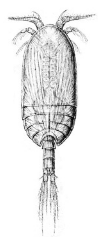
Cropland de-poldered and returned to saltmarsh condition

Multiple benefits including:

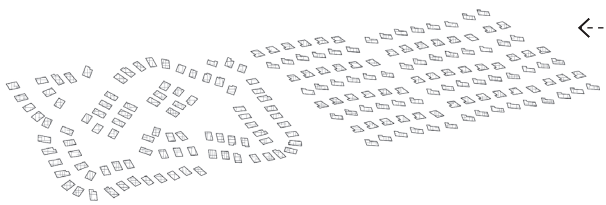
Flood benefits
- wave energy attentuation (may reduce maintenance on secondary dike infrastructures)
- encourages sedimentation (to increase the land elevation and reduce risks associated with sea level rise)
- flood attenuation and water storage

Environmental benefits
- nom. 100kg / ha / year of nitrogen uptake
- nom. 1500kg / ha / year of carbon uptake[1]

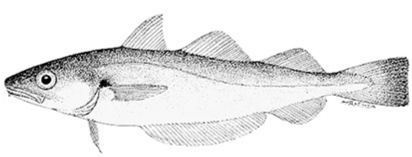
Habitat benefits
- increased foraging grounds for bird species
- increased habitat for benthic (plankton and crustacean) ecosystems



Copepoda spp., larval stages of copepods



Increased opportunties for recreational visitors.



See part 2 overleaf

Figure, 16: Spatial infrastructures, part 1

Current, predominantly agricultural, landuses with thin estuarine edge

Branta bernicla, the Brent Goose

5.1 spatial systems

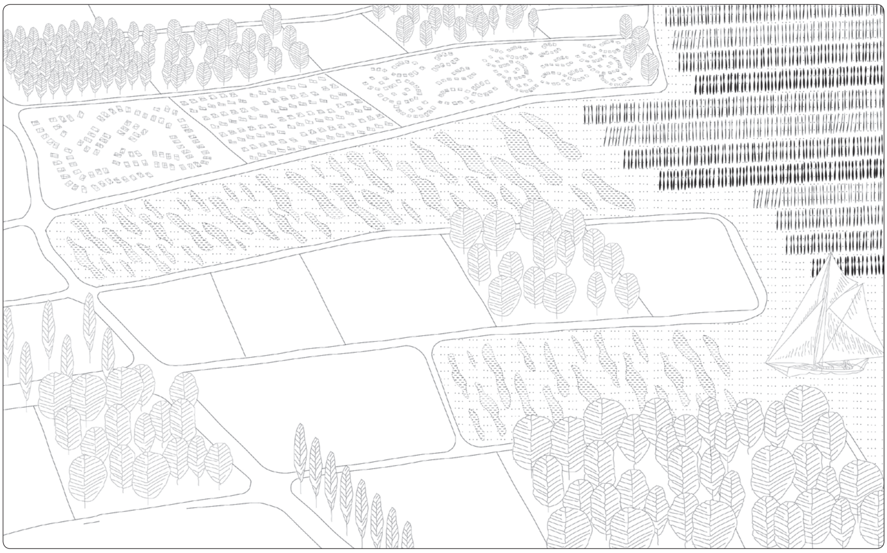
As mentioned in the regional analysis, traditional agricultural landuses dominate the landscapes of Zeeland with 70% of this landuse dedicated to the production of three crops: wheat, potatoes or sugar beets[1]. Yields per hectare of these (and most other) crops have been stagnating or declining in recent years (with the exception of beets)[2] and the declining economic benefits can therefore also be quantified (at €1,030 / ha / half year, €4,640 / ha / year and €2,470 / ha / year respectively)[1]. The return of a portion of land behind the primary dike line to saltmarshes (de-poldering) would provide a flood and wave attenuation buffer between the estuary and inland areas but could also have many other benefits.

These areas could be used for saline agricultural cropping that might offset the losses were the current agricultural crops to be replaced in this process. It is estimated for example that harvesting the wild growth of Samphire as a food crop could net €84,000 / ha / year[1]. There are already a number of operations growing or harvesting Samphire in the Netherlands and while it was a traditional food crop, a permit is currently required to collect the plant in the wild[3]. Given the growth of these crops are promoted by the sort of nutrient run-off currently considered a pollutant from traditional cropping, these saltmarshes could be used as nutrient filters (as well as means to sequester carbon and fix nitrogen).

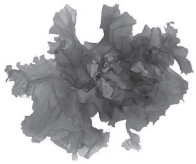
The natural habitat benefits might also have broader economic implications. The delta is already of great importance to birds migrating along the NW European routes and the Scheldt estuary is of international significance to at least 21 bird species[4]. These saltmarshes provide foraging and resting grounds for these bird species and the quality of the foraging plants on the saltmarshes in Zeeland for instance, has been shown to impact the breeding success of Brent Geese in the Arctic tundra[5].

These marshes also shelter phytoplankton and benthic communities in the intertidal shallows[4] which then provide a food source for larval fish populations such as Merlangius merlangus, Whiting[6]. The expansion of these bird and fish populations have the potential to in turn bolster the tourist and recreational fishing industries within the delta and provide added economic benefit in the form of accommodation and restaurant spending for instance.

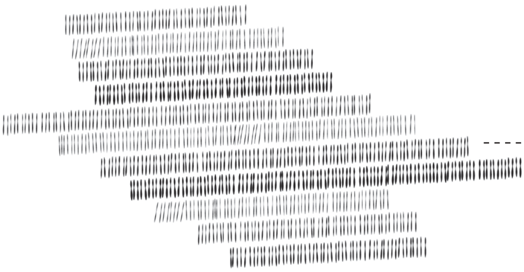
1. Wiersma et. al., 2014
2. www.cbs.nl, Zeeland crop productivity
3. Gunning, 2016
4. Meire, P. et. al., 2005
5. Bakker et. al., 1993
6. www.ices.dk

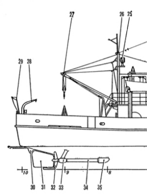


Addition of macroalgae (seaweed) plantations

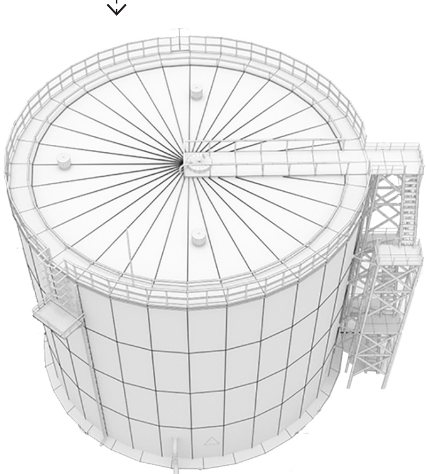


Seaweed plantations act as nutrient filters and shelter juvenile fish populations

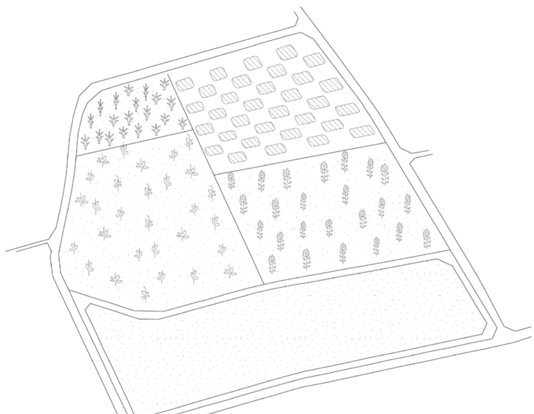




Macroalgae plantations produce chemicals, pharmaceuticals, feed or protien crops as well as biomass and bio-oils

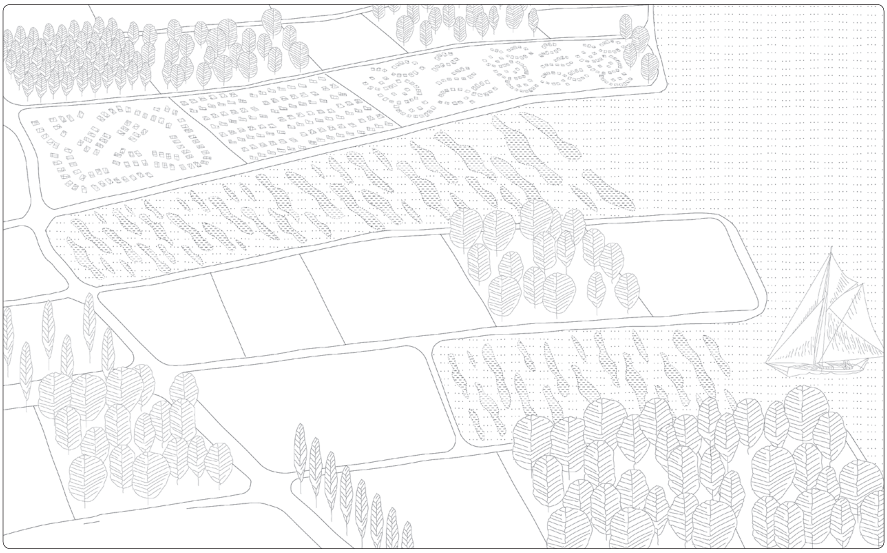


Were we to replace 50% of the raw crude oil input to the Vlissingen refinery with bio-oils from the macroalgae plantations, we would need an area of 350km^2 (producing 2.6 million kilolitres of biofuel per annum)

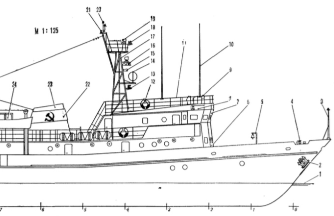


The nutrient content of this biomass digestate could be used to subsidise and reduce fertiliser costs for the remaining traditional agriculture within the archipelago

Figure, 17: Spatial infrastructures, part 2



Saltmarsh condition



Potential to arrest declining commercial catch of whiting and spawning stock biomass in the North Sea

A second new estuarine ecological spatial typology, that of macroalgae (seaweed) plantations, could extend the filtration of nutrients but also provide shelter for the juvenile Whiting populations as they move from the sheltered inshore areas towards the open ocean. As well as a common recreational fish species, Whiting is also a commercial catch in the North Sea though the numbers caught are declining to an historic low[1].

Seaweed plantations could shelter the young fish as they congregate along the Dutch coast in summer but their main productive crop is the harvesting of the macroalgae itself (fed by water-borne nutrients). The products we are able to obtain from seaweed are numerous from industrial chemicals, medicines, oils for bio-plastics as well as its use as a food crop (both for humans and as animal feed). Another promising avenue is the use of macroalgae as a source of oil for biofuels or biomass that could be converted into biogas in anaerobic digestion chambers. The annual yields from these macroalgae plantations could be up to 110 tonnes of biomass per hectare (dry weight) or up to 100,000 litres of unrefined bio-oils per hectare[2].
As bio-oils from sources such as seaweed are relatively easy to substiture for crude oils these products could be used as a means to reorient the petro-chemical industries towards more sustainable inputs without a substantial change in their processes. For example, the Vlissingen refinery processes around 7.5 million tonnes of crude oil per year[3] and were we to replace a third of this input with bio-oils from the seaweed crop, we would need a plantation of approximately 28,700ha[4]. While this represents an area around 80% of the size of the Oosterschelde, these plantations could be spread across the whole of the delta's inshore and offshore areas and produce up to 2.15 million kilolitres of biofuel per year[5].

As a natural material, the waste product from the conversion process to biogas (a nutrient rich digestate) could also be recycled. It is estimated that around 7% of the biomass input could be recovered as Nitrogen (or 7.7tonnes / ha / year) and 1% recovered as Phosphorus (or 1.1tonnes / ha / year)[2], which could be used to subsidise the fertiliser costs of the remaining traditional agriculture or be used to sustain the nutrient demands of the saltmarsh crops.

1. www.ices.dk and www.fishinginholland.nl

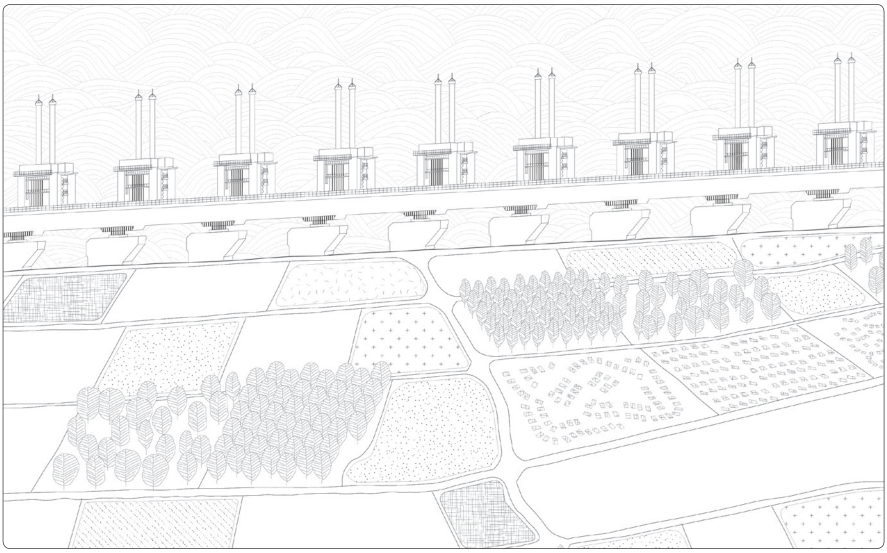
2. www.iea-biogas.net

3. www.zeelandrefinery.nl

4. Using an oil density of 870kg/m^3 to convert from tonnes to litres

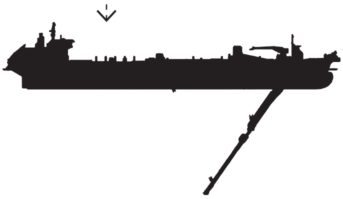
5. Using a refined yield of 75kilolitres / ha / year as per www.iea-biogas.net

Sediment demand of estuarine landscapes not being met by natural processes leading to the erosion of mudflats and intertidal habitat

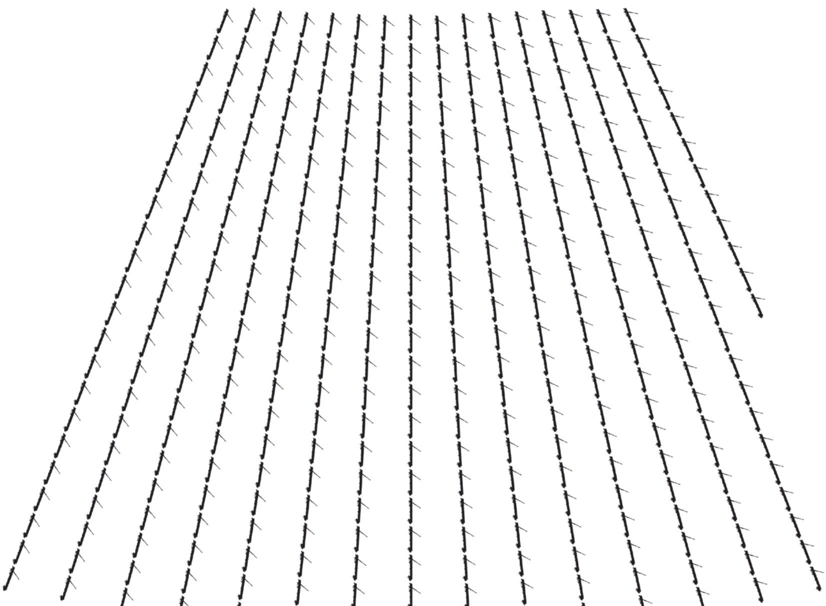


Current condition with engineered defences

This defecit is exacerbated by sea level rise as sands required to build up land elevation are not available

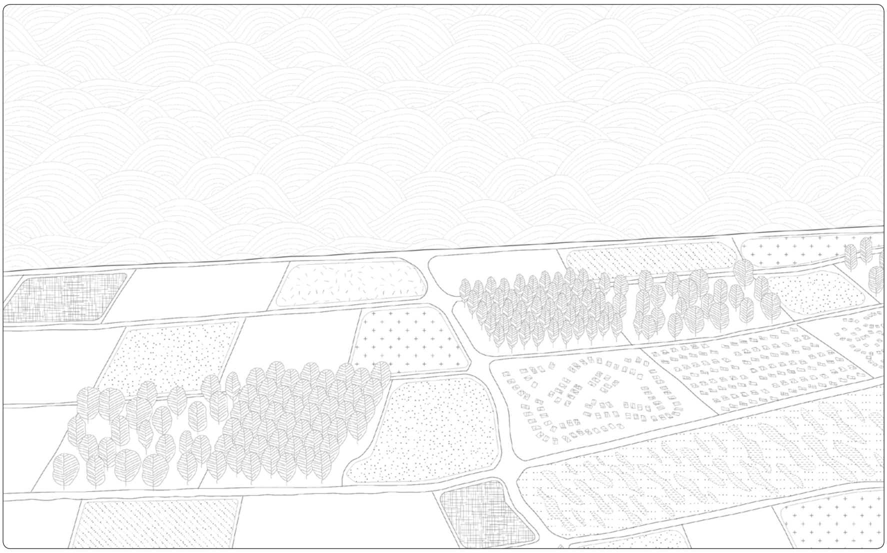


The 20million m^3 required each year represents 1250 trips by a medium sized trailing suction hopper dredging ship or four boats working full time



x 4

Figure, 18: Sediment infrastructures, part 1



New condition with sedimentation processes deployed as a means of flood defence

5.2 *infrastructural systems*

While the infrastructural force that now holds sway in the Southwest delta is that of engineered dams, barriers and dikes, for thousands of years the islands and habitats were physically shaped by the movement of sediments. As previously discussed, these sedimentation processes have been interrupted with erosive effects on the intertidal areas that support much of the habitat and biodiversity in the delta.

The main infrastructural implication of the above is that to maintain the sediment budgets in the Southwest delta and to address the implications of sea level rise, around 20 million cubic metres of sand will need to be imported into the system each year[1]. This assumes a sea level rise of 8.5mm per year or around a 0.7m rise by 2100 (around the middle of the range of predictions used by the Delta Commission in its 2008 report). To put this into context, this requires 1250 trips of a 16,000 tonne capacity trailing suction hopper dredging ship such as the *Prins der Nederlanden* or four ships working full time throughout the year[3] at the cost of between €60-240 million per year (assuming costs of €3-12 per m^3)[4].
Were we to re-activate the estuarine processes and reinstate the infrastructural role of sediments in the delta then these habitats could be maintained as part of a new flood protection regime that moves from engineered to natural processes, thin lines of hard barriers to broader zones of softer infrastructures and from static defences to those able to adapt to changing conditions (such as rising sea levels).

In this scenario, the sediment requirements of the estuary would largely be met by coastal exchange, accreting between 10mm and 15mm[4] per year and effectively elevating the land such that the intertidal fringes and areas exposed to these sedimentation processes could keep up with sea level rises of over 0.8m by 2100. One of the implications though of this new sedimentary infrastructure at the estuarine fringes, is that lands not subject to these accrection processes will remain the elevation they are now (or continue sinking if they are affected by subsidence,) introducing a height discrepency that could be problematic for the generally older, more urbanised polders.

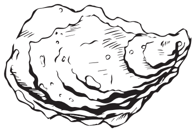
1. https://publicwiki.deltares.nl/

2. https://boskalis.com

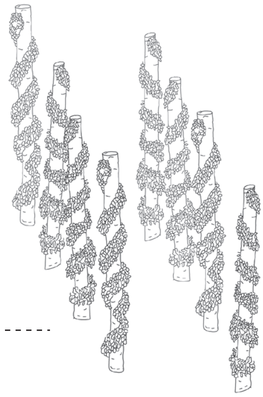
3. assuming 50km between collection and dump sites and avg. speeds of 16knots. So 2 trips possible per day and assuming 50% downtime for each ship

4. Wiersma et. al., 2014

Saltmarsh cropping

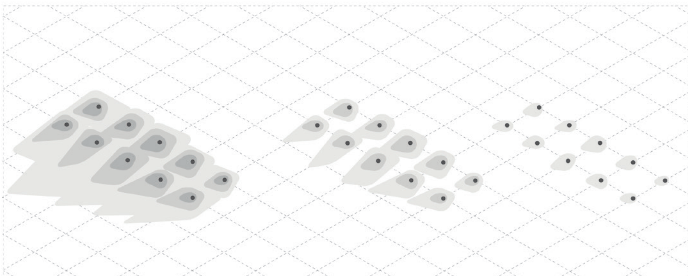


Oyster reefs



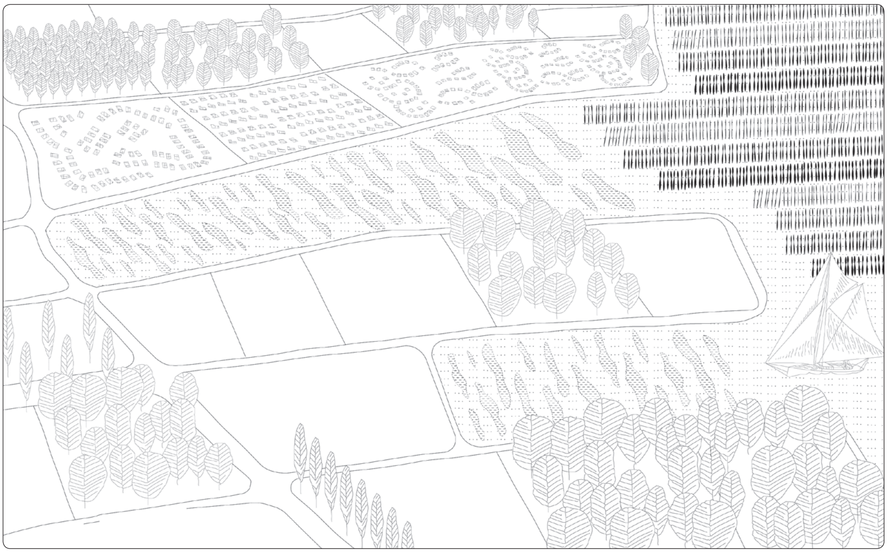
Mussel bouchots

Ecosystem engineers used to retain and re-circulate as much sediment as possible within the estuarine system...these mechanisms could be used to direct sedimentation, build spatial character and physically shape the archipelago



Were there to be an oversupply of sediments, these could be directed to physically expand the delta seaward

Figure, 19: Sediment infrastructures, part 2



Sedimentation processes as strategic infrastructural tool

This height discrepency might require a more strategic approach to the settlement of the delta where urban areas are restricted to zones of absolute safety or, in the longer term, these mechanisms might be used to effectively grow land and a decade long process of sediment accretion on a piece of land might render this area suitable for habitation once the lower lying, currently settled areas become unsafe.

In the same spirit of strategic thinking, an anthropocentric approach to these new sedimentary infrastructures could allow us to harness these processes to both maximise the benefits and meet broader strategic goals.

One of the characteristics of certain ecological and aquacultural landuses such as mussel poles (bouchots as used along the northern coast of France), oyster reefs and saltmarshes is that they both encourage sedimentation and reduce erosion. These actions can promote both the conditions required for their own maintenance as well as the pre-conditions for other subsequent landuses that could be used as a sequence to conpletely alter the landscape[1].
For example, mussel poles could be located in the intertidal areas where they begin to trap and retain sediments. Over time these sediments will be substantial enough to allow the establishment of oyster reefs that continue this process until, if the conditions are right and they required amounts of sand are available, saltmarsh vegetation might colonise the area.

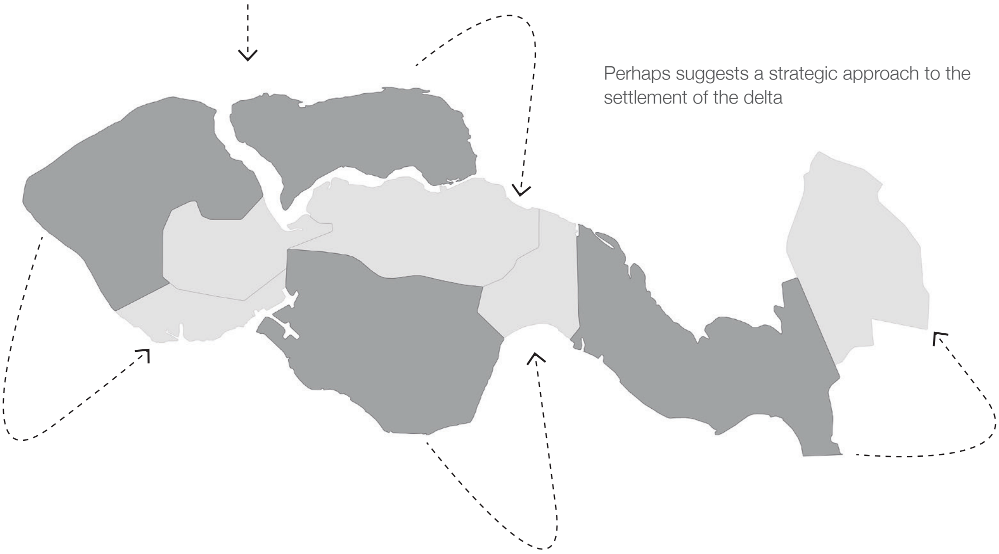
1. Wiersma et. al., 2014

As well as the already discussed implications for increasing the elevation of fringe estuarine areas, there lies in this sequence the possibility of essentially growing land and, were the sediments available, of expanding the physical territory of the delta seawards. This might be desirable for a number of reasons from broadening the natural flood protection barrier along the coast (the existing line of sand dunes), acting as a sediment bank for coastal beach nourishment further along the Dutch coast (a “sand engine” at the territorial scale) or simply the expansion of a productive Dutch landscape (urban or otherwise).

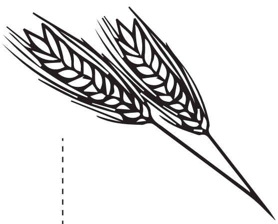
Distance to the nearest hospital
Darker shades indicate further to travel

Population density
Darker shades indicate lowest density

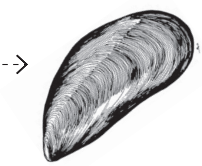
Population growth
Darker shades indicate population decline



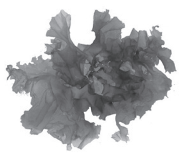
Perhaps suggests a strategic approach to the settlement of the delta



Re-orientation of the agricultural landscapes towards...

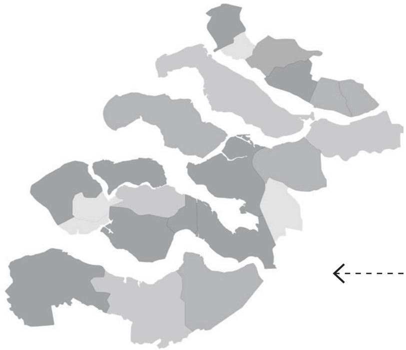


Offshore or onshore circular aquaculture practices and...

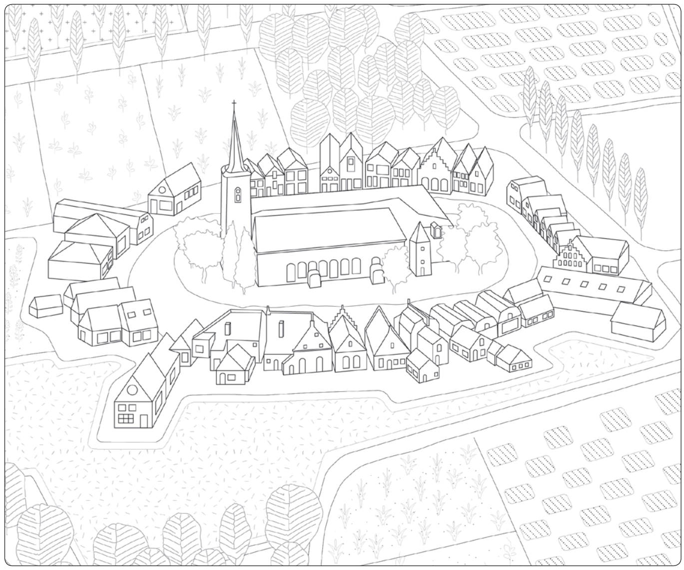


Seaweed cultivation, saline agriculture or salt tolerant crop varieties

Figure, 20: Social and economic patterns



Urbanity
Darker the area the less urbanity



Social and cultural conditions

5.3 social / economic systems

As previously mentioned, the delta is facing a number of demographic and landuse challenges that might direct, or be targeted by, new landuse strategies.

Regional demographic indicators and performances such as those plotted above (urbanity, population growth and density as well as distance to the nearest hospital) are not evenly distributed across the delta, and so while this might identify areas where improvements could be made, it might also identify where a change in landuse is most appropriate. A strategic view of settlement within the delta has to accompany wholesale changes to the flood safety regimes such as those being proposed. As these new, dominant landuses (such as natural areas) will displace the existing patterns, it is necessary to question whether the current extent of urban occupation needs to be reduced to both maintain required levels of flood safety and to allow space for the new landuses...does urban occupation need to retreat to a secure spine of safety to allow for the indeterminate margins? By the same token, could a consolidation of the declining population facilitate a spatial and functional re-orientation of the landscape that could create the conditions to eventually attract people back to the delta?
Might the character of the delta as a productive landscape also need to be re-oriented to accord with these new landuses? Given there is 7.5 times more agricultural land per inhabitant in Zeeland than in South Holland[1], it is likely that this contributes to the cultural (as well as visual) character of the area. This landuse is declining though and between 2000 and 2010[2] Zeeland experienced a:

- 25.9% decrease in number of farm holdings
- 18.9% decrease in number of livestock
- 27.4% increase in average farm holding size
- 5.6% decrease in total agricultural area
- 17.2% decrease in agricultural labour force
- 11% increase in Potassium use per ha,
- and from 2010 to 2016, 10% more Nitrogen use per ha[3].

The current character of Zeeland as a food production, processing and consumption hotspot could be bolstered and new, more sustainable and circular crops and production methods are already being employed. For example at Kingfish Zeeland where nutrient-rich waste from the onshore aquaculture operation is proposed to feed saltmarsh and algae crops[4].

1. Regional key figures for the Netherlands, www.cbs.nl

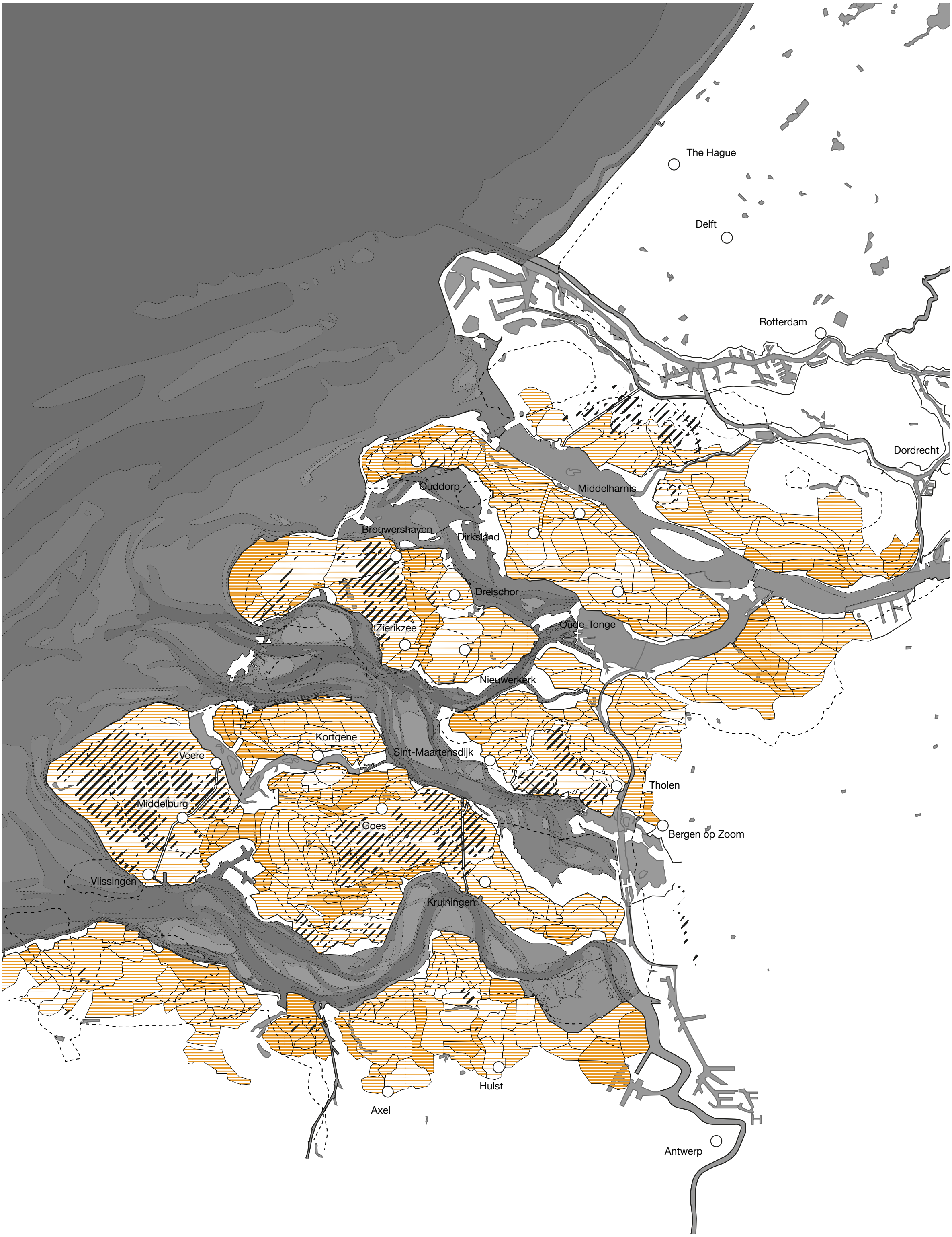
2. Agricultural trends by region from http://ec.europa.eu/eurostat

3. Agricultural change 2010-2016, www.cbs.nl

4. www.kingfish-zeeland.com


Source: Google Earth

sub-regional mapping



Key

Polder soils

Newer polders and those approx. 2-15m above sea level

Low lying polders, up to approx. 2m above sea level

Polders with significant areas below sea level

Coastal defences, dikes and dunes

Approx. configuration of islands ca. 12th century

Peat and heavy clay soils

Source: AHN Zeeland height mapping, TUDelft Kaartenkamer. H. Meyer Et. Al. (2015), New perspectives on urbanizing deltas. Soils, http://pdokviewer.pdok.nl/

Figure, 21: Polder spatial units

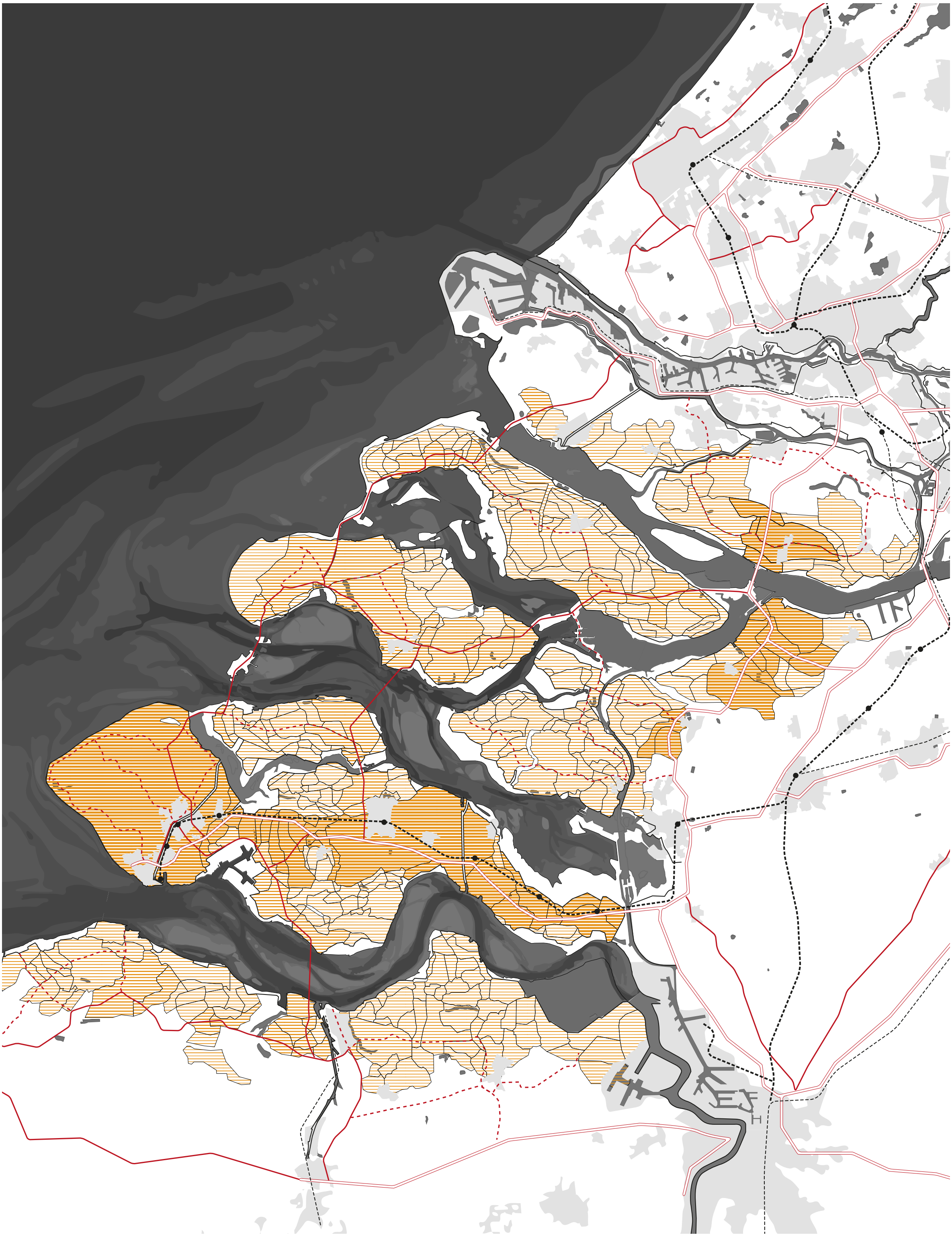
Zeeland polders

6.1 *polder as spatial unit*

The preceding relational mapping exercise identified a number of possible mechanisms, synergies and interrelations between alternative (natural) infrastructures. Pre-eminent amongst these is the potential of the reclamation of polder landscapes by re-establishing their functional relations with estuarine processes and promoting salt marsh landscapes for habitat and biodiversty generation, nutrient waste filtration and as a flood defence mechanism.

This would infer that we approach this landscape manipulation polder by polder, as the polder spatial unit becomes the venue for each step in the process. In the Southwest delta, the progression of polder expansion has broadly taken place radially: in other words, polders were progressively expanded outwards and so today's landscape consists of layers of (previously primary and coastal) secondary dikes that could both provide an existing defence role were the newer polders re-flooded and re-activate a currently redundant landscape component.
In the Netherlands there is a relationship between the age of a polder, its soil type and elevation. As polder landscapes (particularly those founded on peat soils) tend to subside over time and the newer polders are the result of more recent accumulations of sediment, generally the older the polder, the lower its elevation.

As such, some of the older polder areas in the delta are up to 2.5m below sea level (NAP) while the newer polders generally sit up to, or over, 2m above sea level (see map opposite). This has sometimes counter-intuitive implications for which polder areas are most appropriate to be flooded. Clearly the lowest areas are easiest to flood and might benefit most from the vertical accretion the import of sediments might attract but these are also the most populated (being the oldest) and house a large proportion of the most critical infrastructure. Despite often being the highest areas then, the newest polders, adjacent to the current estuarine edge, are generally considered most appropriate to re-flood.



Key
Polder accessibility

- Rail line with station
- Motorways (100km/hr limit)
- National routes, primary (80km/hr limit)
- National routes, secondary (60km/hr limit)
- High accessiblity (by rail and/or motorway)
- Moderate accessiblity (by primary routes)
- Low accessiblity (by secondary routes)
- Very low accessiblity (by local roads)

n 0 10 20km

Source: https://www.viamichelin.com/web/Maps/Map-Netherlands, www.googlemaps.com, TUDelft Kaartenkamer

Figure, 22: Polder accessiblity

6.2 polders ranked by indicator

As the polder compartment is likely to be the spatial unit for application of the terrestrial landuse changes proposed, it follows that the identification of a sub-regional case study location should be conducted by reviewing the relative characteristics of each of the polder units. To do this, each of the polder units was ranked by a variety of indicators as to its particular potential for, or lack of constraints against, changing landuse from the (likely) current agricultural focus towards a more naturalistic, salt marsh system.

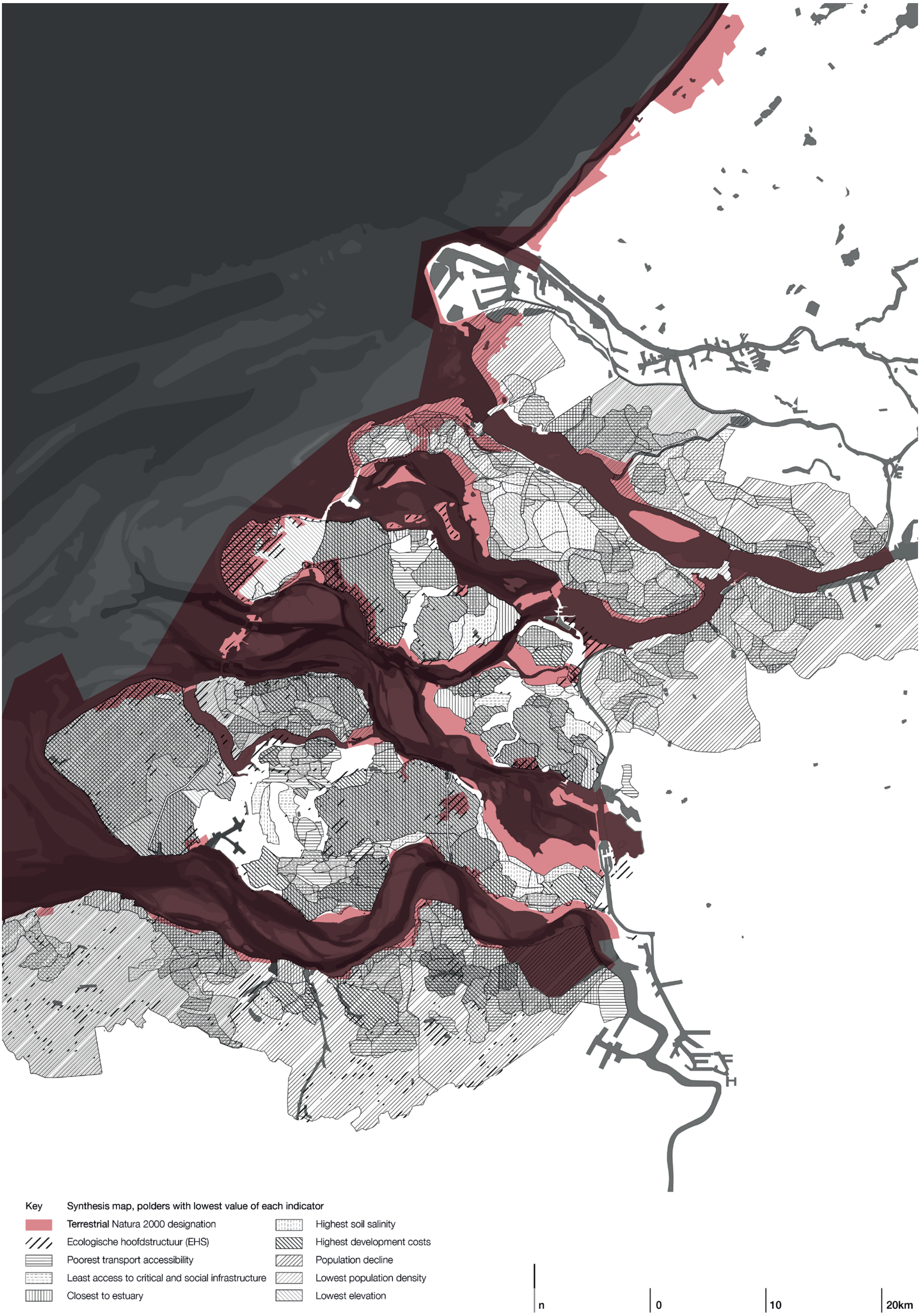
A coloured overlay was projected onto each of the delta's polders with a darker or denser colour indicating that a particular area is less suitable for a change in landuse (for example via being more densely populated or housing critical transport or social infrastructure). Please see the appendix for a comprehensive review of the indicators analysed but they include the following:

- polder elevation (see previous page)
- accessibility via road, rail and ferry (see opposite)
- proximity to critical and social infrastructure
- likely population growth rates (2015 to 2025)
- population density
- proximity to natural areas and estuarine systems
- likely cost of land development (Zeeland province only)
- soil salinity levels as a threat to traditional agriculture.

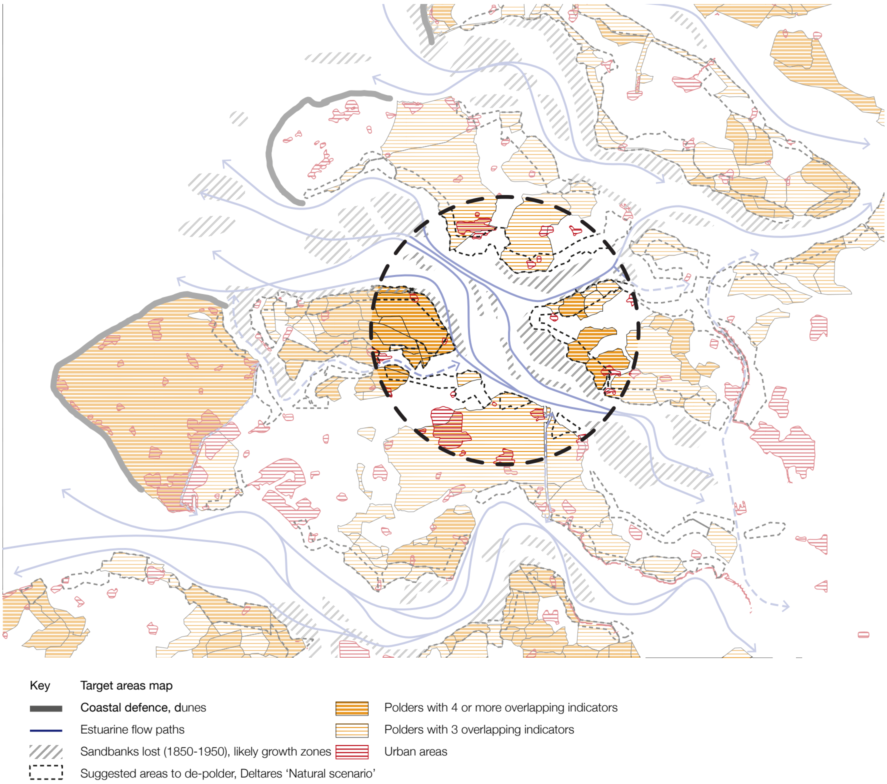
Transport accessibility appears one of the most uneven indicators across the archipelago as only one passenger rail line connects the delta from Vlissingen, via Middelburg and Goes to Bergen op Zoom. This line services only a handful of centres on one island and so ensures that road (and sparse) ferry routes must link the disconnected islands and urban settlements scattered throughout the rest of the delta. The deltaworks also house road links that dramatically improved access across the delta but as ferry connections are minimal, particularly out of summer, these routes (along with the Zeelandbrug) absolutely dictate how and where people move through the archipelago. This clearly has implications for areas that, although they might be located within the heart of the delta such as Stavenisse in Tholen, are very difficult to get to and these difficulties compound their isolation. This isolation has impacts beyond the social as these areas are further away from education, retail and health facilities as well as employment opportunities.

The proximity of a polder to estuarine systems as well as to Natura 2000 areas or other protected natural landscapes is also critical as the salt marsh landscapes are intended to ultimately bolster and connect these natural areas.

The cost of development of a particular polder unit (as suggested by the Province of Zeeland's current spatial plan) has also been taken into account as areas that are more difficult or costly to develop perhaps then better lend themselves to conversion into natural landscapes. Perhaps more critical though, is the level of soil salinity issues within a polder unit. Given it is likely that a regional polder is home to traditional agricultural landuses and that these landuses become less profitable under increasingly saline soil conditions, then these areas might be the first to be converted to salt marshes.



Figure, 23: Heat map of indicators overlay



Figure, 24: Sub-regional site selection

6.3 sub-regional site selection

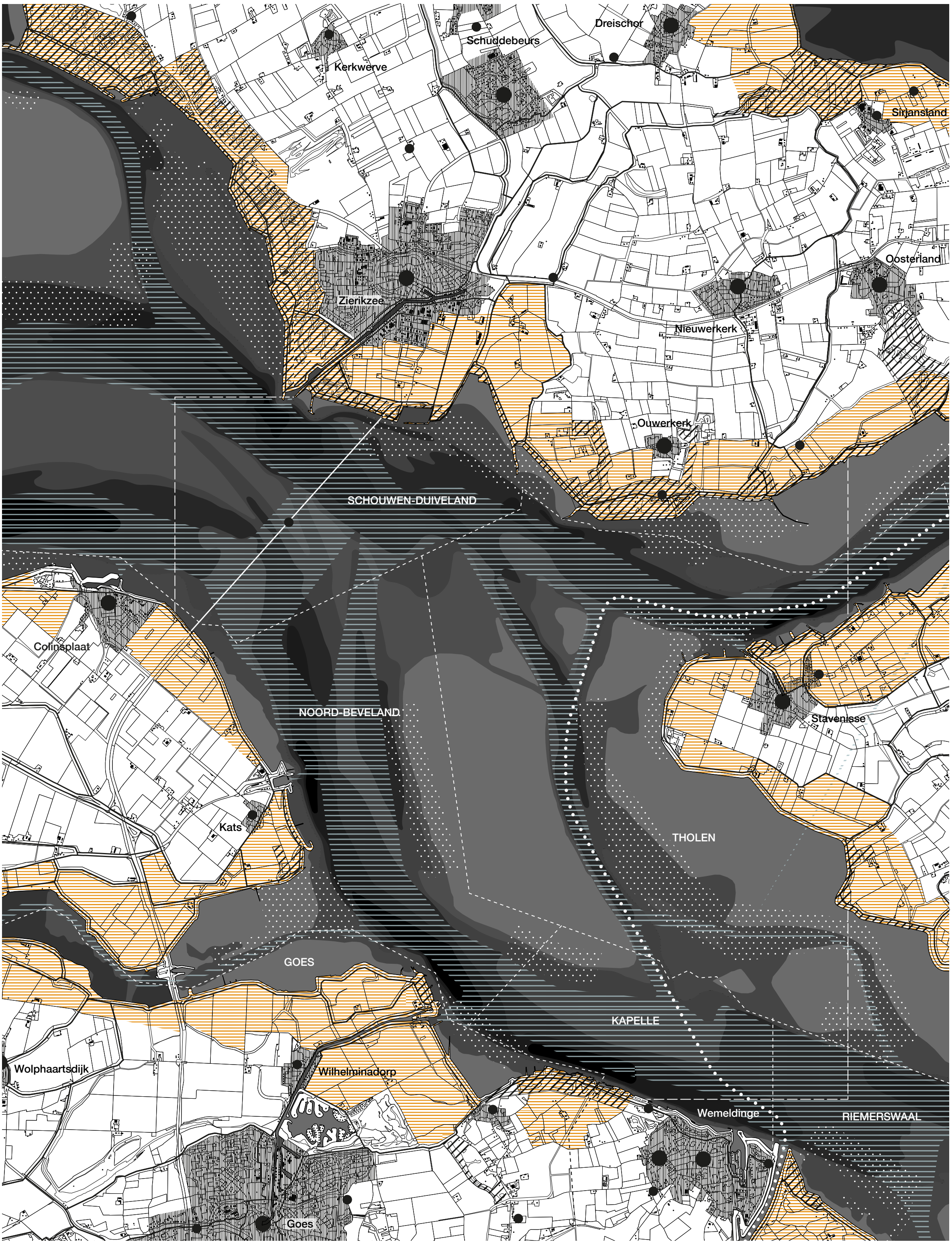
The intention of the polder spatial unit analysis was to identify an area most appropriate to test implications of the imposition of a series of connected ecological infrastructures that included flooding currently dry polder areas as a venue for new salt marsh landscapes. The hope was that an accumulation of indicators might suggest which polders would benefit the most from the natural, social, economic or connective advantages of these new infrastructures as well as show whcih polders exhibit the least constraints for this change in landuse.

The area deemed most suitable for landuse change in each indicator (or those polders with the lowest indicator value) is shown on the heat map opposite and so an overlay of these areas might begin to identify which geographical locations we should focus on. Polders with three or four overlapping indicators are shown on the plan above. The terrestrial (polder) landscape of the delta though, is not the principal location for the majority of the proposed ecological infrastructural landuses, most are housed within, and are fundamentally driven (as are the salt marshes) by estuarine processes. For this reason, the case study (or sub-regional) site should exhibit relatively healthy and functional natural estuarine dynamics. This in effect, limits us to either the Westerschelde or the Oosterschelde as the other water bodies are heavily constrained in their dynamics and connectivity.

The site chosen above in the Oosterschelde is at the confluence of two estuarine flow paths, suffers only diminished (not curtailed) natural dynamics and this patch of estuary is adjoined by multiple, disconnected islands whose terrestrial areas exhibit multiple overlapping landuse change indicators.

Also of consideration was that the study area should house areas suggested for de-poldering by Deltares in their “Natural scenario”[1] and include areas of mudflats or sandbanks lost since the imposition of the Deltaworks; the logic being that these areas would likely be reinstated once natural estuary processes are reactivated and hence, demonstrate a level of dynamism, shallow water and propensity for mudflats required by the new landuses.

1. Wiersma et. al., 2014



Key Sub-regional site and changing landuse

Urban areas
Polder spatial units
Municipal boundaries
Protected natural areas
Mussel plots
National monuments (2 or more/ single)
Primary shipping route
Deltares suggested de-polder areas
Area between navigation markers
Extents of 100km^2 estuarine system

n 0 2 4km

Sources: Urban extents, National Monuments and protected areas from http://pdokviewer.pdok.nl/. Mussel plots from TOP10NL, De-polder areas from Deltares (2012), Sustainable Scenarios for the Southwest Delta. Shipping channels from http://pdokviewer.pdok.nl/

Figure, 25: Sub-regional site

6.4 sub-regional site

The chosen sub-regional case study area then is focused on the estuary from a functional point of view (as the infrastructural driver of new landuse typologies) but also as the element that might connect the urban areas on its fringes and promote a shared sense of cultural (and spatial) identity. Despite the fact that these four islands within the study area (Schouwen-Duiveland, Tholen, Noord and Zuid Beveland) are governed by a number of municipalities (Schouwen-Duiveland, Tholen, Noord-Beveland, Goes, Kapelle and Riemerswaal), they are all connected by the shared estuary landscape.

While the de-poldering proposals[1] were intentionally extreme and one of three possible scenarios tested for addressing issues within the delta, the practical, community and logistical implications become stark when plotted at this scale. These areas amount to almost a third of the terrestrial landscapes as shown in the plan opposite yet clearly have the potential to become a connective landscape to link the various coastal communities as well as the protected natural areas scattered throughout the study area and (usually) alongside the estuarine edge.

In order to better be able to quantify the benefits, as well as limit the extent, of the proposed new ecological infrastructures, an area amounting to 100km^2 of estuarine system has been chosen as the venue for the application of these new landuses. The location and extent of each of the new systems will be determined by the maintenance of their individual functional or habitat requirements and by current anthropological use of the waterway (navigational channels and shipping routes).

In terms of urban and terrestrial character, Zierikzee is the main historic and tourist centre on Schouwen-Duiveland located at the northern end of the principal connective infrastructure and road link in the study area, the Zeelandbrug. Its southern coastline has multiple viewing and entry points to the Oosterschelde National Park, the largest in the country[2], and is also home to the Watersnood Museum commemorating the impacts of the 1953 floods on the area.

Noord-Beveland is sparsely settled yet home to a small fishing fleet based out of Colijnsplaat, a small “village of artists” in Kats and trails interpreting the “verdronken polders” or polder areas drowned and towns wiped off the map in previous floods (of 1530 in this case)[3]. Kats is also home to a small marina and industrial shipyard where elements of the Zeelandbrug were assembled and housed during the bridge’s construction.

Zuid Beveland is the best connected area of the islands in the study area via its access to the national rail network and prominent north-south shipping route through the Kanaal door Zuid Beveland and is also home to the largest urban centre in the study area in Goes. This logistics access is also likely one of the reasons for this island containing more prominent industrial areas (in Goes and Wemelginge), agro-food industry clusters (in Kruiningen) and is also home to a significant oyster and shellfish industry and tourist drawcard (in Yerseke).

Tholen and Stavenisse are the least well connected in the study area and this point of land is surrounded on three sides by the estuarine systems. Perhaps not surprisingly then, Tholen is billed by the tourism association as a place to experience ‘Peace and nature’[3]. Very little industry is present in this area (though it is home to some wind power installations) and while Stavenisse is home to a small marina, it appears to be largely dedicated to pleasure craft and recreational boating.

1. Wiersma et. al., 2014

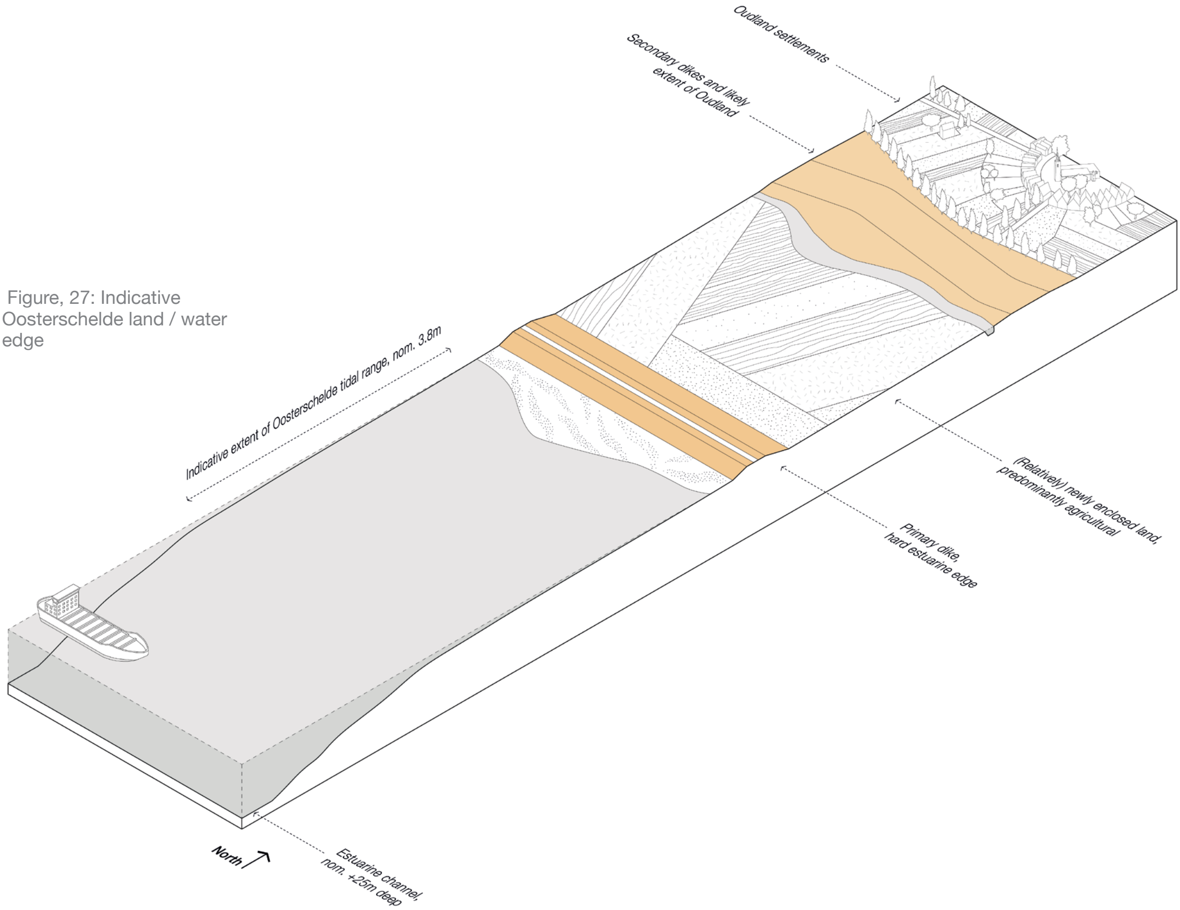
2. www.np-oosterschelde.nl/en/home.htm

3. www.vvvzeeland.nl/en

eco-infrastructural landuses

Source: Landuse from http://code.waag.org/mansholt/map/#wieringermeer.

Figure, 26: A patterned agricultural landscape



Figure, 27: Indicative Oosterschelde land / water edge

7.1 Oosterschelde context

The typical progression of settlement and land accretion followed by indikement that played out across Zeeland is also present in the slice of the Oosterschelde chosen as test site for the ecological and infrastructural landuse application. The original settlements largely lie within belts of agricultural lands that dominate a landscape enclosed within the primary dikes that both protect and sharply delineate the terrestrial bounds of the archipelago. As mentioned, this endikement generally caused a deterioration of estuarine and associated natural processes such that the fixing of water body states precipitated a gradual decline in habitat and hydrological health but also disturbed the sediment regimes that is an enormous driver of both.

These adverse environmental impacts were becoming evident in the already compartmentalised water bodies further north (the Haringvliet, Grevelingen and Volkerak) as construction began to similarly enclose the Oosterschelde[1]. Public concern forced a compromise that amended the design of the proposed dam to allow the retention of (albeit reduced) tidal flows in the Eastern Scheldt. It is these tidal flows that continue to allow a relatively natural exchange of sediments that in turn drives the maintenance of habitat and hydrological health and also supports a variety of ecosystems as well as aquacultural practices. While the series of ecological infrastructures proposed below are intended to address issues of estuarine habitat improvement and augmentation (amongst other things), this level of ecosystem health is a requirement to support the new infrastructures proposed.

The assumption made in this thesis is that, with the opening of the dams and the return of natural estuarine processes[2], the conditions to support a new interpretation of landscape infrastructure within the Southwest Delta might return. Much of this is driven by the likelihood that if the deltaworks barriers were removed, the natural sediment regime within the Oosterschelde would be balanced by sediment imported from the North Sea[3] (currently unable to pass through the barriers) and that these naturally available sediments would drive the vertical accretion of marshes.

1. Brand et. al., 2013

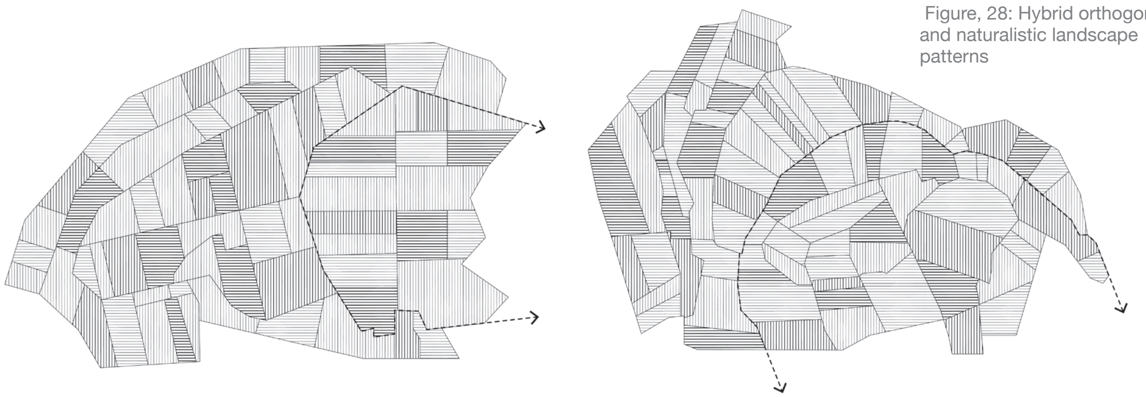
2. Lodder, Q. et. al.

3. See Wiersma et. al., 2014, appendix E: Results of expert sediment workshop

7.2 landscape and spatial typologies

There is no doubt that in the Netherlands in particular, there is a fundamental connection between the spatial and infrastructural organisation of the landscape and the culture that inhabits it. As mentioned in the introduction, this has been explored through Dutch art over the centuries and celebrated in the everyday life of the inhabitants of the polder landscapes. These landscapes clearly have a unique visual character, made up as they are, of a structured groundplane whose organisational (and therefore visual) character is absolutely defined by the need to drain, hold back and contain the (ever-present) water. This horizontal patternation is traditionally contrasted by repeated vertical elements either indicative of occupation (lines of trees), civic significance (church spires) or water management (windmills). All these elements are set against a strong and consistent horizon line that also acts to frame the wide, athmospheric Dutch skies.

If a typical landscape patternation is driven by the interaction between agricultural landuses and water management requirements - all within the functional and spatial bounds of the polder unit - then in the study area, the evolution of this orthogonal management and spatial regime has also responded to, and accommodated, natural processes and forces (in the gradual growth of the islands driven by sedimentation processes or the physical flow paths of water through the landscape). The resulting landscape patterns are a hybrid construction of anthropomorphic organisational structures and natural lines and forces (see diagrams below).



Figure, 28: Hybrid orthogonal and naturalistic landscape patterns

The question is, what might be the estuarine equivalent of these patterned, infrastructural landscapes? How might an alternative system of spatial organisation look and operate? One that is driven by an alternative notion of flood protection, productive landscape infrastructure and landuse logic.

In an effort to co-opt some of the comfortable (to the inhabitants of these polder and agricultural landscapes) Dutch landscape associations, and to relate the proposed new infrastructural and ecological landscapes to traditional typologies, these new landuse mechanisms will adopt a similar visual language: a structured groundplane whose spatial character is driven by interactions with water and vertical elements that contrast the overriding horizontality of Dutch landscapes in general, and estuarine landscapes in particular.

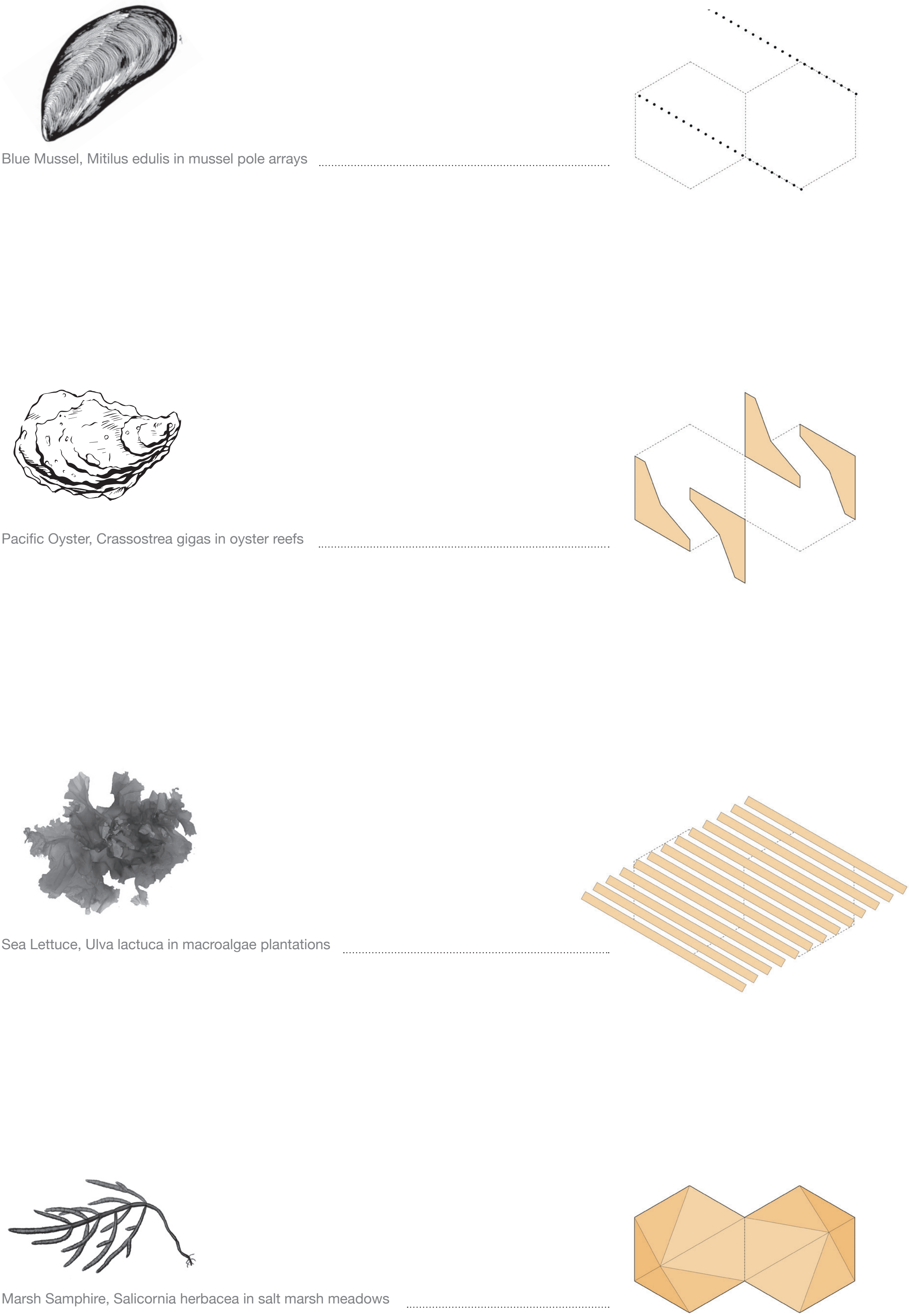
The resulting estuarine landscape will obviously operate under a different logic to its terrestrial counterpart but the hope is that the cultural and visual connections might be similar in order to promote both acceptance of these new infrastructures as well as use this new spatial typology as a means to visually and functionally connect currently disconnected urban settlements and cultural identities.

Structured groundplane

Vertical elements

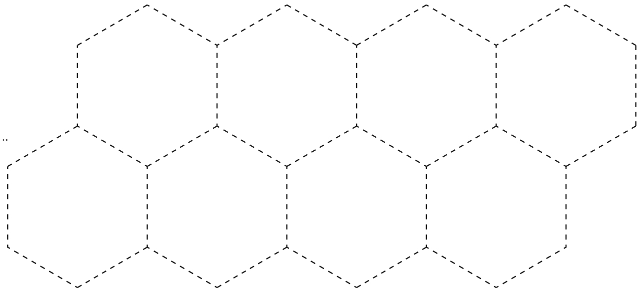
Figure, 29: Polder landscape elements

Strong horizon line framing the sky



Figure, 30: Ecosystem engineers and spatial typologies

New spatial organisation logic



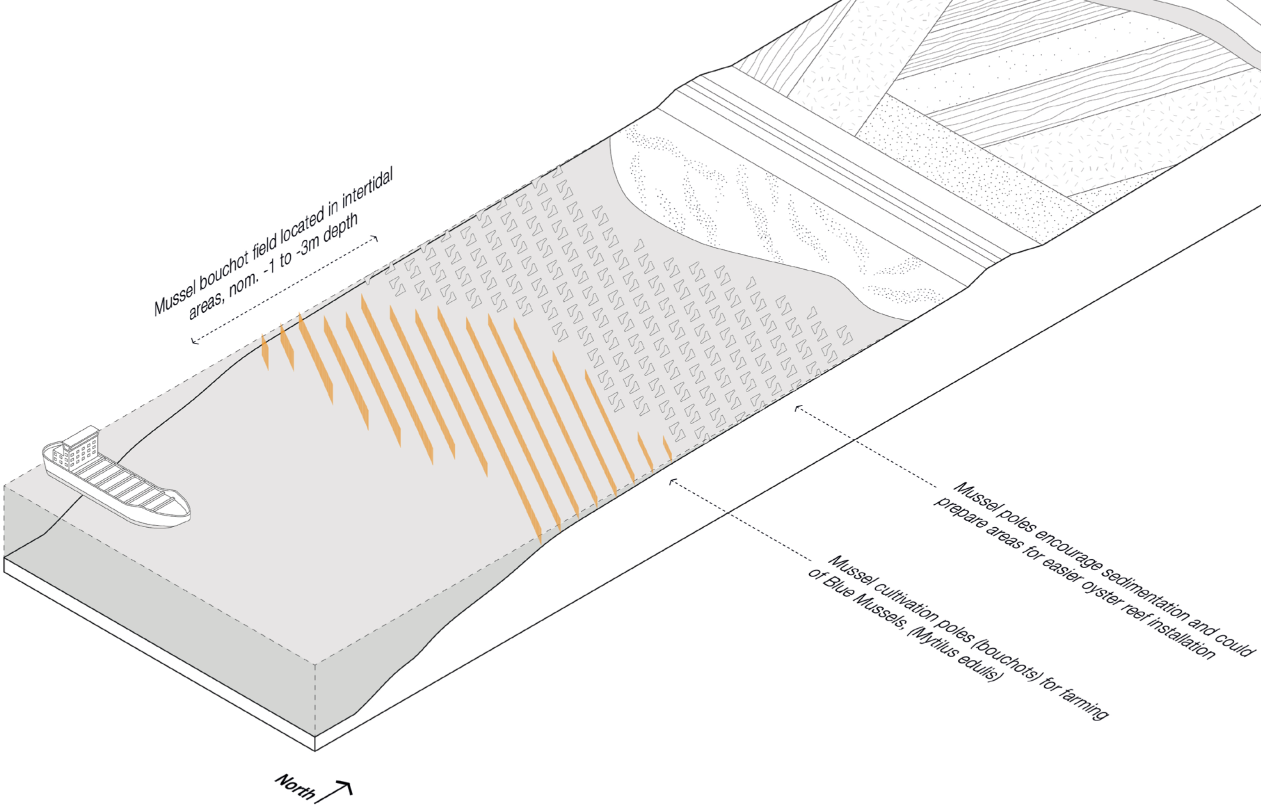
7.3 a new ecological infrastructural landscape

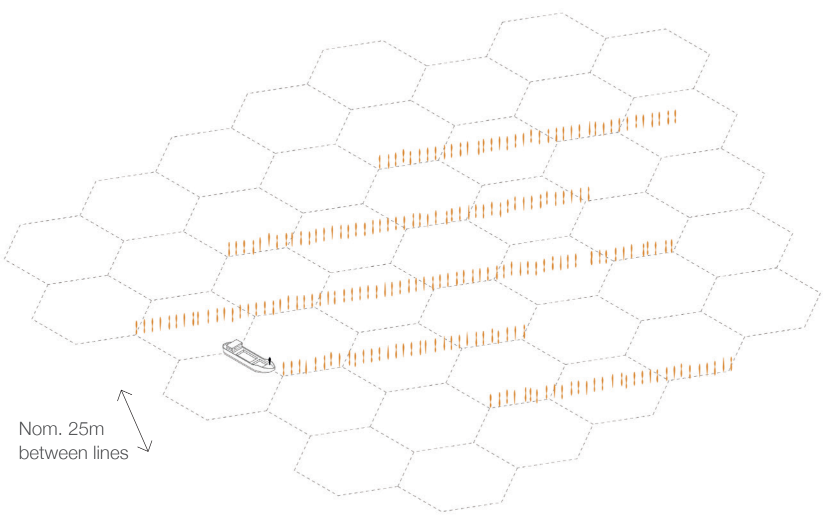
The proposed new interpretation of infrastructures that drives a new spatial landscape logic in the Oosterschelde is that of ecosystem engineers. These are plants or animal communities that through their particular characteristics or behaviours, have the potential to alter the shape or functioning of the habitats and landscapes that they inhabit. For example a beaver that builds a dam that in turn alters the flow, alignment and functioning of a particular river system.

Principally these ecosystemic landuses should contribute towards improving environmental, biodiversity and habitat values as well as a reorientation of the flood defence and water management within the delta from hard, engineered measures (as typified by the Deltaworks) towards softer, more naturalistic infrastructures that are able to keep up with sea level rise. In order to extend the benefits though, an additional requirement for this project is that the landuse typologies resulting from a designed deployment of these ecosystem engineers are of economic, cultural and social benefit but also exhibit strong spatial characteristics that could typify this new infrastructural landscape.

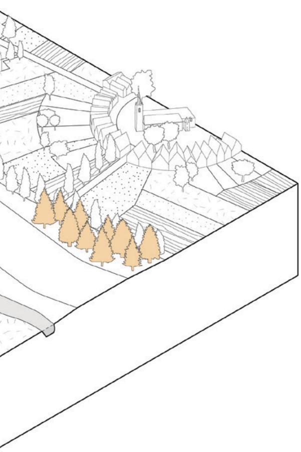
The four new typologies consist of particular applications of mussel pole cultivation fields, oyster reef installations, macroalgae (seaweed) plantations and salt marsh meadows. The design of the supportive structures and spatial arrangement of each of these typologies is driven by the Oosterschelde context and these new landuses all conform to a spatial grid that is in turn, defined by their individual ecosystemic, productive and / or locational requirements.

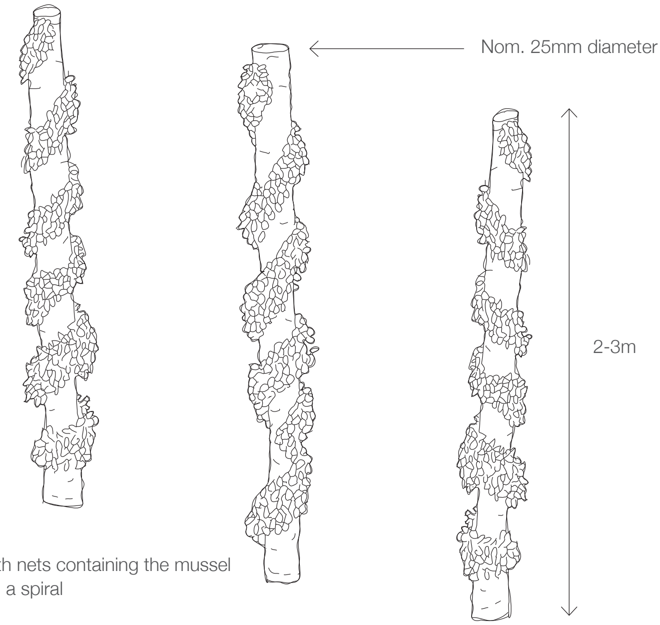
Blue Mussel, Mitilus edulis





Figure, 31: Design rationale for Oosterschelde mussel pole fields





Mussel poles with nets containing the mussel crop arranged in a spiral

7.4 *ecological infrastructures, mussel pole field*

Mussels have a long history of cultivation in Europe and Yerseke, in the Oosterschelde is a significant centre for the processing of around 90 million kilograms of mussels per year (over half of which come from Dutch waters)[1]. Mussels represent a significant cash crop and contributor to the cultural and culinary identity of their production areas but it is also their role as sedimentation catalyst of interest here.

The predominant cultivation technique in the north of France is in nets arranged in a spiral on poles located in intertidal areas (bouchots). An added benefit of this technique is that these fields can encourage sediment build up through normal deposition but also through bio-deposition of waste matter produced by the mussels. This deposition could be used as a forerunner for the establishment of oster reefs to minimise costs but also to render the process and succession of landuses apparent to the public. An additional link between the mussel pole fields and the spatial character of the adjoining landscapes might be the planting of pine trees (whose timber is required for the poles). This would act as a new vertical element in the Zeeland polders and clear visual link between terrestrial and aquatic landuses.

Infrastructural benefits:

- Some **wave attenuation** benefits
- Encourages **sediment deposition** as a forerunner to oyster reefs
- Primarily an **aquaculture crop** with the potential for each pole to produce 60kg of mussels every 12 to 15 months and for a hectare of mussel poles to yield up to €42,000 per year[2]

Environmental benefits:

- Some **provision of habitat**
- **Water filtration** function similar to oyster reefs

Location / design requirements:

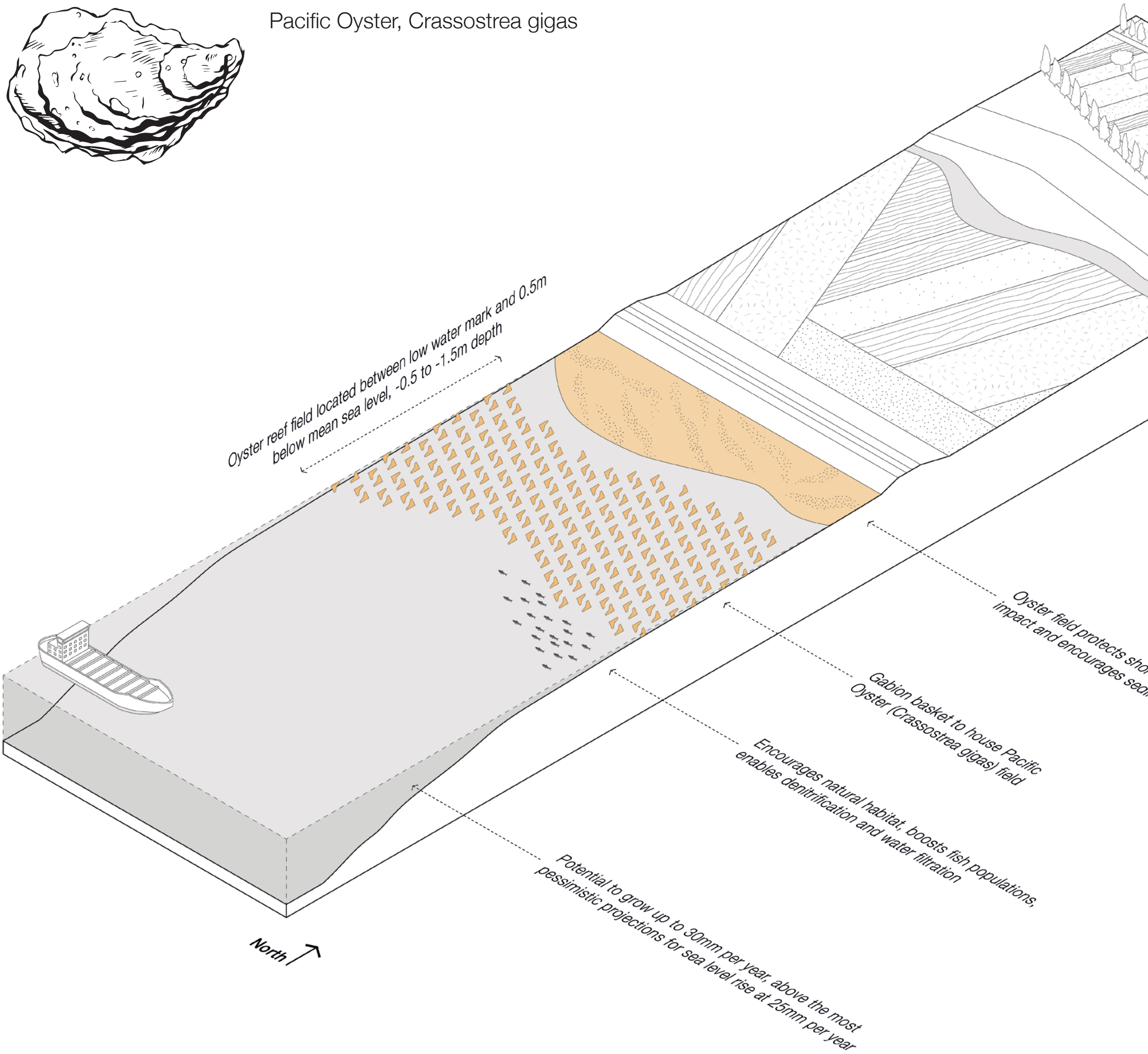
- Mussel pole fields to be **located in intertidal areas** to ensure mussels are periodically inundated, 2-3m above the sea bed and **between 1m and 3m below sea level** in the Oosterschelde
- Poles generally 4-7m high, 15-25mm diameter and made from pine or oak[3]
- **Tolerate a range of environmental conditions**
- Crop harvested mechanically so requires approximately **25m between rows**

1. https://www.mosselen.nl/en/mussel-info/about-mussels/

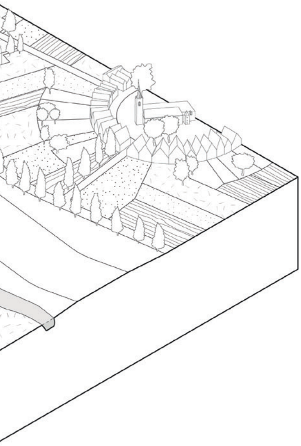
2. Wiersma et. al., 2014

3. https://thefishsite.com/articles/production-methods-for-blue-mussels

Pacific Oyster, Crassostrea gigas



Figure, 32: Location rationale for Oosterschelde reef units



7.5 oyster reef

Oyster or mussel reefs are considered the front line of coastal defence principally for their ability to attenuate wave energy and encourage sedimentation, whilst providing valuable and varied natural habitat[1]. They are used to stabilise shorelines and intertidal areas to reduce or prevent erosion and damage to coastal defense infrastructure but also encourage, protect and maintain other habitats that might also play a role in coastal defence and/or flood attenuation (sea grass meadows and saltmarshes for example). As well as buffering shoreline habitats from storm and wave damage (with up to a **40%** reduction in wave energy[1]) and helping to retain sediment where it is most needed (in the case of artificial beach nourishment for instance), these natural infrastructures grow upwards over time and so have the potential to keep pace with rising sea levels.

Oyster reefs might also act to boost nutrient availability in the system as they enclose filtered sediments in faecal matter (bio-deposition) simultaneously encouraging sedimentation and improving nutrient content[1]. There have been some experiments carried out in the study area to explore the viability and potential benefits of artificial shellfish reefs within the intertidal zones of the Oosterschelde that showed artificially fixed oyster substrate can generate self sustaining colonies that reduce wave impacts and promote sediment accretion[2]. These trials also suggested that gabion wire baskets were most appropriate to initially fix and retain the substrate that the new oyster attach to (usually empty oyster and mussel shells) but might also erode (rust) over a number of years and once the reef has stabilised itself against dislodgement by wave impacts.

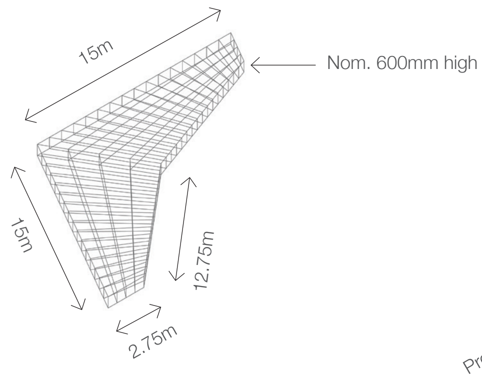
The proposal here is to utilise a gabion basket format, each unit made up of two, mirrored basket components a maximum of 15m long and 600mm high. These chevron shaped reef units are designed to present a face to both the prevailing westerly winds in the Oosterschelde and the winter southerlies as it is these winds that drive the wind waves that are most likely to cause damage to shorelines and dike faces.

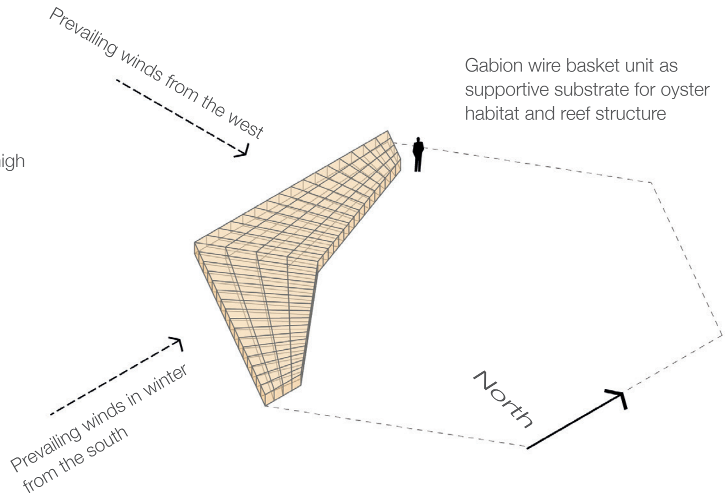
The chevron units are also intended to individually affect and defract the local flows of water and hence add complexity to both the water flow (providing areas of faster flows as well as protected areas with slower flows on the lee side of the units) and sediment deposition patterns (as deposition patterns for sediments carried by the water largely depend on flow rates). This is proposed to encourage a highly varied tidal flat landscape that should both maximise the number of potential micro-habitats as well as creating an interesting visual landscape, particularly under normal conditions when only the tops of each unit are exposed above the water and in low water conditions when the modulations of the mudflats in and around the units are also visible.

1. Wiersma et. al., 2014
2. See www.publicwiki.deltares.nl

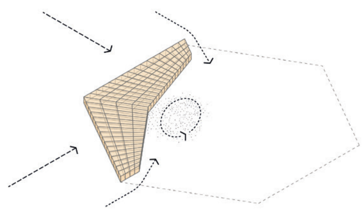
Naturally occurring oyster reefs in the Oosterschelde near Zierikzee

The natural fixing mechanisms of the oysters persist after an animals death so the reef unit foundations endure as successive populations build on and expand the reef. The initial, highly designed and artificial, visual character of the chevron reefs will therefore naturally change over time to produce a hybrid landscape shaped by natural processes manipulating its orthogonal origins.

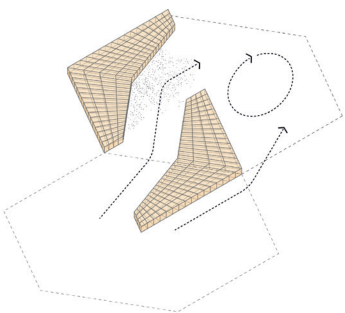


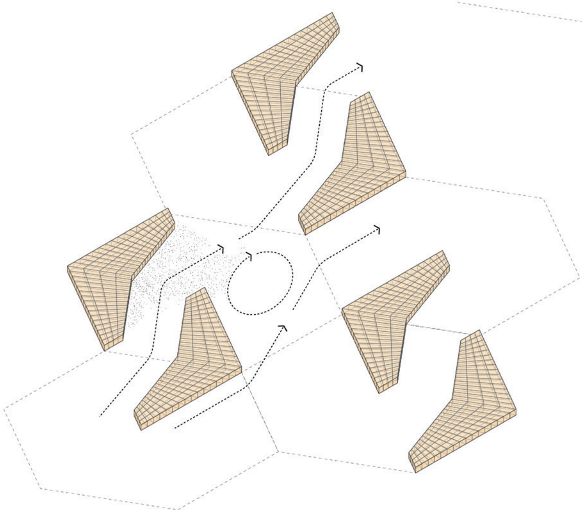


Gabion wire basket unit as supportive substrate for oyster habitat and reef structure



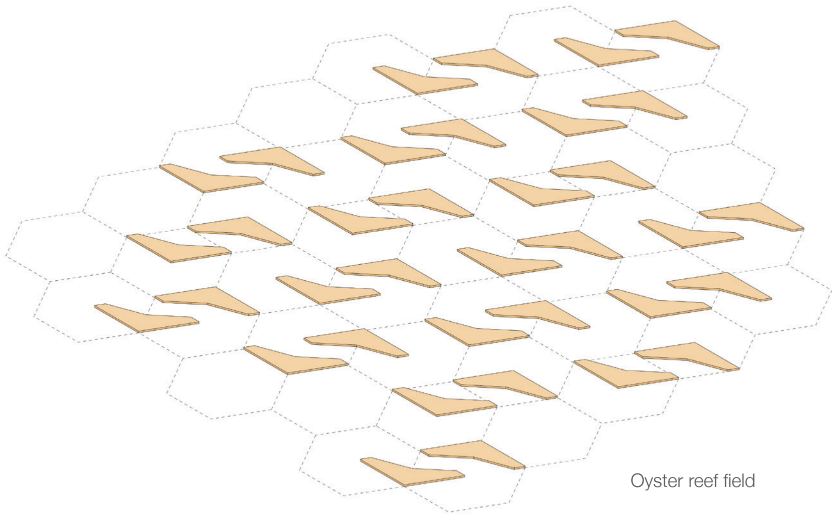
Oyster reef unit deflects currents, creates local variations in flow and A sediment deposition





Repetition of reef unit accentuates deflection of currents and creates multiple flow paths

Figure, 33: Design rationale for Oosterschelde reef units



Oyster reef field

oyster reef field, design considerations

Infrastructural benefits:

- **Reef accretion,** oyster reefs have the potential to grow up to 30mm per year[1], potentially matching the pace of sea level rise and hence maintaining their role despite rising water levels
- Protection of coastlines by **attenuation of wave energy** (by up to 40%[2]) and therefore reducing erosion as well as encouraging the establishment and maintenance of salt marsh habitats
- Encourages **sediment deposition**

Environmental benefits:

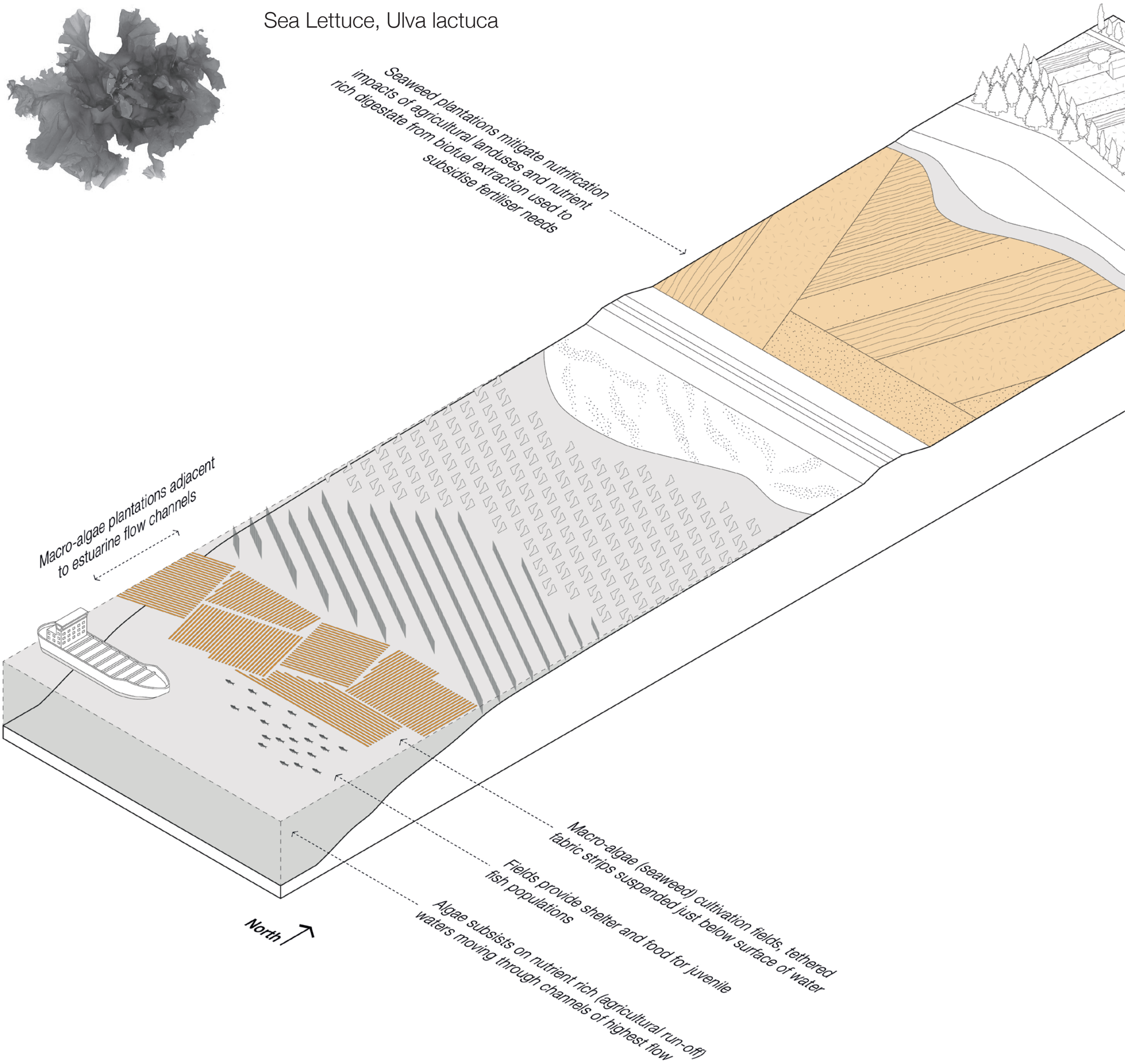
- **Habitat provision** including for both juvenile fish populations and supporting benthic (plankton and minute crustacean that constitute an important food source) biodiversity
- **Water filtration** (up to 500 litres per cubic metre of oysters per hour) improves water clarity via bio-sedimentation as well as de-nitrification of sediments (thereby reducing eutrophication and improving oxygen levels in the water)

1. Walles et. al., 2016

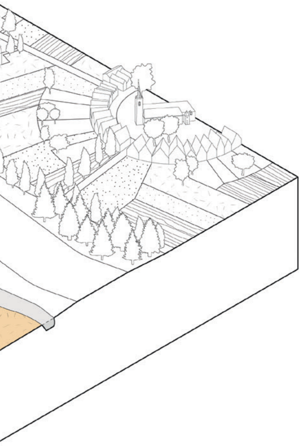
2. Wiersma et. al., 2014

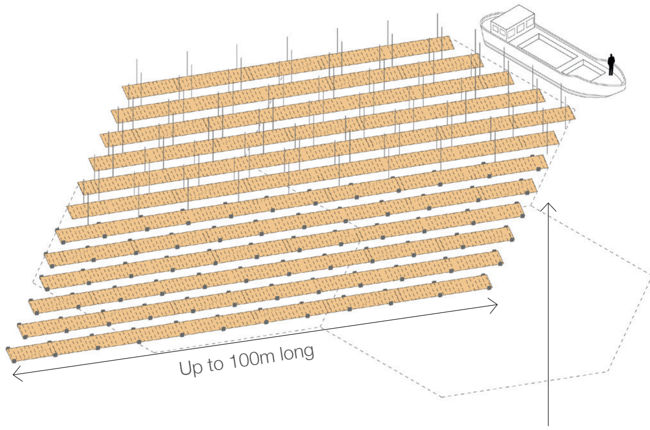
Location / design requirements:

- Reef populations require a **stable supportive substrate** to ensure the oyster structure can resist wave and tidal flow action
- Often the **middle tier** between seagrass and salt marsh populations
- Should **not be located too close to shore** to minimise sedimentation impacts
- Generally reefs are **over 500mm high**
- Located between the low water mark and 500mm below mean intertidal level (assumed to be sea level), **between 500mm and 1500mm below sea level** in the Oosterschelde
- Oyster health determined by water temperature and quality (salinity, acidity) as well as the currents, predation, food availability and sediment dynamics (too much sediment is detrimental)



Figure, 34: Design rationale for Oosterschelde seaweed plantations





Seaweed cropping lines

1-2m wide fabric strips suspended just below water level either from poles or by floating bouys

7.6 *macroalgae (seaweed) plantation*

Macroalgae (seaweed) is already cultivated throughout Europe as well as in Zeeland[1] as a source of biochemicals and food but there is increasing interest in its potential for animal and fish feed, as a source of biomass and biofuels and (given it subsists on excess nutrients in waterways) for its potential to remediate eutrophic estuarine systems.

It is largely for this use that seaweed plantations are proposed here to be located alongside estuarine flow channels to maximise exposure to nutrient rich water as it moves out to sea and reduce the nutrient impacts on the North Sea...in effect, using the Oosterschelde as a filter for nutrient waste from upstream agricultures.

Infrastructural benefits:

- Primarily an **aquaculture crop** containing proteins, iodine, vitamins and minerals for food, animal and fish feed, industrial chemicals, skincare and medicines
- **Source of biomass and oils** for production of bio-plastics, bio-fuels and as input into anaerobic digestion plants for the production of biogas
- Biomass yield up to 300tonnes / ha and bio-oil yield up to 100,00litres / ha / yr
- Nutrient digestate from biogas process up to 70kg per tonne of Nitrogen and 10kg per tonne of Phosphorus for agricultural fertilisers

Environmental benefits:

- Some **provision of shelter and habitat**
- **Nutrient trap** to remove excess nutrients (agricultural runoff etc.) from eutrophic estuarine waterways. Could combine with aquaculture to reduce nutrient waste
- **Indicator of pollution** and excess Nitrogen in waterways

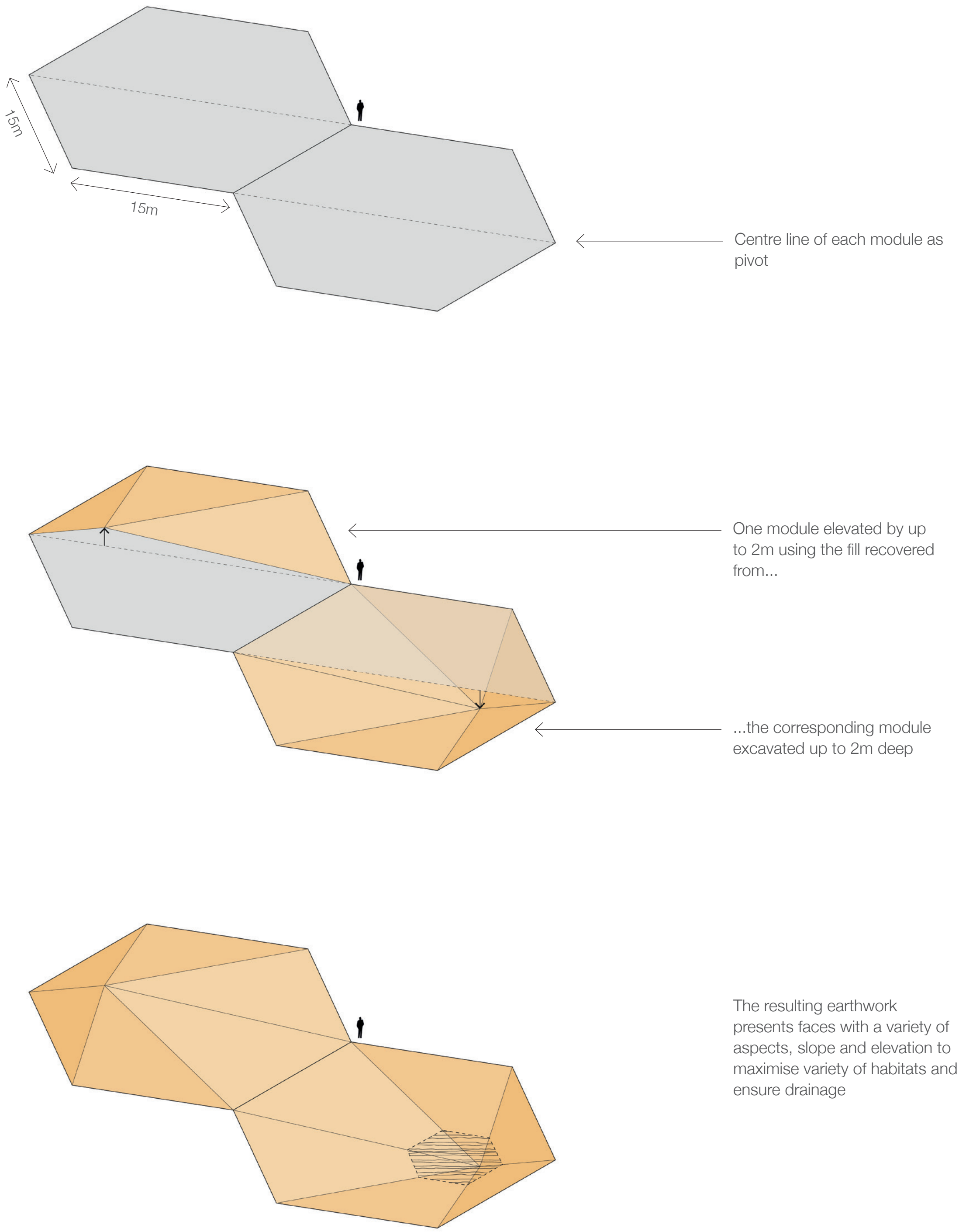
Location / design requirements:

- Seaweed either suspended from horizontal lines (up to 30m deep) or contained on fabric strips that are suspended just below the surface
- Fabric strips 1-2m wide and 50 to 100m long either supported from poles or suspended from floating bouys and harvested mechanically from a boat

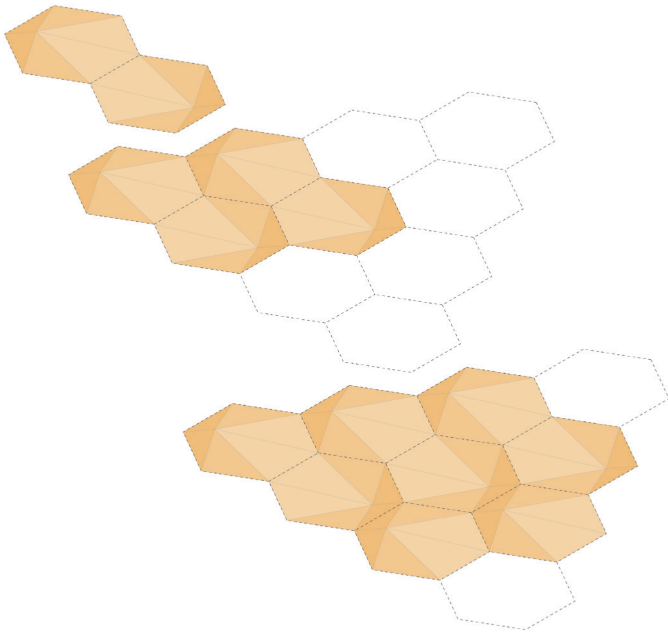
1. https://seaweedharvestholland.nl/english.html

2. http://www.iea-biogas.net

Marsh Samphire, Salicornia herbacea



Figure, 35: Design rationale for Oosterschelde salt marsh meadows



Single module of elevated and excavated saltmarsh field

Module arrayed along hexagonal grid

Modulated and complex landscape emerges as a simple structure is repeated

7.7 salt marsh meadows

Salt marshes play a similar wave attenuation (by up to **50%** as compared to bare tidal flats[1]) and erosion protection role to oyster reefs by also encouraging sedimentation and therefore vertical growth, in this case of a varied terrestrial habitat that evolves and changes character over time.

It is these changes to the vertical elevation of an area of terrestrial / aquatic fringe (driven by sedimentation and hence, sediment availability) that enables the progression of salt marsh landscapes through a number of (increasingly dry and productive) phases. The initial establishment of a salt marsh area occurs when a tidal flat accretes to just below the mean high tide water mark, inundated twice a day but otherwise remaining dry. These conditions allow pioneer plant species to take hold (such as Salicornia) which encourage sedimentation and allow higher order species to establish as the ground level moves above the high tide level. Each phase is characterised by a particular elevation (and hence, a particular inundation regime from daily to once every 100 days or so) as well as particular plant and animal communities and relations until the salt marsh can support the grazing of higher order animals such as cattle: a process that can take up to 100 years to complete[2].

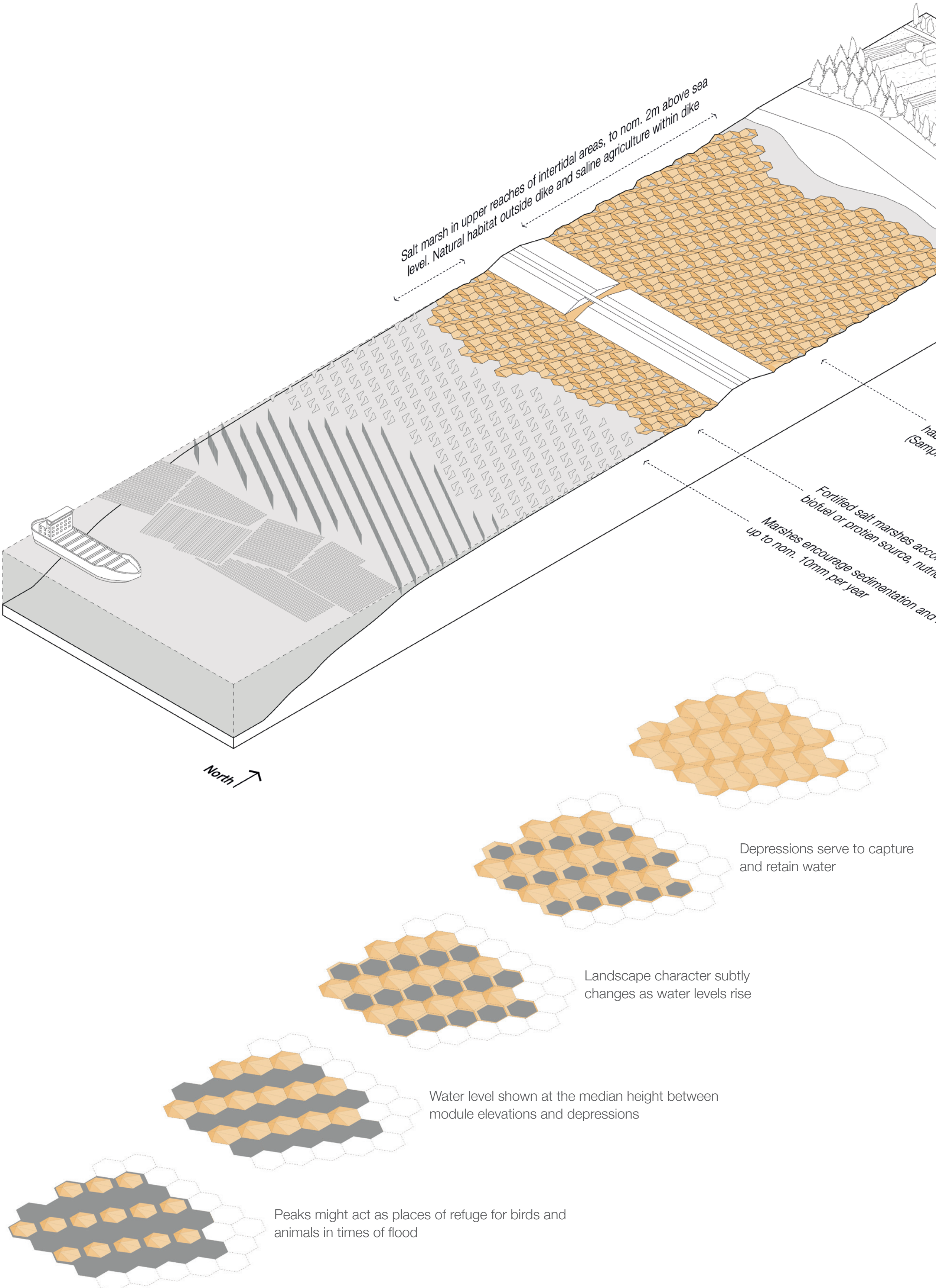
The habitat (discussed in the relational mapping chapter) and environmental benefits (outlined below) of salt marsh landscapes do not necessarily require these areas to be abandoned to nature as indeed, the grazing of cattle on the more established marshlands improves both the plant species diversity and attractiveness to birds for foraging grounds[2]. These landscapes can also be cultivated for saline agriculture or naturally occuring plants be collected as a natural harvest.

The intent of the specific design configuration for salt marshes in this thesis is to manipulate the groundplane in order to present various slopes and aspect to ensure drainage and a variety of habitat conditions. The repeated elevated and excavated areas might also ensure some areas remain dry during flood events as refuge for bird and animal species while other areas retain water in prolonged dry spells (also playing a flood attenuation role and prolonging water infiltration periods).

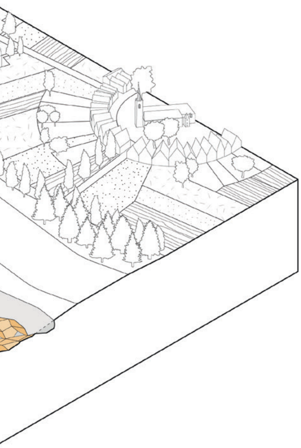
The visual character of these landscapes is also of importance as the repeated modulations, water bodies and palette of subtly coloured plant species that occupy varying slopes and elevations present a unique landscape typology.

1. Wiersma et. al., 2014

2. Salt marsh ecology from waddenacademie.nl



Figure, 36: Location rationale for Oosterschelde salt marsh meadows



salt marsh meadows, design considerations

Infrastructural benefits[1]:

- Principle landuse suggested for areas of **managed dike realignment**
- Protection of coastal defences by **attenuation of wave energy** (by up to 50% compared to tidal flats) to reduce erosion, wave impact and maintenance costs
- Encourages **sediment deposition** with the potential to accrete by up to 1cm per year but will also naturally extend shorewards with the rising sea levels
- Where used as a **saline agricultiral crop,** harvesting of the wild Salicornia crop (Samphire) could yield up to 15 tonnes per hectare worth up to €84,000 per year
- As salt marsh plant species have a high cellulose and oil content, **biomass** produced could be used to produce biogas and fuels

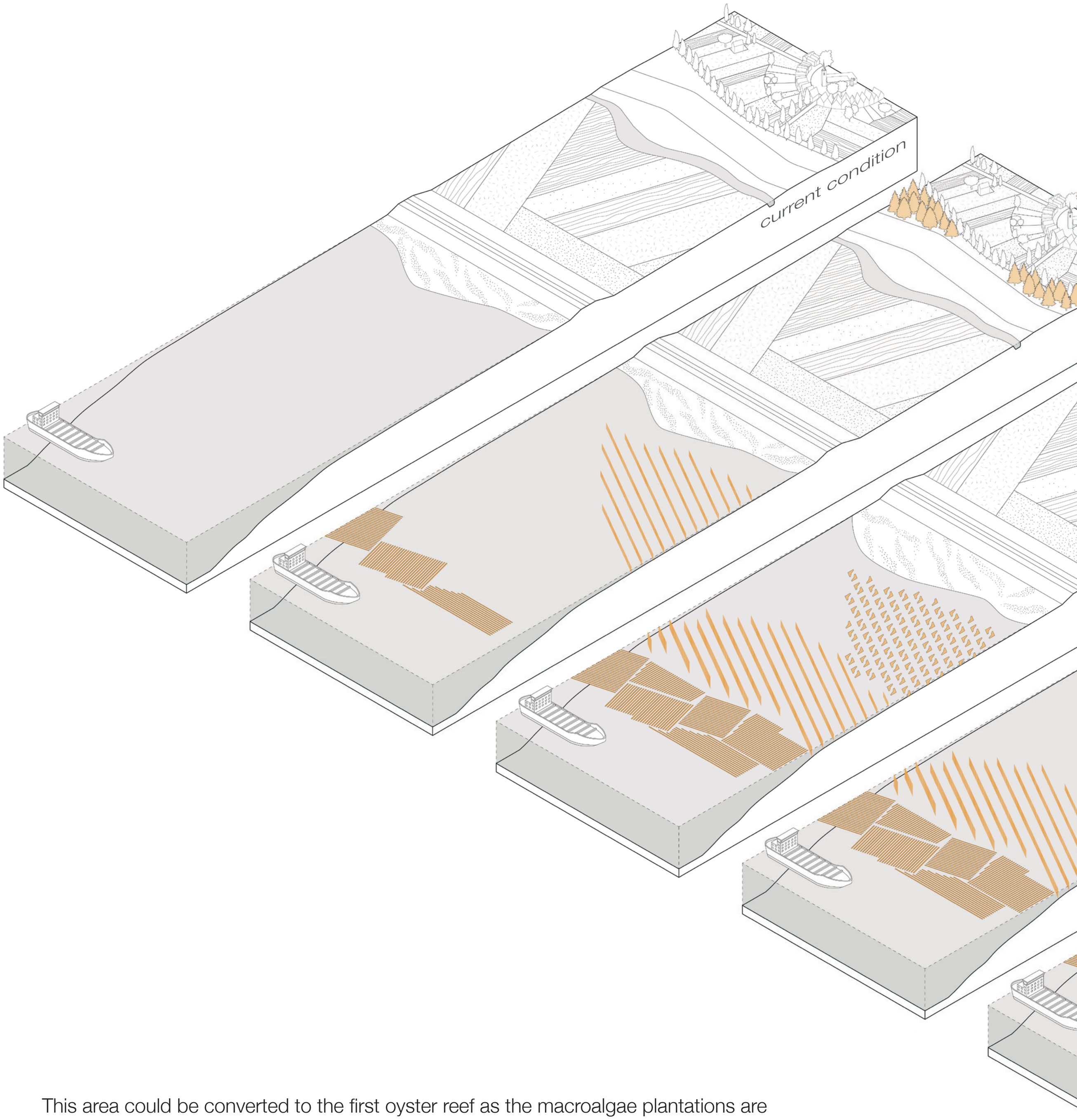
1. Wiersma et. al., 2014

Environmental benefits:

- **Habitat provision** for a range of benthic, plant, animal communities as well as foraging and resting grounds for birds
- Aids **Carbon capture and storage,** removing up to 1500kg of Carbon / ha / yr
- Plant processes aid **denitrification** of water and sediments, removing up to 100kg of Nitrogen per ha per year and helping to remove excess nutrients from surface runoff before it enters the estuary therefore **improving water quality**
- As the plants require nutrients to grow the salt marshes might become **sinks for excess nutrients** such as those produced by nearby aquaculture operations

Location / design requirements:

- Located from 1m below the mean high water mark and up to around 2m above sea level. So **between 1m and 2m above sea level** in the Oosterschelde
- Ideally on slopes of 1 to 2% to **ensure good drainage**
- Salt marsh fields preferably wider than they are deep to maximise sedimentation
- Given filtration role, could locate on fringes of farmland to filter nutrient rich runoff

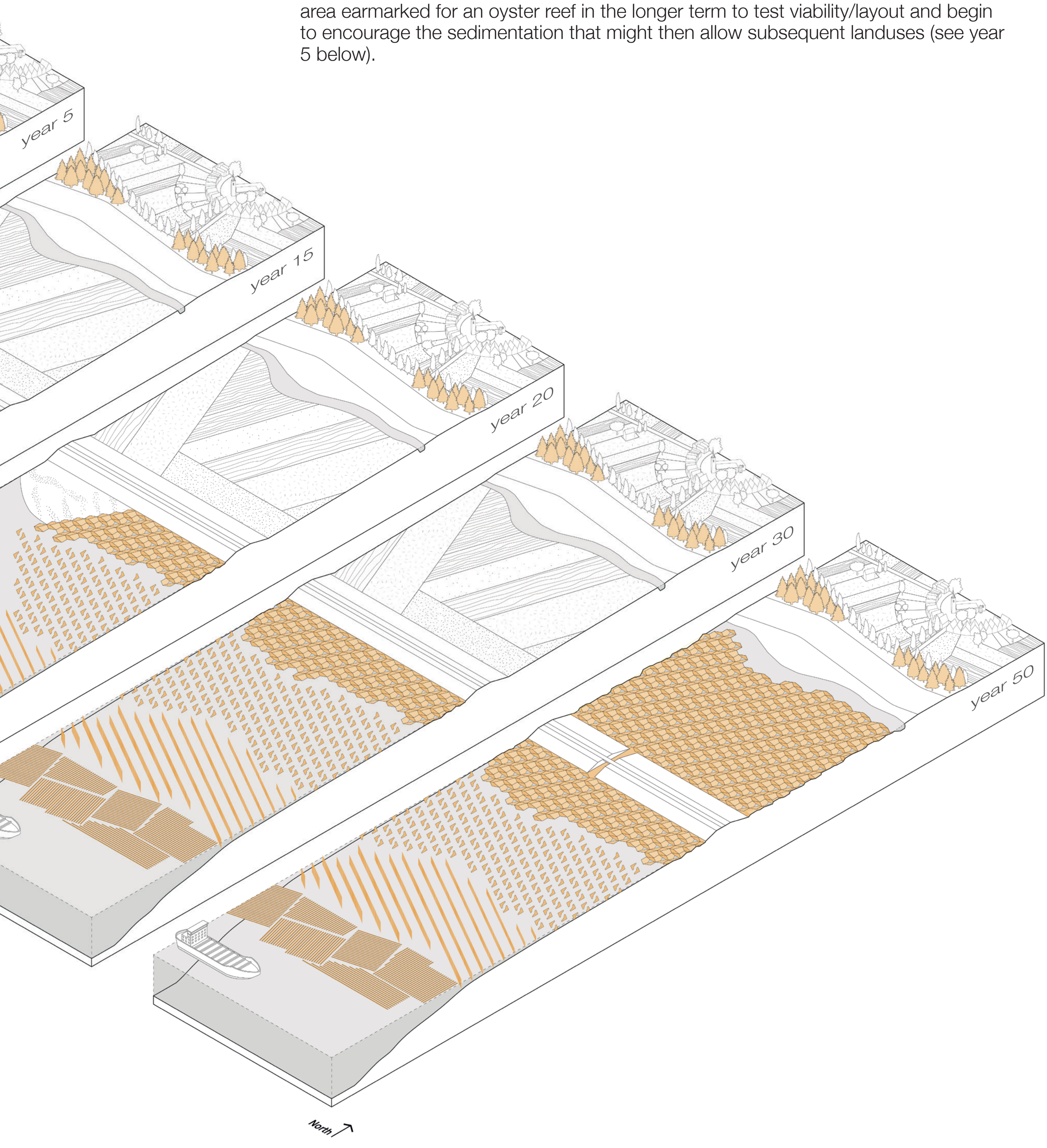


This area could be converted to the first oyster reef as the macroalgae plantations are expanded and the mussel poles relocated to their final position in the intertidal range. After 15 years, the pine plantations would be able to locally supply all of the required mussel poles and the oyster reefs will begin to impact the estuarine sediment regimes (year 15).

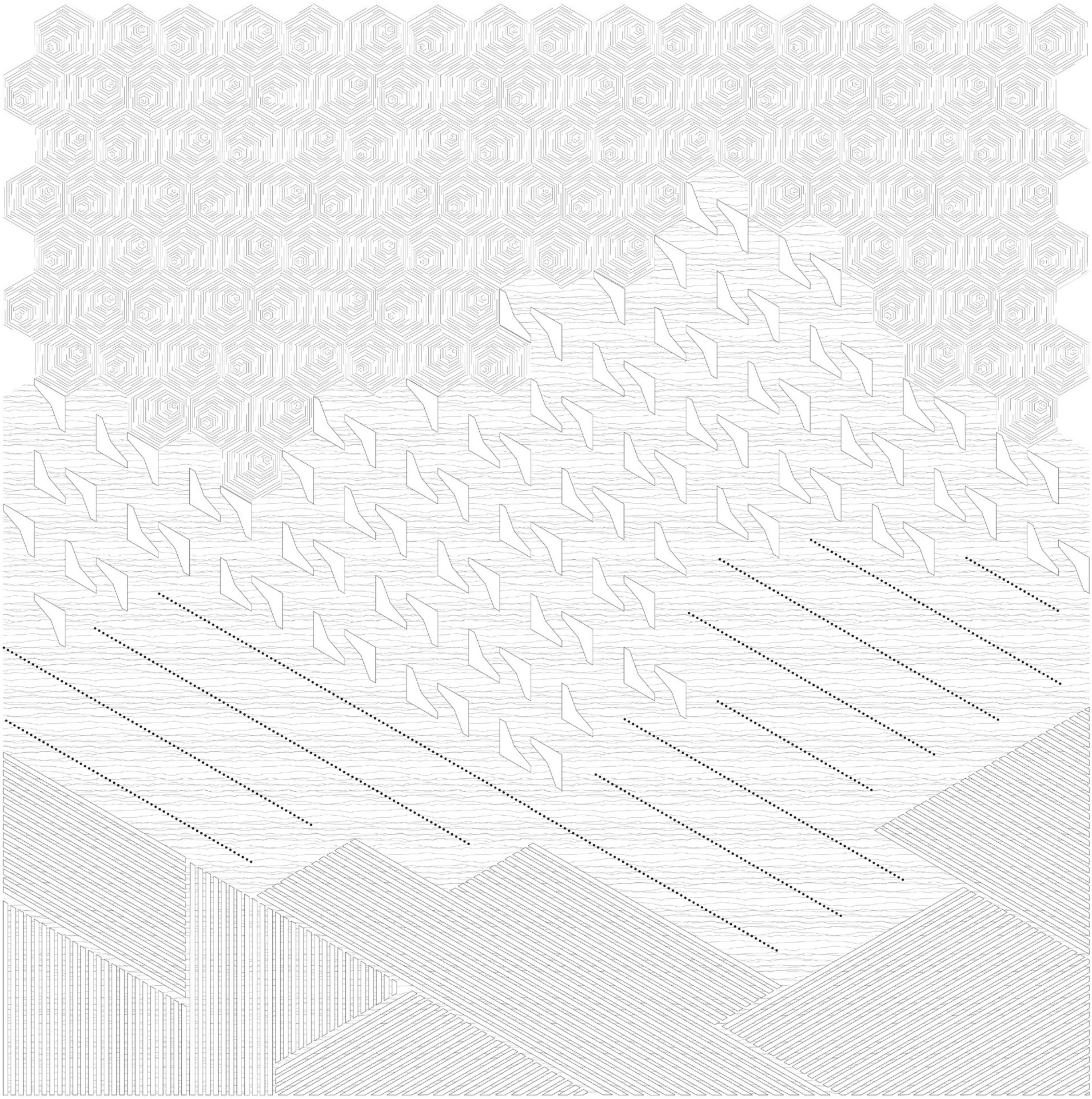
The expansion of the oyster reefs will create protected conditions along the coastal edge and allow the early establishment of an estuarine salt marsh habitat (year 20). It is only once the whole suite of wave attenuation, accretion and coastal protection landuses have become established, that the final step of breaking through the primary dike to recolonise the youngest agricultural areas can occur (year 50). This step concludes the recalibration of the protection infrastructures, natural habitats and spatial landscapes of the Oosterschelde from hard to soft, from simple to complex and from agricultural to ecological.

7.8 *initial spatial progression*

The new infrastructural landscape least dependant on sedimentation regimes and having the least visual and spatial impact is the macroalgae plantations alongside the estuarine flow channels. These could provide an immediate nutrient reduction, economic and power / heat benefit as well as spur new industries to locate in the delta (bio-plastics, seaweed processing etc.). At the same time the pine plantations that would eventually supply the timber for the mussel poles could be installed as a visual "indication of intent". A trial plot of mussel poles could be established in an area earmarked for an oyster reef in the longer term to test viability/layout and begin to encourage the sedimentation that might then allow subsequent landuses (see year 5 below).



Figure, 37: Ecological infrastructure progression



application at the sub-regional scale

Key

Estuarine use typology zones

- Cultivated estuarine saltmarsh
- Oyster reef installations
- Mussel pole (bouchot) fields
- Macroalgae (seaweed) plantations
- Municipal boundary
- Extents of 100km^2 estuarine system
- Cultivated terrestrial saltmarsh

n | 0 | 2 | 4km

Sources: Top50NL mapping, Deltares (2012), Sustainable Scenarios for the Southwest Delta.

Figure, 38: Landuse application, maximum case over 100km^2

8.1 site application, 100km² field

In order to assess the likely impacts and possible synergies that might emerge from an application of these new ecological infrastructures within the Oosterschelde, an estuarine area of 100km² has been chosen as a test bed. The supposition is that this example should represent the maximum application possible within this area (i.e. the best case scenario in spatial and productive terms) to allow quantification of the potential monetary benefits (both in terms of productivity and the value of ecosystem services provided) of the system as a whole.

This is clearly not a reasonable assumption as the logistical requirements as well as costs of installation and maintenance of these systems prohibit their immediate implementation. The following exercise does however provide an initial sense of whether these proposals are remotely economically feasible and begin to suggest locational, infrastructural and social requirements, associations and limits.

As the majority of suggested new landuses have specific locational requirements (generally dictated by their relative location and depth in the tidal regimes of the Oosterschelde) we can relatively accurately determine the maximum extents of their estuarine application (constrained as they are within the notional 100km² limits). The extent of proposed terrestrial salt marsh landscapes conform with the suggested areas to be depoldered by Wiersma et. al. (2014), again limited to parcels directly adjacent the 100km² area. The extent of macroalgae (seaweed) plantations are not (absolutely) dictated by depth and so have been sited in estuarine areas not occupied either by one of the other ecological infrastructures or by shipping and navigation channels.

It is these maximum new landuse extents (2200ha of macroalgae, 1120ha of mussel poles, 2780ha of oyster reef, 250ha of estuarine salt marsh and 3500ha of terrestrial salt marsh) that will allow us to quantify the products, costs, benefits as well as logistical, functional and location constraints that might apply to this new web of habitats and spatial typologies.

8.2 $100km^2$ field, macroalgae

The maximum application of possible seaweed plantations in the $100km^2$ scenario is an area of approximately **2,200ha**. Given the conservative design and indicative layout of a proposed area of macroalgae plantation (see opposite), the actual area of seaweed production medium is around 22% of this 2,200ha, or approx. **485ha**.

The yields of seaweed farming differ by location, species, season and technique but for the purposes of this thesis we will assume the yield to be 300 tonnes[1] of wet weight per hectare per year (based on Saccharina latissima), or **145,500t** / year of algal biomass. Assuming a 1.5m wide fabric strip as supportive substrate for the growing of the seaweed, the above installation will require 1.46km of fabric with 3km of perimeter ropes and approximately 290 fabric floatation bouys[2] per hectare. In addition to the materials production requirements (fabric sheets, bouys and ropes), this system will require onshore seaweed hatchery and lab facilities, port facilities for installation and maintenance materials and vehicles as well as onshore processing or drying facilities. Installation, harvest and maintenance requirements are unknown but estimated at approximately ten boats (50t capacity each loading 1km of substrate per day) working full time (300 days per year) and with 3 crew per boat (36 in total assuming a 250 day working year per person) with a third of that again as onshore support, which suggests a staff requirement of around **50** full time workers.

There is also potential to couple these nutrient traps with aquaculture to minimise (and employ) their nutrient waste streams. A two year old Atlantic Salmon (nom. 4.5kg) produces around 130g of Nitrogen over its life which could be sequestered by around 60kg of seaweed[4] or, to eliminate the Nitrogen produced by **2000t** of aquaculture fish (Kingfish Zeeland's 2020 production targets), less than 20% of the proposed plantation area (producing 27,000t of seaweed) will be required.

Terrestrial implications / benefits

This 145,500t of biomass has the potential to produce **26.3 million m^3** of biogas per year via anaerobic digestion processes[10] as well as **223,080MWh** of energy (assuming 365Gj/ha/yr[1] or 101.4MWh/ha/yr[5]). This might equate to the annual electrical power needs of **33,231 people**[6] or more than the 2011 populations of Kats (285), Colinsplaat (1350), Ouwerkerk (430), Nieuwerkerk (2360), Stavenisse (1250), Zierikzee (5140), Oosterland (1930), Wemeldinge (2710) and over half of Goes (29,795)[7]. In addition, as seaweeds have the potential to fix around 30% of their weight of carbon dioxide[8], the 145,500t of seaweed could sequester the equivalent of **4,840** people's carbon emissions[9]...effectively almost rendering the populations of Colinsplaat, Stavenisse and Nieuwerkerk carbon nuetral.

This biogas could also be used in combined heat and power plants (CPH) to heat local homes as well as in closed greenhouse systems (that also benefit from the carbon dioxide produced in the combustion process). This quantity of biomass would amount to the annual feedstock required to maintain around **14** anaerobic digestion (AD) and 500Kw capacity combined heat and power plants (CPH)[10] which represents around 5.5% of the number of AD plants the Netherlands had in 2013 and around 2.5% of their installed energy capacity[11]. Additional benefits could also flow back to the traditional agricultural industry in the form of fertilisers produced from the nutrient rich digestate of the biogass production process. With the biomass input from the proposed scenario, this digestate could consist of around 1,527t of Nitrogen and 218t Phosphorus[12]...with a potential cost savings of over **€1.2 million**[13].

Using figures of €3,500 per Kw capacity for installation costs of a small scale CHP plant and ongoing operations and maintenance costs of 3.5% per year[14], the 14 plants proposed would cost €1.75million each to build and €61,250 per year to run. This equates to a total of €24.5million construction and €857,500 p.a. running costs.

As mentioned, seaweeds have a number of other commercial applications with biomass for power and heat production having the lowest value but perhaps most potential to retain and distribute benefits to adjacent communities. Seaweed could be sold for animal feeds (approx. €80/t), plant fertiliser (€400/t), and high end food products (€2,000/t), amongst others[15]. This would value the production in this scenario around €11.6 million, €58.2 million and €291 million respectively.

1. IEA, State of Technology Review, Algal Energy, (table 9.3 for yields, rounded up)

2. From AtSea Macroalgae farming protoype system, assuming 1 bouy every 10m

3. Assuming 2 x installalation, harvest and maintenance cycles / yr staggered to allow continual harvest

4. Jacob et al, 2016

5. Using 1KWh = 3.6mj

6. At 6,713KWh pp from World Bank 2016 energy consumption per capita stats

7. Population numbers extracted from http://pdokviewer.pdok.nl/

8. Slade and Bauen, 2013

9. At 9.92t/person/year, from World Bank 2016 carbon emissions per capita stats

10. See IRENA biomass to energy report, table 2.5

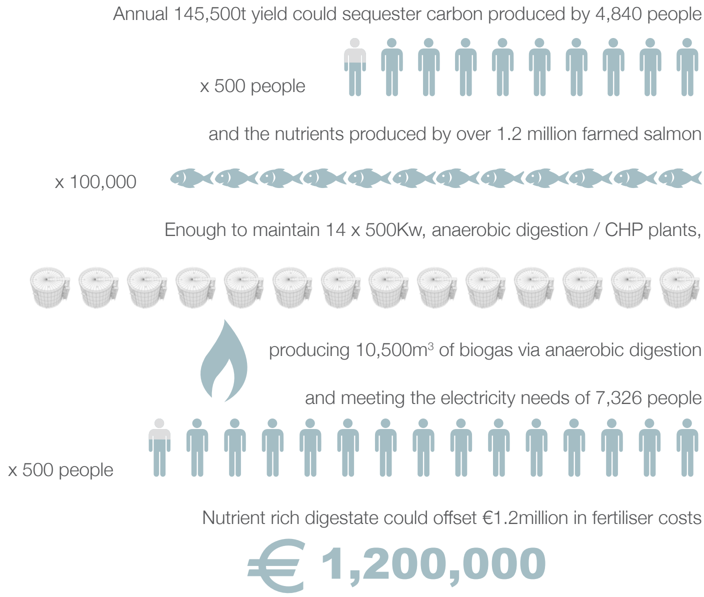
11. Biogas stats in the Netherlands from world biogas association

12. 15% dry weight from IEA review. 7% N, 1% P of dry weight, Slade and Bauen, 2013

13. Based on €800/t for N based fertilisers, from Jacob et al, 2016

14. IRENA biomass to energy report, tables 5.5, 5.6

15. Seaweed products and prices from fao.org



Macroalgae production system

Total area covered, 2,200ha

Total area of macroalgae supportive substrate, 485ha

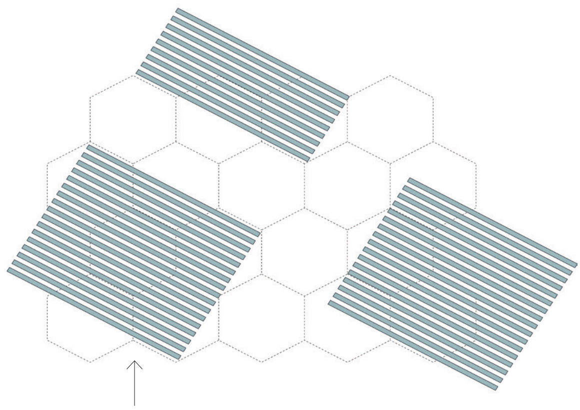
Length of 1.5m wide substrate fabric, 708km

Length of perimeter ropes, 1,455km

Number of floatation bouys, 140,650

Total seaweed biomass yield (wet weight), 145,500t / yr

Yield per hectare of area covered (as per design below), 66t / yr



Patches of 17 x 1.5m by 60m long substrate strips with floatation bouys every 10m

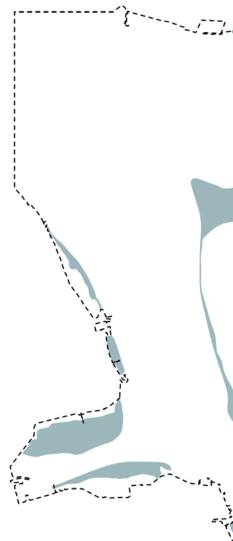
Limiting factors

Aside from aquatic environmental factors required for seaweed growth (the right water salinity and acidity levels, low impacts of pests and diseases etc.), the principal requirement is consistent water flow and **nutrient availability**. As Brand notes[16], the deltaworks have cut the influence of the North Sea (nutrient exchange) on the Oosterschelde by a third, have doubled the residence time of the water in the estuary as well as reduced tidal volume by a third and tidal range by at least 12% (less nutrient and water mobility and throughflow). Hopefully the reinstated estuarine flows, North Sea exchange, increased ecological habitats and nutrient rich riverine flows will provide the seaweed's required levels nutrients. If not, coupling the plantations with aquaculture could provide additional nutrients within a productive and circular system.

16. Brand et. al., 2016

The practical logistics of continually harvesting this amount of biomass are substantial. Ten boats cannot operate simultaneously out of one marina although the Kats marina would appear the perfect base for the operations given the existing (likely over 20t capacity) cranes and storage areas that were built for the Zeelandbrug construction but currently appear little used. Were the boats to stagger unloading shifts, perhaps three to four boats could operate out of one marina and so three marinas would be required, perhaps one in Kats, one in Stavenisse (new docking and unloading/storage facilities required at currently small scale, recreational marina) and one in Zierikzee, Goes or Welemdinge (existing industrial facilities to be expanded).

8.3 *100km^2 field, mussel poles*



The mussel pole (bouchot) fields have been suggested as a new cultivation method for the Oosterschelde for their strong spatial characteristics as well as productive capacity and ability to encourage sedimentation. This technique is extensively used to produce mussels along France's north coast and while Zeeland is largely a nursery or larval (spat) collection site only, large numbers of mussles grown all across Europe are processed and sold in or around Yerseke, just south east of the focus area[1]. Mussels clearly already play a significant role in cultural (the "Zeeuwse mossel"), culinary and economic (as part of food production and processing industries) associations with Zeeland and this proposed ecological and productive landuse would seek to broaden and build on this.

The poles are to be located in the Oosterschelde's intertidal areas between 1m and 3m below sea level. These constraints allow a maximum area of **1120ha** to be installed in the 100km^2 scenario between the macroalgae plantations and the oyster reef fields. This would consist of modules of two lines of poles spaced around 1m apart, each line to be accessed from the outside. These modules are placed 25m apart to allow access for installation and harvesting and as each pole might produce up to 60kg of mussels every 12 to 15 months, a hectare of poles might produce up to 42t of mussels with a yield of up to €42,000 per year[2]. The total 1120ha of poles would then produce up to **47,000 tonnes** per year with a value of over **€47 million**.

Currently the Oosterschelde appears to contain abundant quantities of natural spat but if needs be, propogation and ongrowing facilities might be required onshore. Similar infrastructures (onshore processing and storage facilities) and assumptions (for installation, harvest and maintenance requirements) that were made for the macroalgae case have also been applied here. The busiest time will obviously be during harvest but the hope is that this could be spread out to 6 months of the year. The logistics of harvest (assuming a 20t boat with two crew can strip around 240 poles per day (30 per hour) and working 25 days per month during the harvest season)[3], requires approximately 22 boats working full time for those 6 months with two to three crew per boat so around 50 in total. Assuming twice the number of workers are required as onshore processing and support, this suggests a staff requirement of around **150** full time workers.

Terrestrial implications / benefits
Each hectare of this plantation would require around 880 timber support poles to house the mussel nets. The assumption is that these (pine) trees be grown locally to contain the economic benefits but also make apparent the (spatial and visual) links between terrestrial and aquatic landuses. Assuming these poles are an average of 6m long, 15-25mm in diameter and pine plantation yields
are around 150m^3 per ha per 15 year growth cycle of Pinus sylvestris (approximately 500 trees per hectare)[4], then the 1120ha of bouchot poles would require around **3125ha** of pine plantations to supply these raw materials...one hectare of mussel pole field therefore equates to almost three hectares of pine plantations onshore. Using €4000 management costs per hectare of pine plantation over 15 years (assuming Daugaviete's yields (nom. €2000 / ha)[4] represent an economically viable plantation in eastern Europe and doubling this figure for the Dutch case), the pine plantations would cost €835,000 per year to run.

This obviously reinforces a sense of natural / biotic timescales in the expansion of the project and a causal link in landscape changes as the felling of three hectares of pine plantation would see the installation of a corresponding hectare of mussel poles. The terrestrial component of the study area makes up 185km^2 (18,500ha) so if we were to give **1%** of this area over to pine plantations, they would supply the poles for 60 hectares of mussels every 15 years. While the **280 years** therefore required to locally provide the timber for 1120ha of mussel poles seems unrealistic, these 60ha blocks are likely the increments of expansion that would suit each extra boat and crew (one boat could harvest approx. 51ha per year). In this instance there is a terrestrial / estuarine / social chain established where 180ha of pine trees are grown over 15 years to allow 60ha of mussel fields that will sustain one extra fishing vessel, its crew as well as onshore staff and their families in perpetuity.

1. Dutch mussel industry info from mosselen.nl

2. Wiersma et. al., 2014

3. Assuming 1 x installalation, spat transfer and maintenance (4x) cycle every 15 months, staggered to allow 6 months of continuous harvest

4. Daugaviete, 2017

5. Colijnsplaat fishery info from unitedfishauctions.com

Annual economic value of 47,000t crop worth up to €47 million

€ 47,000,000

Mussel pole system

Total area covered, 1,120ha

Timber bouchot poles, 880 / ha

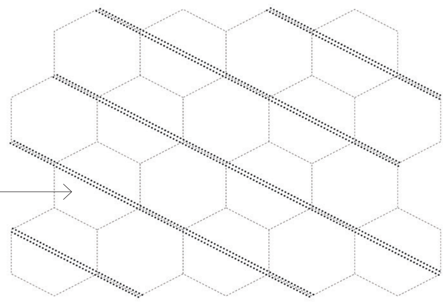
Total number of poles, approx. 985,000

Total area of pine plantation to supply poles, 3125ha

Total mussel yield, 47,000t / yr

Yield per hectare (as per adjacent), 42t / yr

Double lines of poles spaced 1m apart



Limiting factors

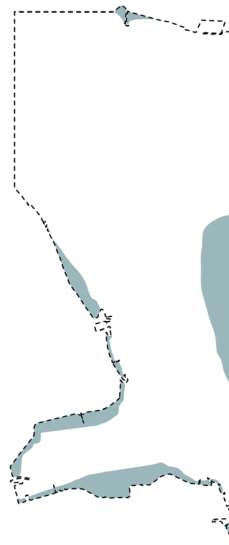
As with the macroalgae cultivation, 22 boats would need to be spread amongst the harbours in the area but as the unloading and processing of mussels is likely less infrastructure and space intensive than seaweed, this industry might be located according to current and / or traditional fishing centres such as Yerseke mentioned previously. Colijnsplaat would be an obvious contender as it currently houses a small fishing fleet (10 to 20 vessels) and auction house (landing around 1,250 tonnes of fish and shrimp per year with a turnover in 2008 of €4.5 million)[5]. Zierikzee is another obvious choice given its historical focus on fishing, easy access by canal, existing industrial areas and as a number of fishing vessels currently appear to have their moorings here[8]. Given the spacing requirements of these fields, it is likely that some of the areas identified for mussel fields would not be economic to farm (too long and thin for example) and so the 1120ha area (as well as corresponding port and processing infrastructure) would probably be somewhat reduced.

Suitability of environmental habitat obviously impacts the success of mussel cultivation (salinity, water temperature, predation etc.) though Mytilus edulis (the Blue Mussel) is highly adaptable to a wide range of conditions and is raised all across the northern European coast[6]. As mussels are a food crop, there may be issues with biotoxins impacting food safety by these can potentially be purged from the mussels by additional processing. The likely limiting factor again, is the **availability of nutrients** as this is a key factor (along with carbon dioxide and sunlight) in the growth of the phytoplankton that mussels feed on.

As such, this landuse relies on the very same core component as the seaweed farms. Like macroalgae plantations though, there has been research[7] suggesting that mussels might take up waste nutrients from adjacent fish farms and therefore be a means to both maximise growth of the mussels (particularly in times of natural phytoplankton deficiency such as in winter) as well as minimise the release of aquaculture nutrient wastes into the environment.

6. Mussel cultivation info, fao.org
7. Handå, 2012
8. As seen during a site visit

8.4 *100km² field, oyster reef*



The oyster reef system suggested here is intended to be contained within wire gabion baskets that would likely require an initial oyster shell substrate to be seeded but should then require little ongoing maintenance. They are to be located in the upper intertidal areas between 0.5m and 1.5m below sea level. These constraints suggest a maximum area of **2780ha** to be installed in the 100km^2 scenario between the mussel pole fields and the areas of salt marsh.

This is made up of around **48,650** reef modules, or 17.5 modules per hectare that can each initially contain approximately 55m^3 of oysters (110m^2 modules 0.5m deep at installation). As each square metre of oysters has the ability to filter 0.04m^3 of water per day[1], these oyster reef fields might filter up to 1925m^3 per hectare or almost the equivalent of nine olympic sized swimming pools each week. This infers that in a week, the oysters within this 2780ha of reef can filter around **5%** of the water in the entire Oosterschelde[2].

The wire basket modules would likely be constructed onshore in two sections that would be placed on site, wired together, filled with oyster substrate and topped with a lid wired to the base. The separate module halves would nest together such that a typical Dutch canal barge[3] could transport up to 24 modules or enough to cover 1.5 hectares. These baskets would be filled by a second boat of a similar size that could transport and gradually unload the 1320m^3 of substrate required. While these quantities are realistic, the time required to unload, place, fix, fill and then close each module is likely the limiting factor. At one hour per module it is likely that three boats operating concurrently (one to place, one to fix and one to fill) could perhaps install a hectare of reef per day. This suggests the entire the 2780ha would require over nine years to roll out (assuming 300 work days per year) and a staff of around 14 people on the boats and perhaps half again on land, so 21 in total[4].

Wiersma (2014) has suggested that the installation costs of oyster reefs are in the order of €30-50 per square metre. It is unclear whether this figure pertains to the oyster reef pilot projects that were placed in the Oosterschelde in 2009 but (given the modular and prefabricated nature of the modules) if we accept the lower figure of €30 / m^2, the proposed reef layout would cost in the order of EU3,300 per module, €57,750 per hectare and €160.5 million for the whole 2780ha.

Assessing the economic benefits of these types of infrastructures is problematic and will be addressed later but one fairly clear benefit is the reduction in maintenance costs for coastal defences given the wave attenuation role measures such as oyster reefs can play. It has been estimated that the costs of dike reinforcement in the Oosterschelde over the next 50 years might be between €25-260 million[1] so even a small cost saving via oyster reefs (that might reduce the need for, and / or frequency of, maintenance) would net a tangible monetary benefit.

Terrestrial implications / benefits
If unable to be naturally maintained, the life cycle of the oyster dictate that a number of stages be undertaken in the preparation of an oyster reef, from the collection of seed in the wild (in the Oosterschelde in this instance), followed by 2-3 weeks in an onshore hatchery, then transfer to a nursery environment (either on shore or in protected offshore conditions) before being installed on site[5]. There is some potential for community involvement and stewardship of this process as has been suggested by SCAPE Landscape Architects in their proposals as part of New York's Rebuild by Design plans. Locals could be involved in all stages of the process from shell collection at markets and restaurants, annual public processions of the juvenile oysters to their nursery grounds under coastal jetties and stewardship of the nursery pods prior to final installation[6].

These types of measures involve the community in the process and inform them of the characteristics of this particular habitat but also, by extension, of the coastal defence and flood mitigation role they play. A sense of community ownership of, and connection to, a patch of oyster reef in front of a township might also be bolstered by these types of community engagement...important as otherwise, the risks of public damage to, or theft of, the oysters is greater.

1. Wiersma et. al., 2014

2. With 800 billion litre tidal flow over 37,000ha from fun facts, np-oosterschelde.nl

3. Assuming a cargo space of approx. 46 x 9 x 3m deep.

4. Assuming 4 crew for 2 x large boats and 3 for a small boat over a 250 day work year

5. Oyster cultivation info from fao.org

6. Wakefield, S. and Braun, B

5% of the water in the Oosterschelde filtered in a week

40% reduction in wave energy

Oyster reef system

Total area covered, 2,780ha

Total number of oyster reef modules, 48,650

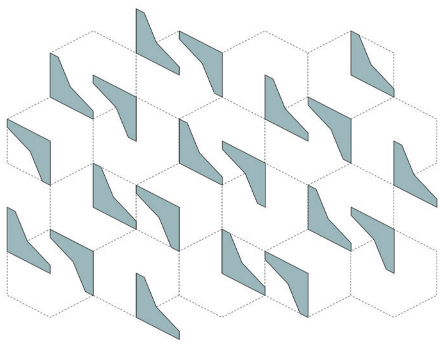
Area of each oyster reef module, 110m^2

Volume of each oyster reef module, 55m^3

Number of oyster reef modules per hectare, 17.5

Area of oyster reef modules per hectare, 1925m^2

Volume of oysters per hectare, 962m^3

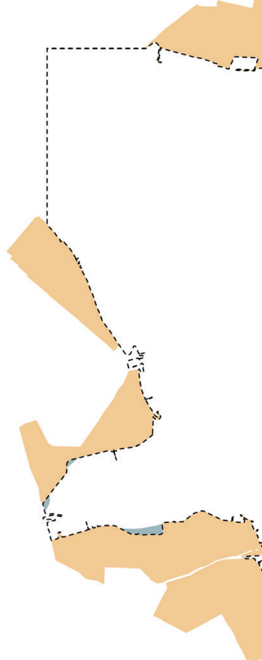


17.5 x 55m^3 (nom. 26 x 7 x 0.5m) modules per hectare

Limiting factors

As with the mussel based infrastructures, oysters form a biotic network that is susceptible to changing environmental conditions, pests and disease as well as an adequate phytoplankton food supply (dictated by **nutrient availability**) and replenishment. The benefit of the oyster reefs though is that the shells of previous generations of oysters remain in place within the gabion basket modules even if the live layer of animals is damaged or killed. If this were caused by a temporary change in conditions, a new generation would establish itself from natural seeding once conditions are again suitable. One other limiting factor though is the presence of **excess sediments** and the threat that too fast a sedimentation rate might smother the oysters, killing the live organisms and effectively negating the wave attenuation benefits.

8.5 $100km^2$ field, salt marsh



The area of salt marshes proposed for the $100km^2$ scenario consist of **250ha** of new estuarine salt marsh areas outside the dikes (1-2m above sea level) and a nominal **3500ha** within the primary dike proposed to occupy lands newly exposed to estuarine processes in Deltares' "Natural Scenario". This is made up paired modules where one is excavated to maximum 2m deep and the fill used to build the other up to to a maximum 2m high. This not only provides a variety of slopes, aspects and drainage regimes but also increases the surface area (and therefore productive as well as remediative capacity). Each module has a surface area of around $590m^2$, or around **1.015ha** per hectare on the map.

The installation costs (apart from changing the dike regime) are estimated here purely in terms of labour and machinery required to move the earth to construct the elevated / excavated modules. With each paired module requiring the movement of approximately $390m^3$ of material, this might take a single machine two days to complete or around three working weeks per hectare. A team of eight machines could likely complete two hectares per week and a staff of 30 working full time might complete 100ha per year...or take 37 years for the whole area proposed[2]. Given the substantial cost of this process, the surface area benefits and species richness improvements of adding levees and depressions (suggested by Bakker[3]) need to be evaluated and weighed against the costs.

Through all their evolutionary stages, salt marsh landscapes provide a multitude of natural habitat and environmental benefits but might also support other productive economies. From an environmental point of view, salt marsh landscapes have the potential to annually fix 107kg of nitrogen per hectare in brackish conditions and sequester 1500kg of carbon. The total area proposed of 3750ha therefore, has the potential to remove over **400 tonnes of nitrogen** and over **5600 tonnes of carbon** per year (almost accounting for the carbon emissions of Kats and Ouwerkerk's populations)[4].

These landscapes should also be used to test models for saline agriculture or the harvest of naturally occuring plants. Using the previously discussed potential yields for harvested Salicornia, were only 10% of the proposed salt marsh area be harvested, the net economic benefit might be in the order of **€31.5 million** per year (depending on market prices).

It has also been suggested that these fringe landscapes between traditional agriculture and estuarine systems could house other productive economies such as aquaculture ponds that require abundant supplies of seawater[1]. These uses might both provide elements for the maintenance of salt marshes (excess nutrients) as well as subsist on the products of these areas (fish food in the form of algae and other protein sources, Ragworms for instance as is already being put in practice near Kats[5]). In this vein and again linking 10% of the proposed salt marsh area with an aquaculture operation, the nitrogen produced by over **2.75 million tonnes**[6] of fish could be captured.

Limiting factors

Given the cycle of growth and evolution of a salt marsh landscape is driven by **relative sea levels** and the **availability of sediments**[3], this could be seen as a significant limiting factor to the accretion of salt marshes and therefore, the efficacy of their role in coastal protection...if there is not enough sediments available, the salt marsh will not continue to grow along with sea level rises and may be subject to erosive forces.

By the same token, and as a biotic environment, salt marshes require a steady supply of **nutrients** for the plants to subsist on. This is likely usually provided by the periodic inundation by estuarine waters but in this case (as numerous mechanisms have been proposed that remove nutrients from the water) this supply might not be forthcoming. Indeed the salt marsh areas might be required to act as a means to produce, or at least convey, nutrients for the benefit of the estuarine infrastructural landuses. Given

1. Wiersma et. al., 2014

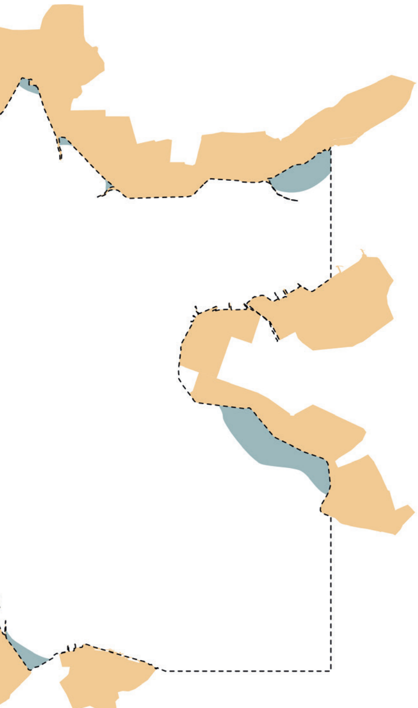
2. Assuming a hydraulic excavator with a $0.5m^3$ bucket can move $30m^3$ / hr, 20 staff will operate the 8 diggers rotated to allow a 250day work year

3. Salt marsh ecology from waddenacademie.nl

4. At 9.92t/person/year, from World Bank 2016 carbon emissions per capita stats

5. Onshore aquaculture from kingfish-zeeland.com

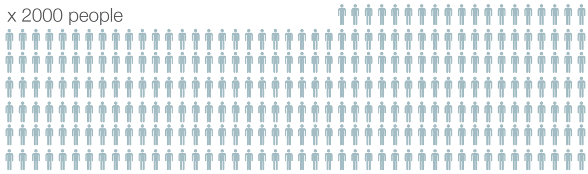
6. Jacob et al, 2016



50% reduction in wave energy

Sequestration of the carbon produced by 567,036 people

x 2000 people

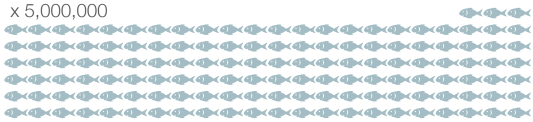


Harvest of wild Samphire over 10% of the proposed area could net €31.5 million

€ 31,500,000

Nutrients producd by over 615 million farmed salmon could be captured

x 5,000,000



370,000m³ Requires 370,000m³ of sediments per year to accrete 1cm

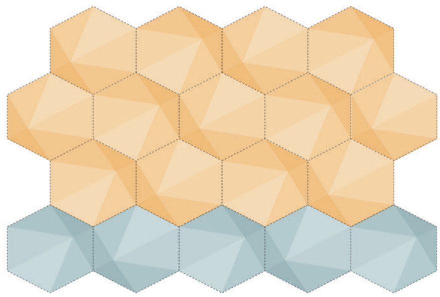
Salt marsh system

Total estuarine area, 250ha

Total terrestrial area proposed, 3500ha

Surface area of each salt marsh module, 590m²

Surface area per hectare, 1.015ha



7. Taking the average yields for potatoes, wheat and maize in Wiersma et. al., 2014

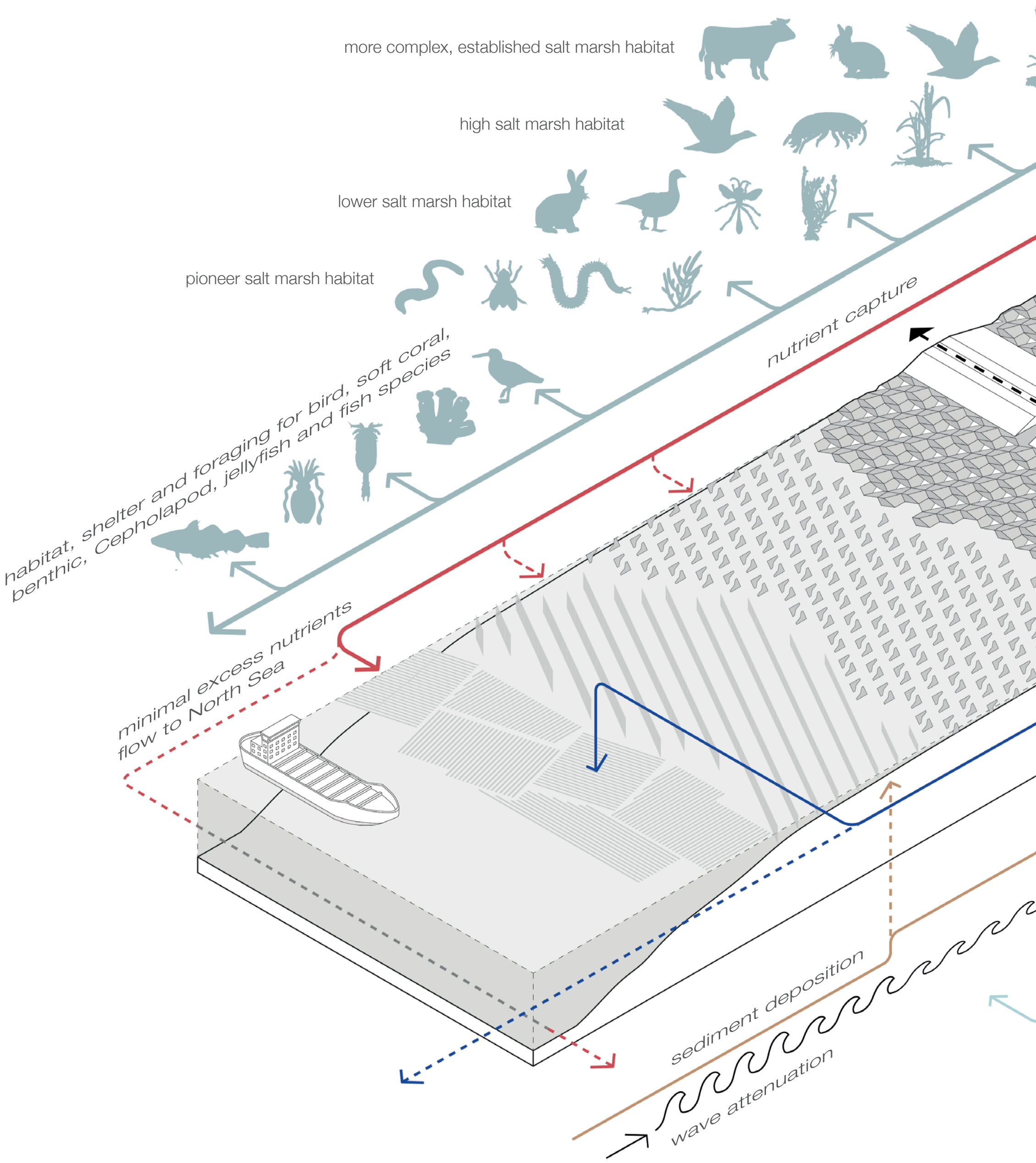
the salt marshes are generally adjacent to traditional agricultural land, we can expect (and would indeed promote) these areas to act as a nutrient filter between farms and estuary waters. The additional animal, invertibrate and benthic communities attracted to these habitats would also be expected to increase the availability of nutrients both for the salt marsh plants and for the adjacent estuarine mechanisms. Were the levels of nutrients still not sufficient, site-appropriate productive industries (aquaculture for instance) could be located in these areas to produce a nutrient waste stream.

Clearly the conversion of this amount of agricultural land will be met with objections, not least of which the loss of jobs and traditional productive capacity: estimated at around €425 / ha / yr[7] or €1.5 million per year in total. It is to address this point that high yield, alternative farming models have been suggested along with potential subsidisation of other agricultural costs (heat, power, feed and fertiliser etc.) and broader connective, knowledge sharing and administrative support networks to ease the transition and maintain both the agricultural skills base and current cultural connections to a productive landscape.

8.6 *measuring the benefits*

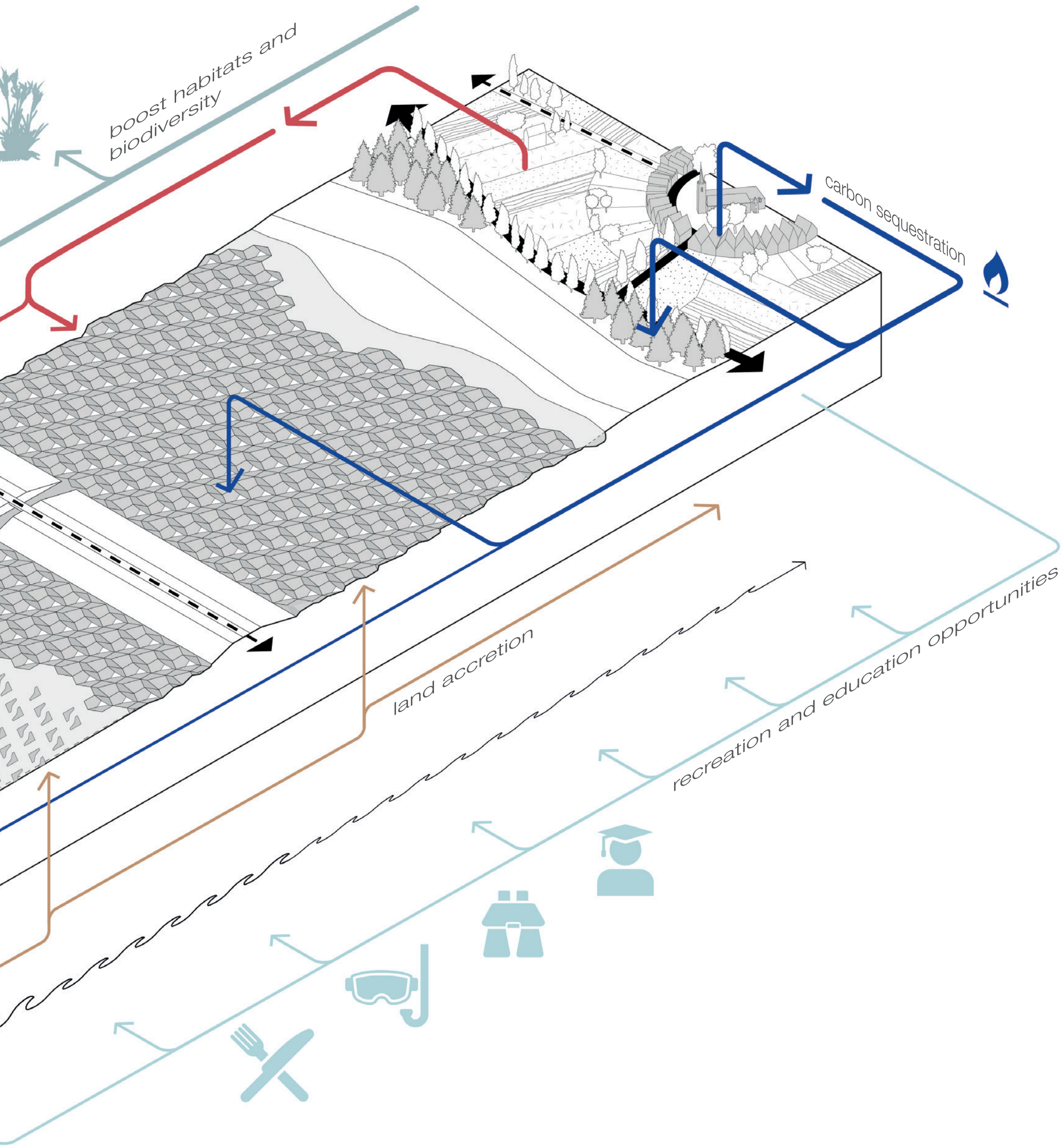
The intent behind this combination of ecological infrastructures is to compound environmental synergies and gains by extending loops of influence and feedback so that simple benefits (such as wave attenuation) are maximised and complex relationships (such as nutrient / carbon cycles or habitats) promoted (see diagram).

These systems of course are also intended to have broader benifits. **T**he Millennium Ecosystem Assessment (2005) of 'Ecosystems and Human Well-being' suggested that the benefits human populations and settlements accrue from the environment can be broken down into four broad themes; these being the **provision** of products (such as food, fuel, building supplies, biochemicals and water etc.), the **regulation** of the environments in which we live (such as the maintenance of air and water quality, pollination, erosion prevention and climate regulation etc.), **cultural qualities** (less

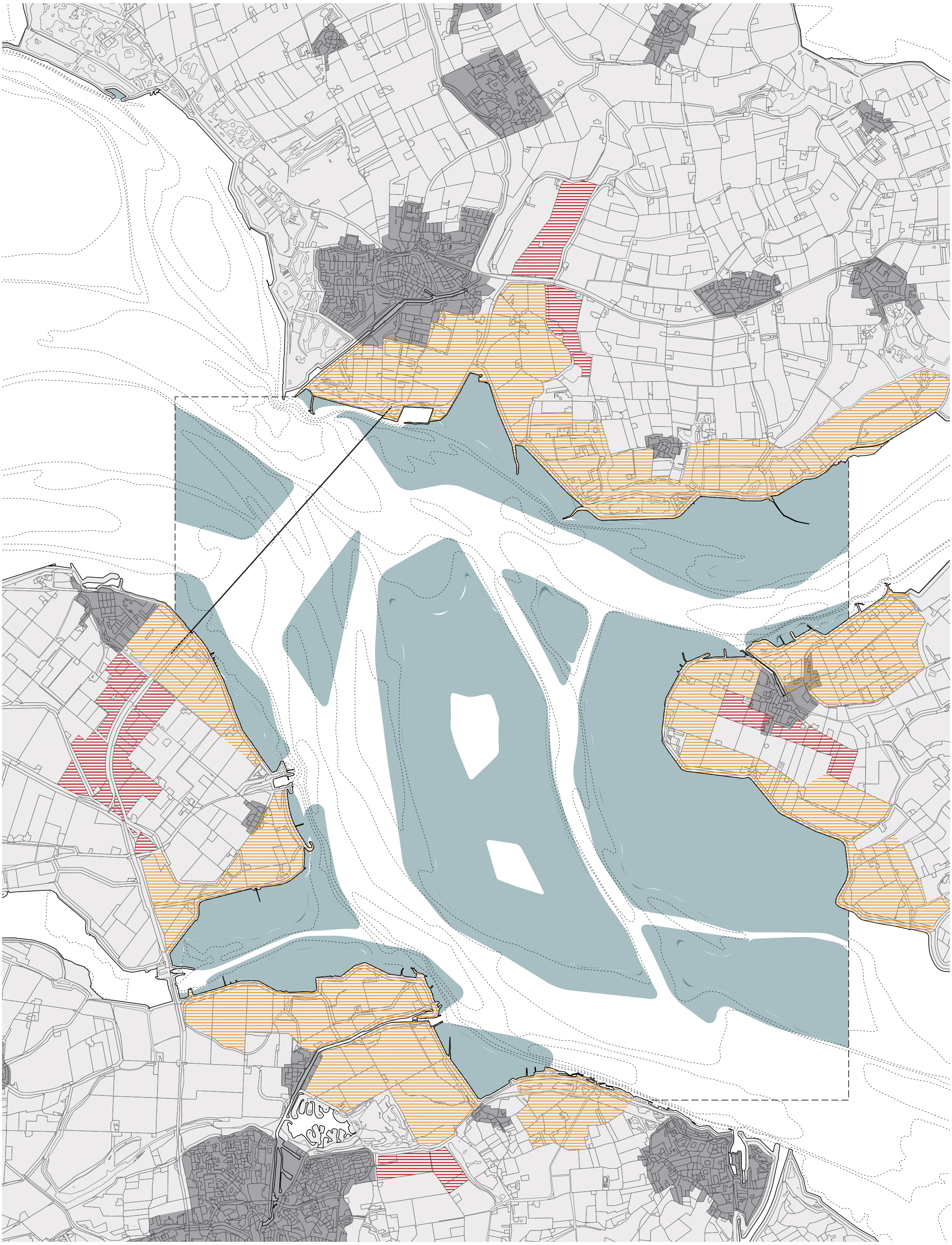


tangible benefits such as provision of recreation, aesthetic values and the sense of place that encourages unique cultural responses) and **supporting services** (fundamental biotic mechanisms such as soil formation, photosynthesis, nutrient and water cycling).

While there is no argument that these aspects fundamentally support and enrich human and urban lives, within developed nations the impacts of ecosystem degradation are often removed from daily life. This is the case in the Netherlands where air and water quality levels are acceptable, urban and rural greenery and recreation space are readily at hand, food and the necessities of life (power, heat etc.) are affordable and available and flood risks have been minimised (or excluded) by a highly rationalised water management system.



Figure, 39: Ecological benefits and cycles



Key

- Estuarine ecological infrastructures
- Cultivated terrestrial saltmarsh
- Pine plantations (540ha)
- Urban areas

n 0 2 4km

Sources: Top50NL mapping, Deltares (2012), Sustainable Scenarios for the Southwest Delta.

Figure, 40: 100km² layout,

In this context, and juxtaposed with urban infrastructures that are absolutely quantified in economic terms, how do we assign a measurable value to ecosystems and the benefits they provide? A number of tools can be used to quantify these benefits including BEST in the UK and TEEB from the Netherlands: both have been reviewed below but have proved less applicable to this particular case.

TEEB logo

The Dutch TEEB[1] scale for example, allows easy quantification of the economic benefits of improving greenery and water values and covers a range of themes by monetising for example, the increase in real estate values due to proximity to green space, improved social cohesion as those living in pleasant surroundings are less likely to move (and so will save on the costs of moving) or reduction in energy and heating costs if a dwelling is sheltered by a vegetated wind break. Given economic value is likely most easily assigned in an urban or social context (land value or loss of productivity through sick days for instance), most of the TEEB indicators focus on urban areas. So health benefits are counted for residents within 1km of new greenery, energy savings through vegetated wind breaks apply up to 100m from the building, increases in land value apply within sight of additional green or water and social cohesion improves with increased percentages of water within a neighbourhood. Very few of these are therefore applicable to this case as most landuse changes are proposed in rural or estuarine landscapes and the increased flood prevention and attenuation benefits of the salt marshes and oyster reefs might be negated by the increased flood risk in reclaimed areas. The careful location of the required pine tree plantations might be used to accrue some benefits but these are by no means universal as if these trees were used as wind breaks from the prevailing southerly or southwesterly winds, they would also block the winter sun from adjacent residences. Some indicators though are less site specific such as the willingness of each additional recreational visitor to pay (suggested at €1 plus tax per visit) but as an increase in visitor numbers cannot be estimated and the tool suggests these visitors may come at the expense of other sites, this also doesn't easily apply to this case.

BEST logo

BEST (Benefits of Sustainable urban drainage systems (SUDS) Tool[2] is largely focused on the benefits of improving urban drainage systems and water management practices (such as improved urban amenity and access to parks and reduction in wastewater treatment costs etc.) but does recognise that the benefits of these types of systems can extend beyond the urban context. This tool is also more comprehensive than the TEEB scale though does then rely more on site specific data to enable a clearer estimation of the benefits of SUDS on top of a base case scenario. In this sense the tool is more difficult to apply to the scenario although the following indicators and economic measures might offer some idea of these less tangible benefits[3].

- **Air quality** (NO_2, SO_2 and particulate matter (PM))...whilst the base case in this rural areas is likely marginal (so the benefits of most proposed systems and the likely changes are difficult to estimate), the strategic location of pine tree plantations (next to highways or industrial areas for example) may have measurable benefits[4]...€14.40 / ha / yr NO_2, €20.80 / ha / yr SO_2, €1600 / ha / yr PM,

- **Improvements in biodiversity**...€1590 / ha / yr (willingness to pay for creation of inland marsh habitat)

- **Carbon reduction** / sequestration...€13.35 / tonne / yr[5]

- Cost (and therefore, inferred benefit) of each additional **educational visit**...€23 (multiplied by the number of trips expected per year)

- **Recreational benefits** from constructed wetland (salt marsh) habitat (it is less the health benefits considered here but the improved opportunity for interactions with nature (birdwatching etc.))...€479 / ha / yr

Wiersma et. al. (2014) have also suggested several additional quantified benefits of salt marshes such as for the grazing of livestock (€17 / ha / yr), the maintenance of fisheries (from €2 to €8975 / ha / yr depending on location) and the creation of particular species habitats (from €1.30 to €36 / ha / yr depending on habitat). While these indices will not be used here, they do indicate the scale of multiple benefits and services that these ecosystems might provide.

1. See teebstad.nl

2. See susdrain.org

3. Rates for the UK taking middle of the range values where offered

4. Using 500 trees / ha and individual tree benefits from mytree.itreetools.org

5. Using the EU carbon credits price as at 30.04.2018 from businessinsider.com

8.7 100km^2 field, summary

The functional and environmental conditions within the re-activated estuarine systems as well as their ability to provide the levels of sediment and nutrients required to maintain these new infrastructural and productive ecologies essentially determine the success of this new augmented landscape. The notion of infrastructural management therefore needs to be reconfigured with these new ecologies in mind. Instead of the stability of dike embankments, we should monitor the levels and movements of sediment in the system. Instead of the lubrication of pumps and storm gates, we should ensure nutrient levels are adequate.

While the pre-eminant danger in the management of this new infrastructural regime is its slow rate of response as, if a problem were detected and a response implemented, the natural systems might take some time to incorporate changes. Nevertheless, in the best of (simplistically modelled) worlds, and assuming that some coupling of nutrient waste producing landuses are required, we can estimate the benefits, economic and spatial requirements of the 100km^2 layout as follows:

Annual productive yields[1]
- 145,500t of algal biomass (80% used for AD process)
- 2.77 million tonnes of aquaculture fish (coupled with 20% algae and 10% marshes)
- 1,222t of Nitrogen and 175t Phosphorus from AD waste
- 47,000 tonnes of mussels
- 5,625t of harvested wild Salicornia

Social / environmental benefits
- sequester carbon of 7,972 people
- 251 full time workers
- maintenance of 13 AD & CPH plants (500Kw capacity)
- electrical power needs of 26,584 people

Economic benefits / savings
- €35.7 million in electricity cost savings[2]
- €31.5 million in harvested wild Salicornia
- €1.1 million in fertiliser cost savings
- €47 million worth of mussels
- €488,000 in animal feed (8% of seaweed crop)
- €6.1 million in fertilisers (10% of seaweed crop)
- €5.8 million in food products (2% of seaweed crop)
- €2.5-26 million dike reinforcement cost savings (assumed 10% over next 50 years)

Annual costs
- €2 million pine plantation management[3]
- €16 million for reef installation (assuming 10yr roll out)
- €1.5 million for AD plant construction & mgmt
- €1.35 million for salt marsh installation
- €8.25 million for mussel installation & maintenance
- €10.25 million for seaweed installation & maintenance
- €6 million for wild Salicornia harvest[4]

These estimates are too broad to be useful and have not accounted for numerous costs that are difficult to estimate (expansion of port facilities, waste management, power conveyence infrastructure etc.) but, even if we discount the energy cost savings as well as the mussel and Salicornia harvest by 50%, the benefits still appear to match the costs (nom. €70 million). If we do not apply these discounts then the system as described produces around **€60 million** per year more than it costs.

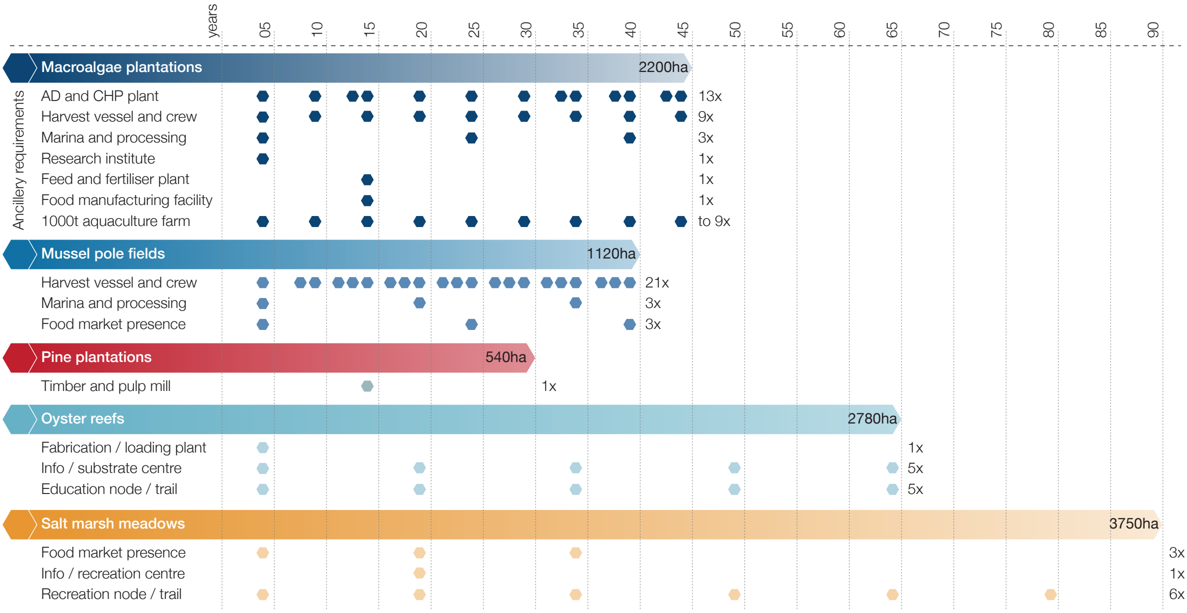
The equation becomes even more unbalanced when we add in the **€22 million** of quantified ecosystem services benefits previously discussed, namely:
- carbon sequestration of €1 million
- NO_2, SO_2 and PM uptake, €48,000, €70,000 and €5.4 million respectively
- BEST biodiversity improvements, €10.4 million
- BEST educational benefits, €140,000
- BEST recreation benefits, €3.1 million

1. See appendix for cost / benefits table. Aquaculture costs and benefits are assumed to be positive but are not included

2. Based on energievergelijken.nl single tariff, not counting transmission or fixed costs

3. Assuming €2000 / ha / yr, high end of yields from Table 4, Daugaviete, 2017

4. Assuming 30 day harvest period with 300 workers paid €15,000 pp



Figure, 41: 100km² timeline

Timescales

Given the logistics and cost of applying these infrastructures wholesale across the landscape as well as some functional and / or flood protection inter-relations between ecological infrastructures, their installation would need to be staged.

One scenario might consist of an initial installation of 110ha of seaweed plantation that would seek to absorb the nutrients produced by an adjacent 500t p.a. aquaculture operation. This area of macroalgae would be maintained by one boat and its crew (based out of Kats) and provide supplemental biomass for one AD plant (providing power for these operations as well as the needs of the village). This would be accompanied by 60ha of mussel poles and 90ha of pine plantations that, after 15 years, would expanded to 270ha to provide the timber poles for an additional 100ha of bouchot fields (540ha would allow this expansion to happen every 5 years). The initial 60ha that is operated by one boat and its crew (based out of Colijnsplaat) would use imported timber and should produce €2.5 million worth of mussels per year.

At the same time and in the first year, 10ha test areas of oyster reef and salt marsh are constructed, sited together (likely off the coast of Noord Beveland) and allowed to run for at least 5 years[5]. Once the functioning of the system is better understood, the stretch of land protected by the mussel poles and oyster reef might be recovered as salt marsh (additional 90ha) and the next 5 yearly increments installed at the rate of 275ha for seaweed and 250ha for mussels, oyster reefs and salt marsh, meadows.

These new landuses will necessitate periodic expansion of associated ancillery infrastructure and economic / logistical requirements to service, harvest and spread the benefits (see timeline opposite). For example the macroalgae system described will require at least one new anaerobic digestion / CPH plant be constructed and a new harvest boast and crew be employed every five years. The mussel plantations would require 2-3 new boats every 5 years and the pine plantations would require a timber and pulp mill be constructed to process the first 15 year harvest. Industrial and harbour facilities will also need to be regularly expanded or constructed as well as ancillery infrastructure such as research and education institutes and labs, processing plants, education and recreation centres and trails, food markets and electricity / goods sharing networks.

5. As suggested by the results of previous oyster reef experiments, see www.publicwiki.deltares.nl,

refined application

9.1 *system linkages and connections*

The 100km² project area is split across 5-6 municipalities though wholly located within the province of Zeeland. These municipalities (broadly) correspond to the four or five islands within the study area (if the canal through South Beveland can be said to separate two islands) and, as discussed in the regional spatial analysis, exhibit different demographic and landuse characteristics as well as varying levels of access. So these islands could be said to be (potentially) disconnected from a physical, administrative and transport perspective but civic identity is also likely split along island lines[1].

This represents an obvious administrative obstacle to the maintenance and management of the new landuses as they largely occupy the estuarine landscape that straddles municipal boundaries. While these areas do derive much of their identity from their esuarine context, their gaze is likely still largely focused landwards (as discussed in the regional analysis and by the simple fact that the water cannot be seen unless you are on top of the dikes). These new spatial typologies though, might enclose estuarine habitats and functions within the first ring of dikes, shift the gaze more towards the water and establish systems, synergies and networks that are required to operate across administrative boundaries and therefore, require closer island cooperation and a shared identity as the custodians (and beneficiaries) of these new augmented ecologies.

1. Based on interviews with E. Mijers

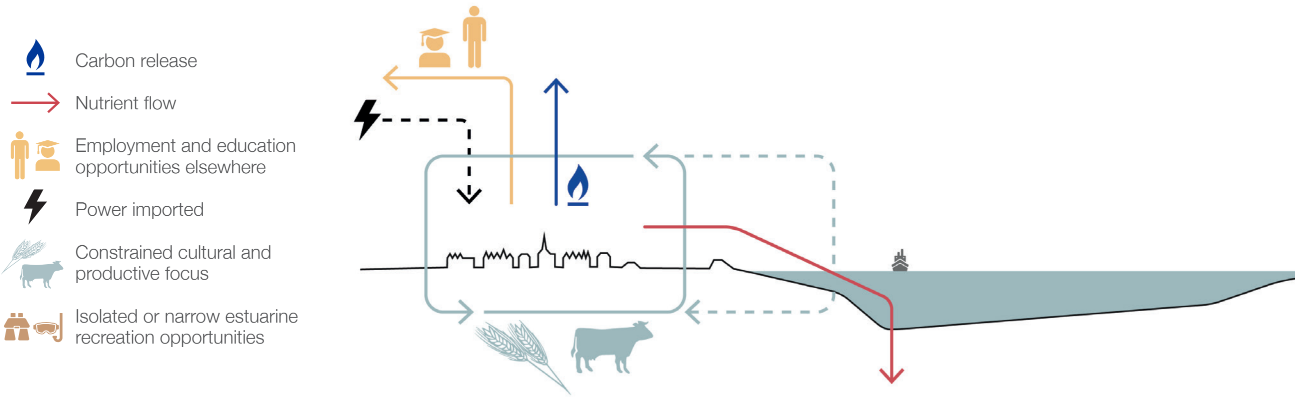


Fig. 42: Current system linkages

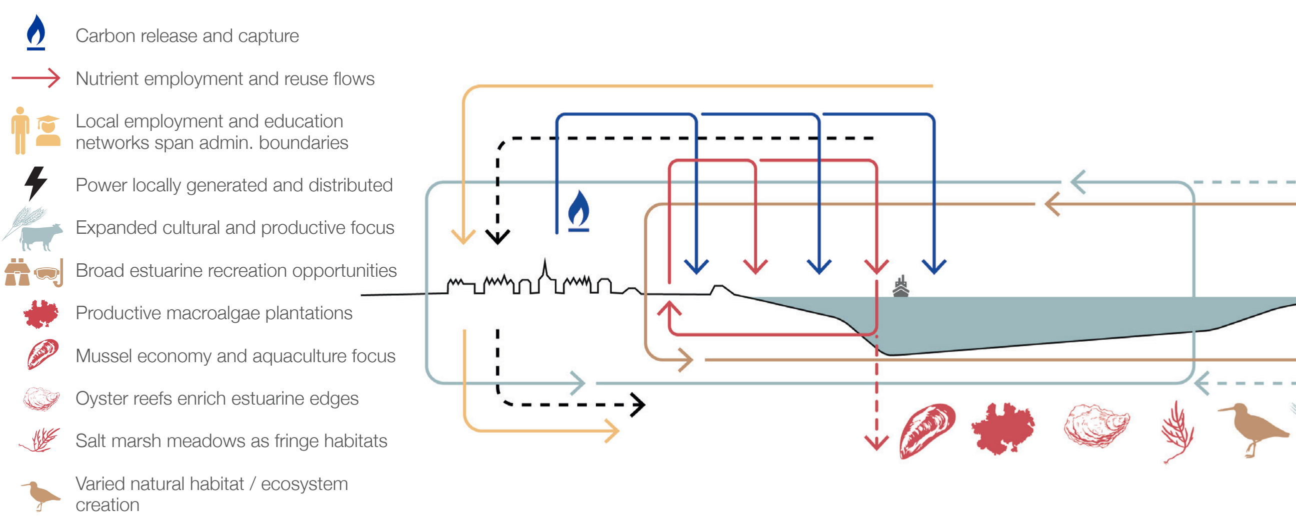
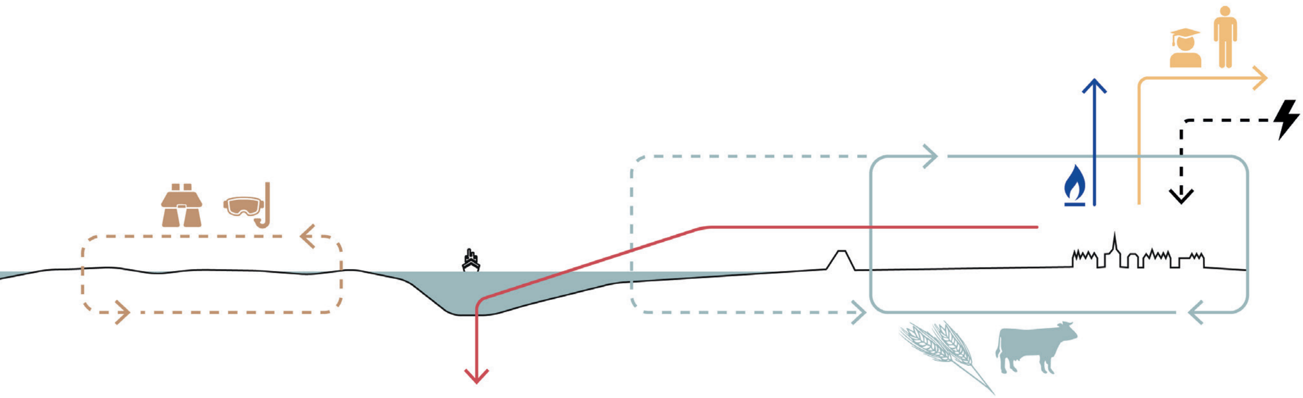
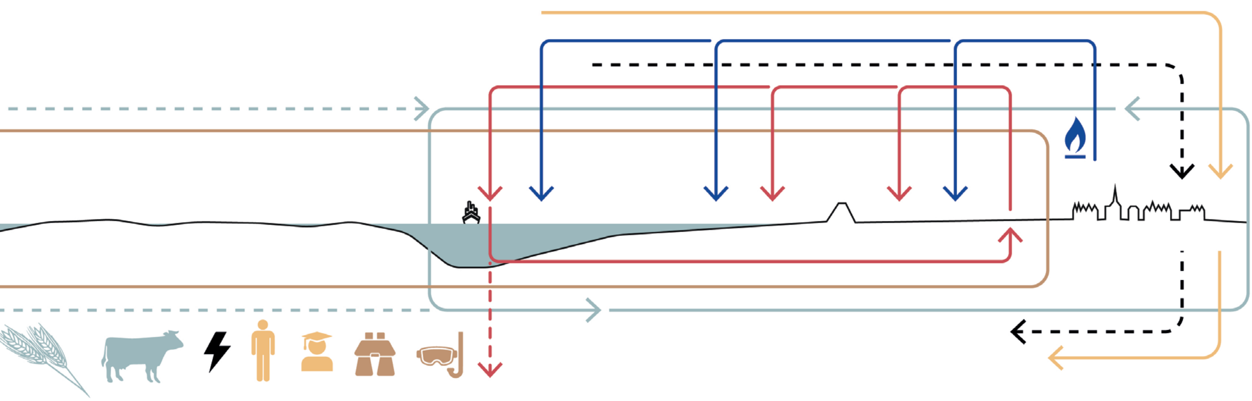


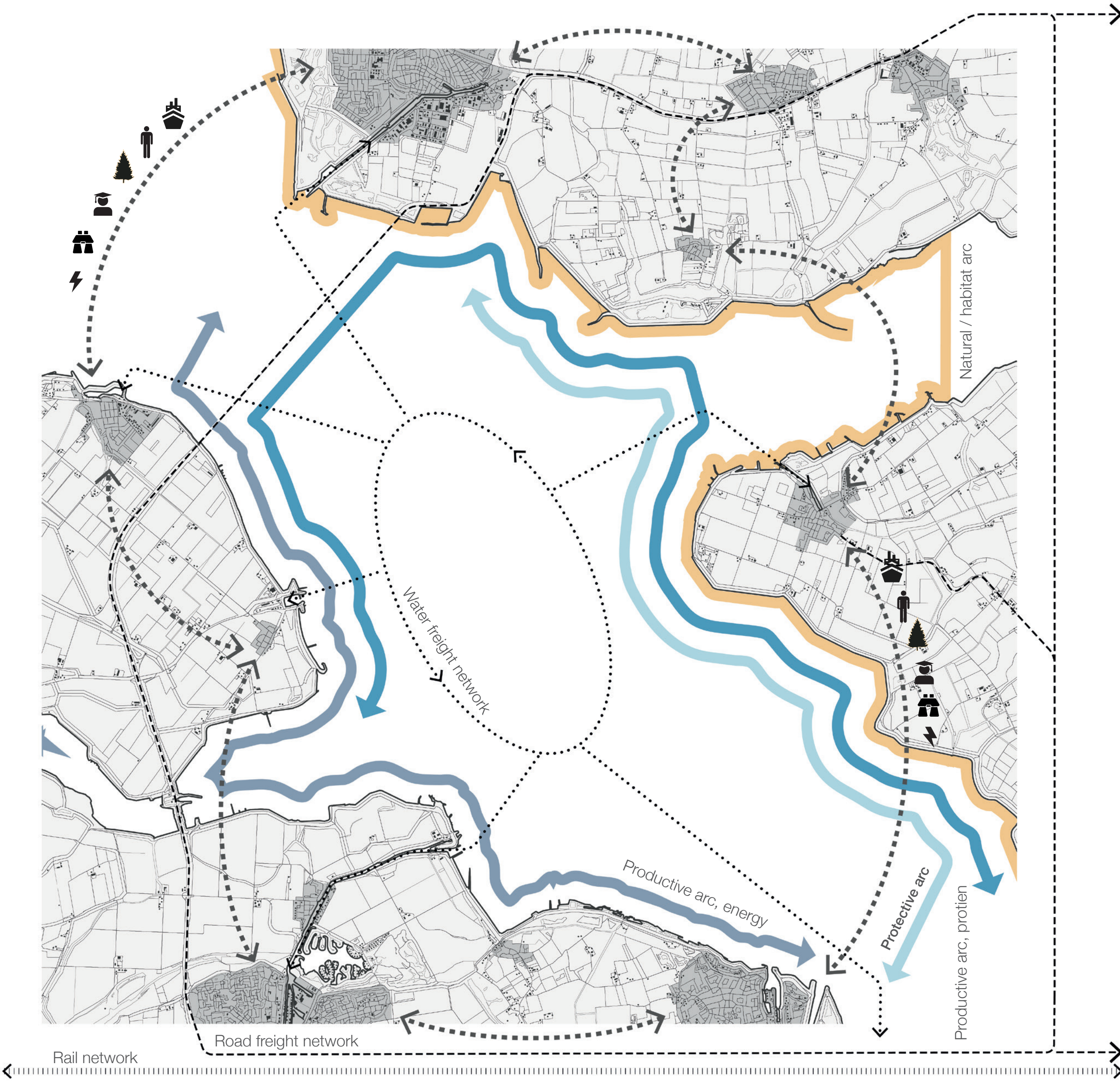
Fig. 43: New system linkages

So functional systems and cultural identity are currently largely internalised within each island or settlement and system linkages are confined or one-directional (see first diagram below). Carbon and nutrients produced by terrestrial functions are released unfiltered, civic identity is contained to the local (or island) surrounds of each settlement or includes only the nearest estuarine areas. Power is imported and labour exported to the adjacent service, industrial or education centres. Estuarine and nature-based recreation is contained to a thin strip along the coastline or more remote habitats accessed by boat.

The potential lies in these new landuses to expand and begin to close these functional and systemic loops (see bottom diagram). Carbon and nutrients could be captured to provide raw materials for the maintenance of the broader system (timber for mussel poles or fertilisers for agriculture and salt marsh meadows). Power and heat could be generated locally and ancillery system requirements (research, skills and training institutes, labs, port, landing and processing facilities) be sited in communities and areas adjacent to these new landscapes. This provides employment but also a functional connection to the estuary that might mirror current associations with terrestrial landscapes. Broader connections could be facilitated by the networks and cooperation required to distribute biomass, local power and heat as well as the new food products produced. These local products also become part of food, recreation and educational trails, centres and networks with a consistent design to emphasise the connective nature and capacities of these new landscapes.







Figure, 44: Systems links, a strategic approach

9.2 *visual and spatial continuity*

The systems linkages described above promote and require cooperation across industries, sectors and administrative boundaries in order to foster a contextualised cultural, economic and social connectivity via a series of networks that operate across these new infrastructures (see adjacent diagram), namely:

- Local electricity generation and distribution networks

- Tourist and recreation trails and infrastructure (both physical and thematic)

- Administrative and maintenance networks

- Research and education networks

- Physical transport and infrastructural / logistics networks

Of equal importance though in this thesis, is the potential for these new landscape typologies to foster visual and spatial connections between disparate urban centres and communities via their shared estuarine context and new relationships with this context as a venue for a shift in the notion of landscape infrastructure from dikes and wheat fields, to salt marshes and productive waterscapes.

From a strategic perspective, Zeeland's current spatial plan[1] suggests three broad character zones to guide the development of the archipelago and (perhaps) unite the islands in common cause. These zones consist of an area focused on relaxation and recreation along the coastal dunes and beaches; a belt of productivity stretching from Middelburg to Terneuzen (production and marine industries) and a nature based zone, 'Bloeien op land en in zee', in which the study area sits. The premise of this new series of ecological infrastructures is that all of these goals might be advanced simultaneously and at a smaller scale. The combination of the proposed new landuses, their promotion of natural habitat and productive capacities establish the conditions for an augmented natural landscape and series of habitats that nevertheless produce numerous goods (mussels and aquacultured fish as well as seaweed products and a new biomass / power generation infrastructure) as well as recreation benefits (nature appreciation and birdwatching etc.).

The provincial notion of thematic crescents that ascribe a character to a portion of the landscape and its related urban centres has though, also been employed in these proposals. The idea is that each of the proposed new estuarine landscape typologies has a particular functional focus (on natural habitat, flood protection or productive capacity for example) and visual character that also is concentrated in a particular physical location...an arc of greatest efficacy or impact. As the functional and administrative systems established by these new ecological infrastructures overlap to maximise synergies and connections, so too does the estuary become a venue for arcs of linked productive, protective or infrastructural landscapes that overlap to maximise functional efficacy, spatial cohesion and cultural interest as a physical mechanism to connect and interlink adjacent communities and urban centres.

1. See Zeeland Spatial Plan 2012-2018 from www.zeeland.nl

The extents of these arcs are dictated by the current industrial, landuse, culinary or tourism characteristics of the various islands and island centres and indeed, this would see the initial processing and logistical centres for the new landuses built on existing facilities (marina and industrial infrastructure at Kats, fishing fleet and market in Colijnsplaat etc.). The broader regional connections are then completed as new industries (seaweed products, timber processing, food and recreation focal points etc.), research and administrative requirements and system characteristics (nature / production / processing based etc.) are strategically sited to spread the benefits and help build community identity.

Local communities might also be engaged via participation in management aspects of the new landuse typologies (festivals, substrate collection etc.) along with having their carbon emissions accounted for (the proposals below seek to capture 20% of the emissions from the populations of Kats, Colijnsplaat, Zierikzee, Stavenisse, Ouwerkerk and Nieuwerkerk) or their electricity needs subsidised.

Key

	Municipal boundary		Nutrient inputs
	Macroalgae plantations		Functional / productive links
	Macroalgae landing facilities		Cultural / research links
	Local AD / CHP plants		Nutrient filtration
	Principal / secondary centres		Spatial / visual links
	Fertiliser use subsidised		

n 0 2 4km

Figure, 45: Macroalgae, refined layout and networks

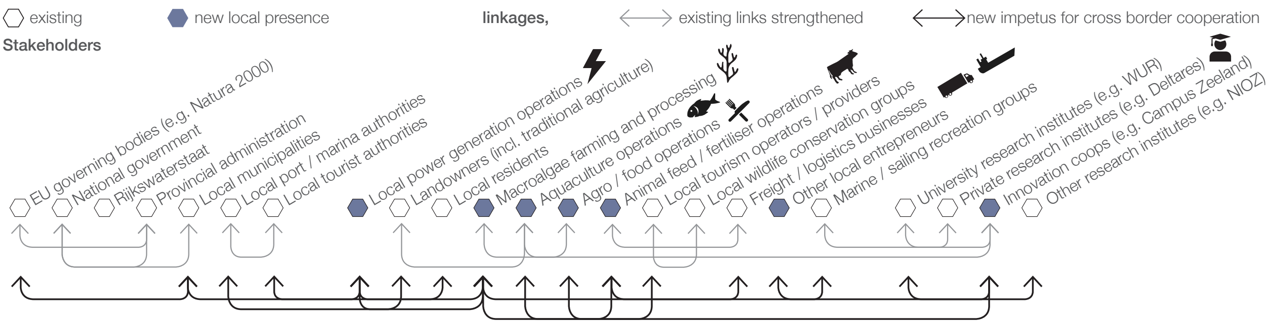
9.3 macroalgae plantations

1. Assuming average needs of nom. 200kg / ha / yr, from Fertilizer use in the Netherlands, www.edepot.wur.nl

2. Wageningen University and Royal Netherlands Institute for Sea Research

The refined layout for the macroalgae plantations has been located principally to establish a nutrient filtration capacity along estuarine flow channels. These pods of seaweed installations are also sited to provide visual and spatial connections between islands but the main potential of this system to foster urban connections lies in the productive and energy chains promoted by the employment of the seaweed biomass. This biomass will mainly be used to locally generate the residential power needs of adjacent and affected centres (Kats, Colijnplaat, Zierikzee, Stavenisse, Ouwerkerk and Nieuwerkerk) within a new network of energy sharing and feedstock distribution. The system could also be used to repurpose neglected industrial / maritime facilities (Kats and Wemeldinge) as points of biomass entry into the terrestrial distribution networks (freight and logistical movements). This biomass also provides the raw materials for new enterprises and research vehicles (animal feed, fertiliser, food products, biofuels and bio-plastics etc.) that (given the breadth of possible products) would be spread across the region. Local, traditional agricultural areas will be linked via the provision of some of their fertiliser needs via the nutrient rich digestate waste from the seven AD plants (satisfying the needs of approx. 80ha of farms per year)[1].

The macroalgae research institute will be located alongside the existing WAG / NIOZ[2] marine research facilities at Yerseke. Initially, the coupled aquaculture operations will consist of those existing near Colijnsplaat and Wilhelminadorp. The proposed animal feed plant (at Colijnsplaat), fertiliser plant (at Ouwerkerk) and food processing plant (at Kruiningen) are all located in existing agro-food clusters or contexts.



Timetable

System elements (years)	05	10	15	20	25	30	35	
Macroalgae plantations							1320ha	
Test plot (ha)	110	110						
System installation, by polder unit (ha)			220	220	220	220	220	
Extend marine research inst. focus (Yerseke)	●							
Port landing / processing facilities	●				●			2x
Additional harvest vessel and crew	●		●	●	●	●	●	6x
AD and CHP plant	●	●	●	●	●	●	●	7x
Coupled aquaculture operation (2000t / yr)				●			●	2x
Animal feed plant (Colijnsplaat)		●						
Fertiliser plant (Nieuwerkerk)			●					
Agro food processing plant (Kruiningen)				●				

Total area 1,320 Ha

Productive crop 87,120 tonnes

Animal feed crop value (8% of area) €292,723

Fertiliser crop value (10% of area) €3,659,040

Food products crop value (2% of area) €3,484,800

Full time workforce (min.) 30

Anaerobic digestion / CHP plants 7

Carbon emissions sequestered (x25 people)

Area of agricultural annual fertiliser use as AD by-product 80 Ha

Electricity use subsidised by CPH plants (x1000 people)

Key

- Municipal boundary
- Mussel pole fields
- Pine plantations
- Timber processing mill
- Principal / secondary centres
- Mussel / festival trail
- Functional / productive links
- Spatial / visual links (mussels / pines)
- Cultural / research links
- Sedimentation catalyst

n 0 2 4km

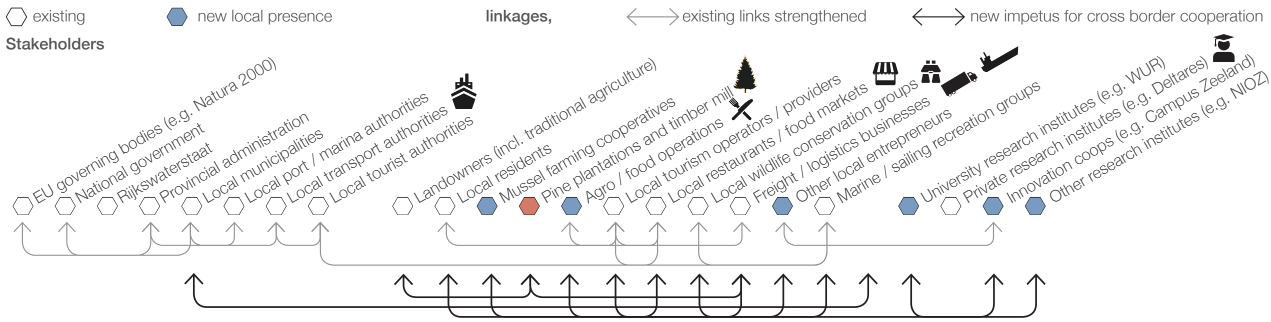
Figure, 46: Mussels, refined layout and networks

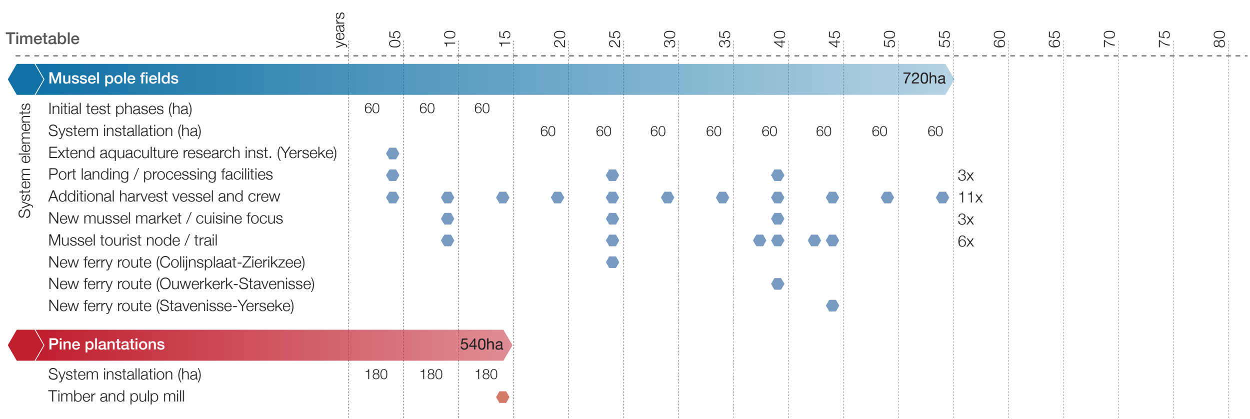
9.4 mussel pole fields

The productive landscape of mussel poles is intended to be the main cash crop and new estuarine aquaculture industry / employer. As vertical elements in the horizontal estuary landscape, the fields are also sited to visually unite stretches of coastline or draw the eye from the foreground to adjacent islands or infrastructure - both existing, such as the Zeelandbrug or proposed, such as pine plantations - in the background.

This new mussel industry is to become the main cultural connective device to link estuarine ecologies, productive landscapes and tourist / culinary infrastructure, building on the area's seafood and aquaculture focus and using tourist interest to establish physical routes (a Mussel Trail) that thematically and physically joins disconnected urban centres (from Yerseke to Stavenisse, along the coast to Zierikzee and on to Colijnsplaat...potentially requiring new, summer ferry connections). Existing fishing or shellfish centres (marina, market, restaurants etc.) at Colijnsplaat, Zierikzee and Yerseke will be bolstered and a new centre at Stavenisse will complete the chain.

The pine plantations contribute to carbon sequestration targets and are spread across the islands to establish a visual connection between the trees and the adjacent mussel pole fields that appear as the trees are felled. After 15 years, these plantations will sustainably provide the timber to sustain mussel farming operations. The timber mill and processing plant is to be sited on Noord Beveland to continue its agricultural / productive character and make use of Kats' neglected industrial area.





Total area	**720 Ha**
Productive crop	**30,240 tonnes**
Mussel crop value	**€30,240,000**
Full time workforce (min.)	**96**

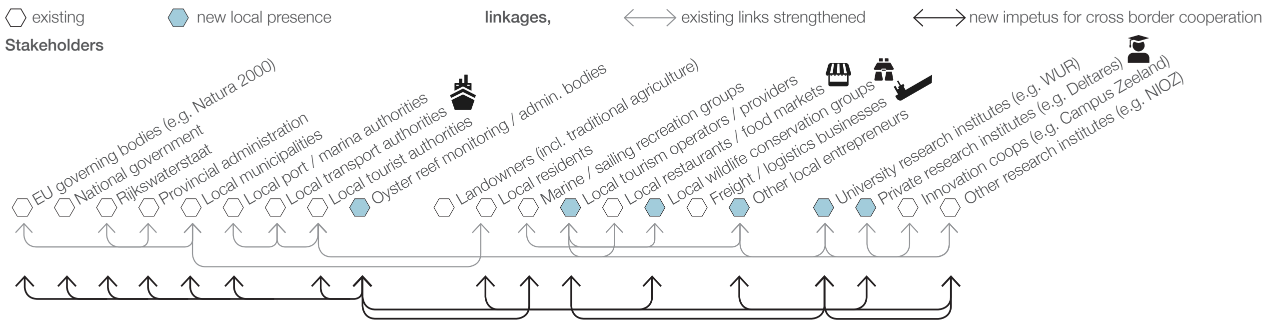
Pine plantations, total area	**540 Ha**
Area of mussel poles from timber harvested every 5 years	**60 Ha**
Carbon emissions sequestered (x10 people)	
Additional ecosystem benefits (nom.)	**€886,519**

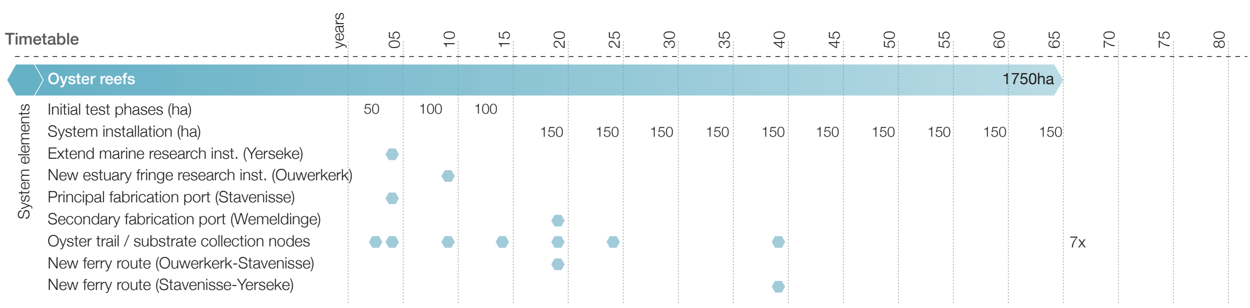
Figure, 47: Oyster reef, refined layout and networks

9.5 *oyster reef*

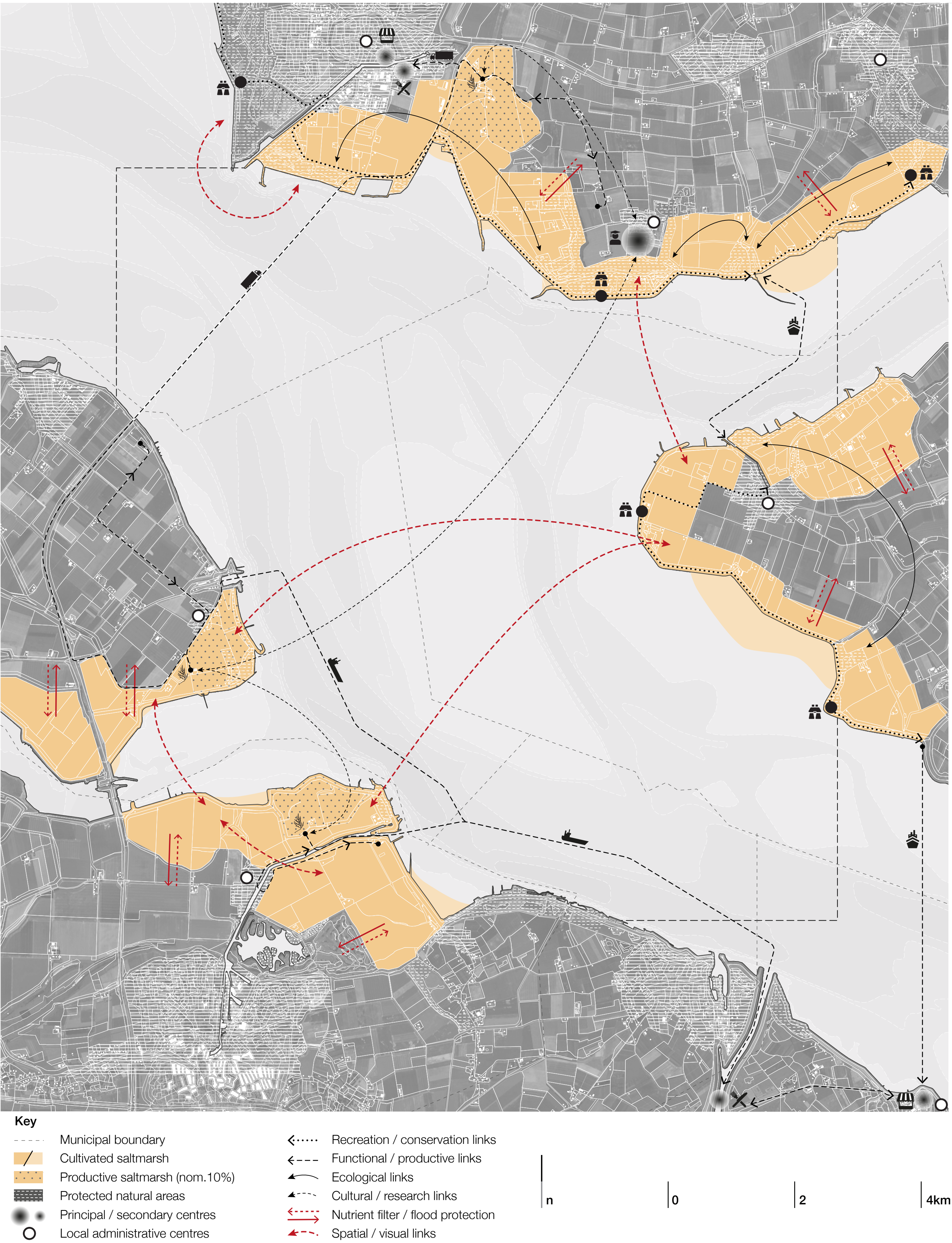
The principal role of the new oyster reef constructed habitat is as a protective buffer to the adjacent salt marsh areas as well as a catalyst to augment estuarine habitats and ecosystems. While this role is of little productive or economic benefit, its strong new spatial character, management and monitoring requirements is intended to reorient local (and broader) culture and communities towards a more ecological sense of an infrastructural landscape as well as help shift the focus from terrestrial to estuarine notions of efficacy, beauty, richness and spatial organisation. As this new landscape crosses multiple administrative boundaries, a new agency alongside Rijkswaterstaat will likely need to be set up to oversee and coordinate the creation and maintenance of this protective infrastructure across jurisdictions.

This new landscape could also become a catalyst for community interaction as locals might be included in the necessary monitoring and administration of local oyster reefs, directed by a new research and monitoring institute in Ouwerkerk (and ancillery research / education / interpretation at Yerseke). The reefs could also become a visual link along a new Oyster Trail between Yerseke and Zierikzee to connect the two principal tourist drawcards (and main points of oyster consumption) in the area. These destinations would house substrate collection points and the trail would pass through Stavenisse as the new centre for the installation of these reefs (aided by the existing loading and storage facilities in Wemeldinge).





Total area	**1,750 Ha**
Ecosystem benefits (nom.)	**€3,620,750**
Number of gabion basket units (nom.)	**30,625**
Volume of substrate (nom.)	**40,425,000m^3**



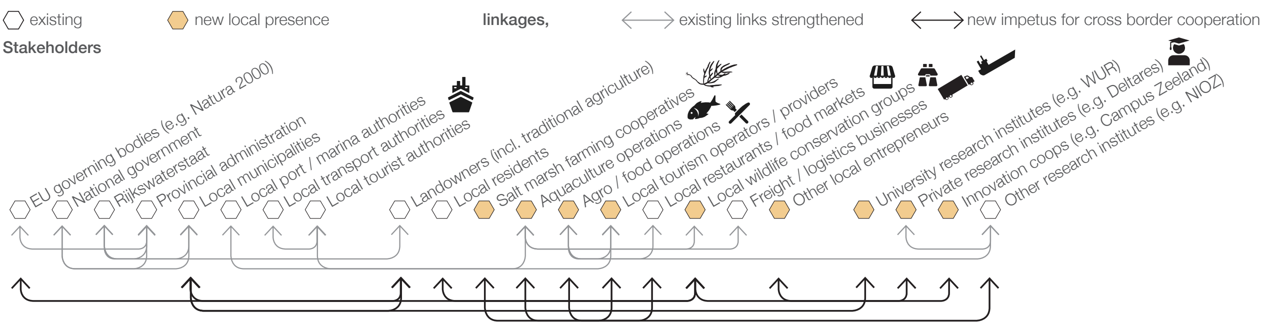
Figure, 48: Salt marsh, refined layout and networks

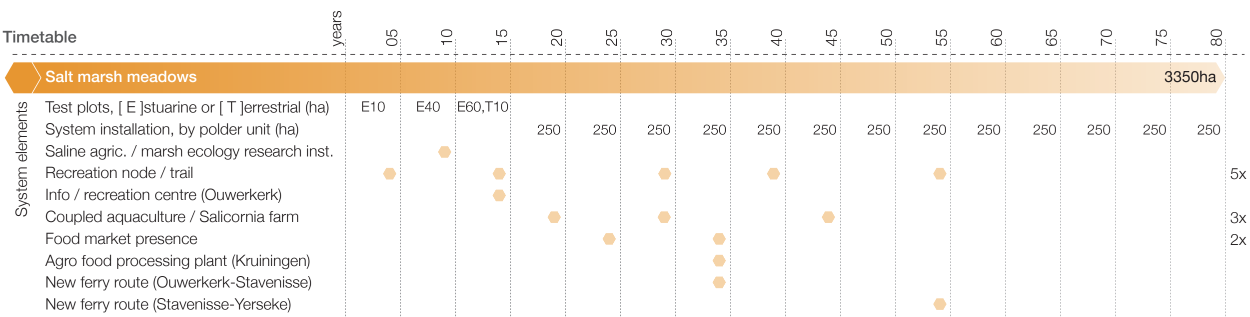
9.6 *salt marsh meadows*

The revised salt marsh layout is broadly in line with the Deltares proposals to maximise flood protection and attenuation but is also,
- located along secondary dikes or road / drainage infrastructure that may ease construction of additional dikes
- the link between existing protected natural areas that forms a continuous zone of natural habitat
- venue for nature based tourist / recreation routes and information / education nodes to link disconnected centres

While this new landscape typology will occupy a significant proportion of previously agricultural land, 10% of the area will be used as a productive salt marsh to provide a cash crop and soften the transition from traditional agriculture. In effect a functional link between terrestrial productive landscapes and new estuarine systems of production. These areas might be linked with new or existing aquaculture operations to ensure a steady supply of nutrients and establish circular relations with additional agro / food industries. The culinary products produced will be processed at new facilities in the Kruiningen agro-food industry hub and marketed at the two principal restaurant and tourist destinations in the region, Zierikzee and Yerseke.

A new salt marsh ecology / agriculture research institute will be located in Ouwerkerk to facilitate intellectual links to the local administrative centres. These local monitoring and landscape maintenance links will be critical (conducted in collaboration with Rijkswaterstaat) to ensure the flood and wave attenuation role is maintained and (along with local research institutes) ensure habitat health.





Total estuarine area **250 Ha**

Total terrestrial area proposed **3,100 Ha**

Productive crop (10% of area) **4,650 tonnes**

Productive crop value **€26,040,000**

Full time workforce (min.) **30**

Seasonal workforce (min.) **300**

Carbon emissions sequestered (x10 people)

Additional ecosystem benefits (nom.) **€6,413,900**

9.7 *a new terrestrial edge*

These proposals for a new approach to spatial, productive and flood defence infrastructures in the Southwest delta broadly conform to Brown's (2014) advocation of 'more diversified, distributed, and interconnected infrastructural assets that simulate the behavior of natural systems'[1] and display all the characteristics she suggests should be present, namely that:

'Systems should be multipurpose, interconnected, and synergistic. Infrastructure should contribute few or no carbon emissions and work with natural processes. Infrastructure should improve social contexts and serve local constituencies, should be resilient and adapt to predicted changes brought about by an unstable global climate.'[1]

Whereas Brown largely suggests that efficiencies and multiple benefits can be secured by mirroring (and sometimes employing) characteristics of natural systems in our contemporary infrastructure, this thesis is suggesting that natural processes themselves be employed as a new form of regional infrastructure. The shift is to harness a series of natural and productive landscapes and the various networks they facilitate (social, economic, spatial etc.) to address a series of context specific issues at the territorial (North Sea eutrophication and resource depletion etc.), regional (biodiversity loss, response to sea level rise etc.) and local (demographic decline, loss of agricultural productivity through soil salinity etc.) scales.

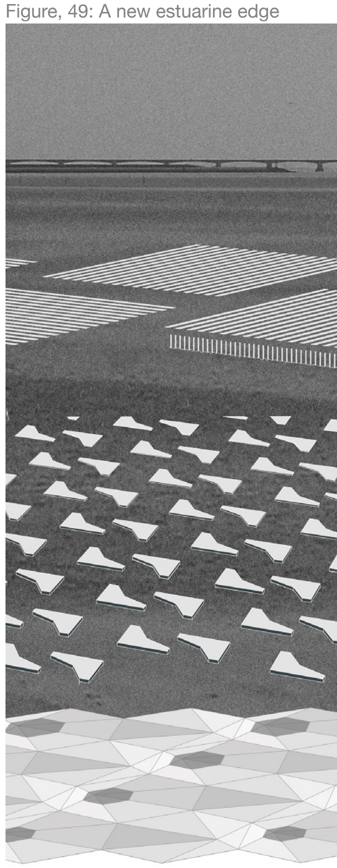
As natural ecosystems do not operate in isolation, so too are the habitat, remediative and productive capacities of these proposed ecological infrastructural landuses absolutely intertwined. A significant proportion of their value is derived from their interconnectedness and the potential for deficiencies in one system (for nutrient cycling, wave attenuation or protein production for example) to be made up by other systems. In the same way that this intends to bolster resilience in their functional facilities, the connective mechanisms that these landuses foster are also intended to interlink and boost logistics, administrative, tourist and recreation as well as knowledge and intellectual networks so as to multiply redundancies and so minimise potential for industries, operators or landowners to be isolated and hence, exposed to failure.

As demonstrated in the previous pages, the visual connectivity achieved through these new estuarine landuses is matched by the potential for disparate islands and island communities to be more closely connected via these new networks. Networks that derive a complex new set of economies, cultural and social connections from landuses that are essentially maintained to provide a measure of flood protection to the remaining polder landscapes in the archipelago. The fact that these new flood infrastructures require healthy estuarine processes and natural habitats to function, enshrines ecosystem health as a fundamental requirement for the maintenance of the urban, social and economic communities within the delta.

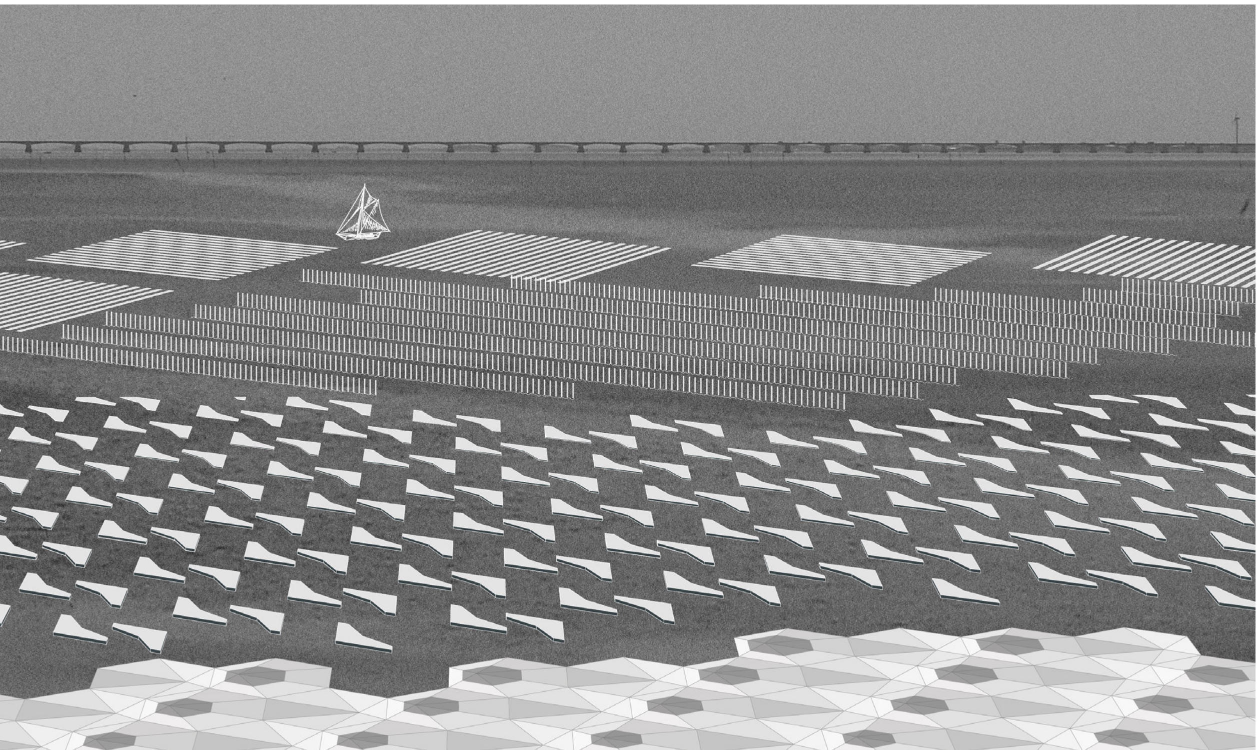
This fundamental change in the relative status of ecosystem health as related to our urban processes does have a significant impact on the (relatively) straightforward estaurine landscapes, particularly at its edges. What were once fairly clear lines of dikes that separated agricultural land from the (visually disconnected) estuarine waterscapes, now becomes a much more complex landscape of natural and designed elements and processes. A much more indeterminate margin that also fundamentally changes the relationship (not only visually) between land and water, urban and natural (see adjacent).

Existing estuarine condition

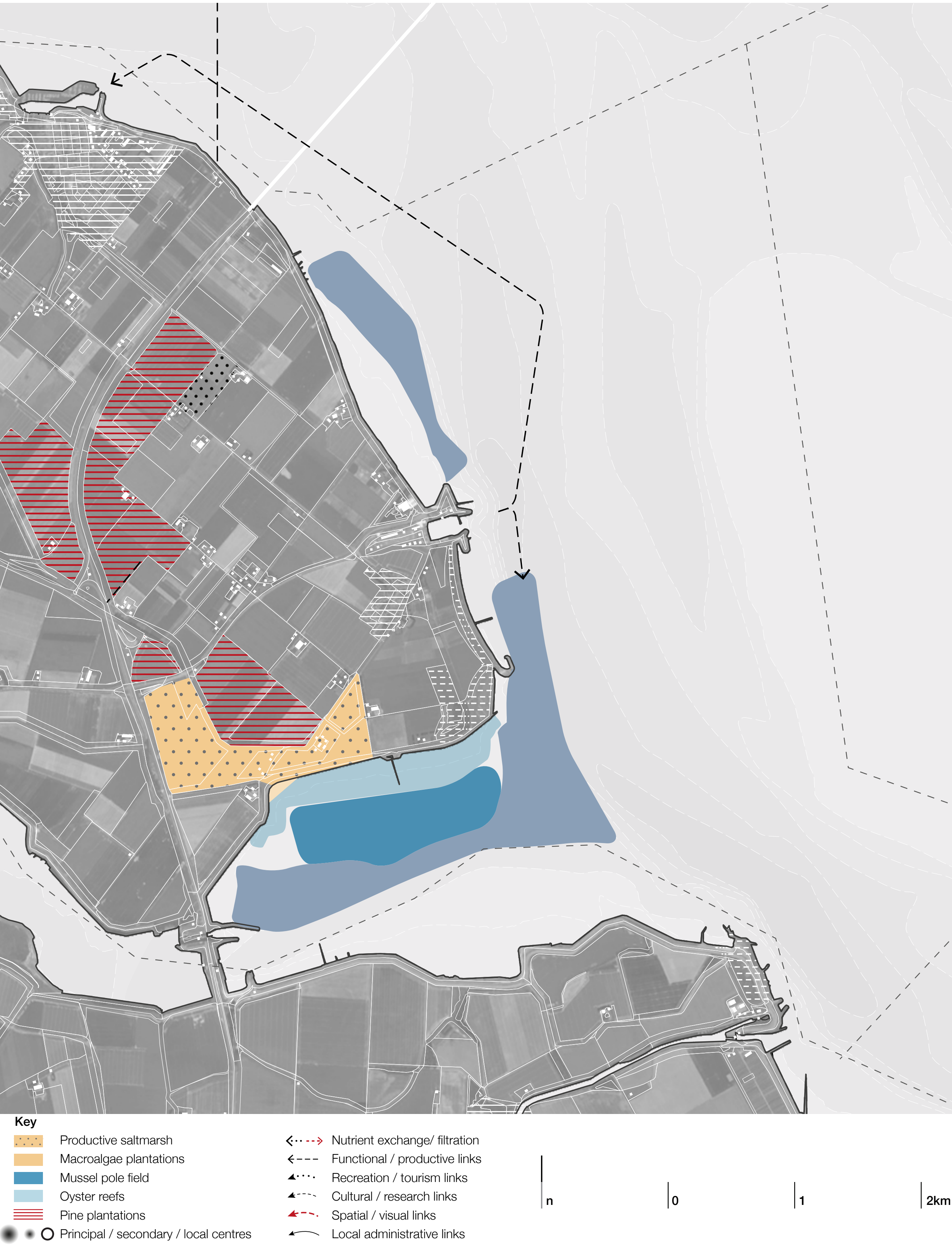
Figure, 49: A new estuarine edge



1. Brown, 2014. P. 11



discussion / reflection



Figure, 50: Minumum application of new ecologies

10.1 a new infrastructure

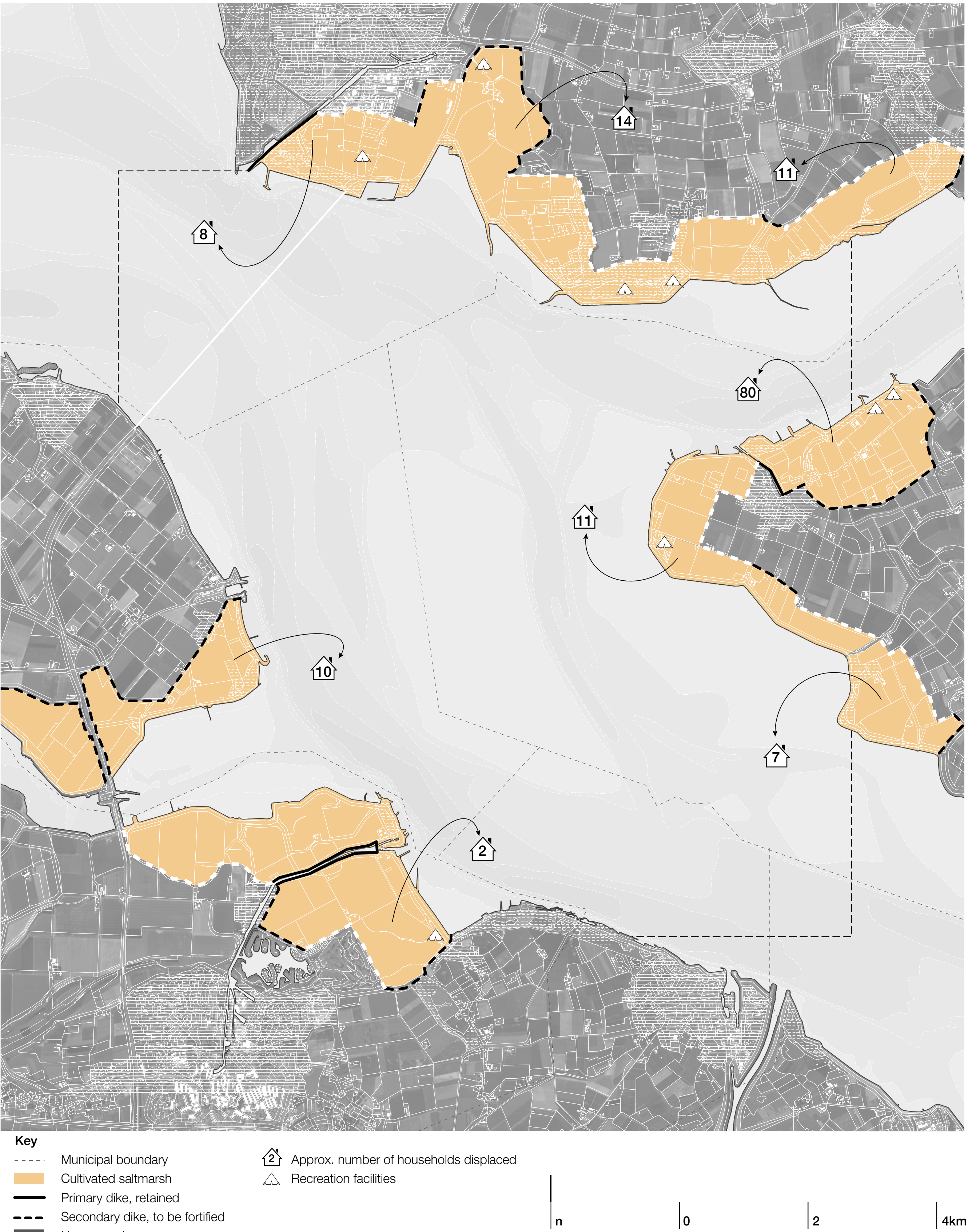
While the suggestion is that the estuary be used as the shared natural, functional and cultural venue for these changes, this obviously demands a dramatic re-orientation of social, administrative, visual, economic and productive attitudes and practices. This is part of the point but despite the suggested benefits and even supposing flood risk fears are addressed, there is likely to be opposition to the landscape changes proposed. The principal argument might be that this represents a ”colonisation” or appropriation of natural landscapes in general, and waterscapes in particular. This is a fair point and it might be difficult to argue that a solution to the damage wrought on natural systems by our social infrastructures is to turn natural systems into a social infrastructure.

Our administrative, economic, industrial and social infrastructures are complicated enough as they attempt to simplify and then accommodate risks (of coastal flooding for example by building a dike to withstand expected storm surge levels). It is a large step to allow the complexities and multiple relations that govern natural systems to determine flood risk in occupied polder landscapes, let alone seek to effectively monitor and manage these systems...perhaps only hubris would prompt us to attempt this. This might follow in a world of certainties but as discussed, our application of reductionist management practices for the natural systems in which we live have existentially threatened these systems and, by extension, our own societies.

The difficulty with this approach is that it suggests an “all or nothing” scenario. The ecological infrastructures likely require a comprehensive return to natural estuarine function yet this infers a removal of the Deltaworks infrastructure that would immediately alter the flood regime, necessitating a response already be in place. While this series of new infrastructural landuse typologies was intended to address issues across the delta, the Oosterschelde was chosen as the sub-regional focus given its approximation of natural estuarine function and potential as a test bed for these new typologies and systemic networks without the need to completely remove the dams. While the cultural and infrastructural shift required is too great to happen immediately and all the connective regional benefits would not accrue from a small scale roll out, there are some smaller polder compartments in the study area (nom. 10 to 50ha) that could be reconnected with the estuary to test the habitat creation design, efficiency of adjacent oyster reef or opportunities for saline agricultures for example. While we could sure up the secondary dike and flood a particular polder, even if this polder were protected by a stretch of new oyster reef, it could not be said to represent a wholesale change to the broader flood management regime.

There are also likely to be certain minimum viable applications of the four new landuse typologies. The minimum extent of seaweed plantations in the suggested scheme is likely to be 185ha (enough to maintain one AD / CPH plant) and the minimum amount of mussel poles would be 60ha (the area serviced by one boat and crew) with an accompanying 180ha of pine plantations to ensure a constant local timber source. Were the above areas to be accompanied by 30ha of salt marshes and 30ha of adjoining oyster reef, then the costs and real economic benefits would balance at around €4 million each with an additional €4.5 million in ecosystem benefits (below these system areas, the costs outweigh the real economic benefits).

This suggests that the most likely scenario is for a single municipality to initiate a test network of combined infrastructures that might allow them to tackle a number of problems simultaneously (re-purposing neglected industrial infrastructure, providing employment, meeting sustainability targets, boosting tourism etc.) and provide a municipal structure for local actors to establish functional or circular connections (such as Kingfish Zeeland is already seeking). This minimum layout is applied opposite in Noord Beveland.



Figure, 51: New coastal protection line

10.2 new settlement patterns

The principal infrastructural management framework in the Netherlands is obviously that overseen by Rijkswaterstaat and changes to the estuarine function, coastal defence, employment of sediment dynamics and recalibration of the terrestrial / estuarine edge would fall under their remit. Rijkswaterstaat no doubt currently collaborate with an enormous number of actors from governmental agencies through research bodies to landowners and the private sector and this proposal suggests that another stakeholder needs to be added to this list...natural ecosystems and habitats themselves. In answer to the criticism of this representing an appropriation of natural systems, essentially the suggestion is to empower the estuary and its fringe habitats and enshrine the health and ecosystem functioning of these natural landscapes within the statutory and regulatory certainty that is the Dutch flood and logistics infrastructure management apparatus. This does not represent simply a romantic re-wilding of the estuarine fringes but positions (and recognises) these ecosystems as active participants in the maintenance of urban and cultural settlements and patterns, participants that are able to adapt to the shifts inherent in a changing climate.

This will clearly have implications for the way the delta is currently occupied and settled; as the notion of flood risk moves from the certainties of the current regime (huge dam and surge barrier constructions and narrow, distinct lines of primary dike defences) to a more "fuzzy" reliance on cumulative benefits from a broader flood attenuation landscape of mussel poles, oyster reefs and salt marshes. As previously discussed, the historical growth of the polder units in the delta progressed via a series of expansions as sediments collected outside the dikes, grew into marshes and were eventually endiked as the primary dike moved outwards to enclose these newly formed lands. As such there remains stretches of (now) secondary dikes that could be fortified as a last line of defence were the outermost polder areas re-flooded as suggested.

The salt marsh areas as proposed are located either within these secondary dike lines or end at existing transport (roads) or natural (drainage lines) infrastructure that could be reinforced to act as a final line of flood defence (see plan opposite). The management and settlement practices within these salt marsh areas newly exposed to potential flooding would also need to change. Housing within these areas would need to undergo dramatic changes (elevated housing pads and evacuation routes for example) or be removed altogether. The removal of accommodation from these areas via zoning laws would cement their status as a new type of land designation, one whose dynamic character (driven by sedimant accretion) and periodic inundation procludes the certainties required by housing and occupation but that nevertheless, might act as a "land bank": a fringe of land that will elevate along with sea level rise and might be re-poldered and re-settled in the future if the occupation of the adjacent lowlands becomes untenable.

Even assuming zoning restrictions prompt a strategic retreat of housing from these fringe areas further inland, commercial, agricultural, logistics, recreation and tourism infrastructure would still be located in these (potentially more flood prone) landscapes. The Dutch government currently bears the brunt of the financial burden for flood damage to this infrastructure given local insurance markets will not cover against flood risk[1] and despite recent advances made by global re-insurance companies[2] to enter the market, the government might be unwilling to oversee an increase in flood risks and therefore, to their potential reconstruction expenses. A robust insurance infrastructure will likely be required to replace the current reliance on robust physical flood protection infrastructure so as to spread the risk and both encourage development of this fringe salt marsh landscape as well as measures to minimise potential damage. Home and business owners in flood prone areas in the UK benefit from a not-for-profit scheme where home insurers pay into a pot that is used to cover payouts in the event of a flood so that individual insurers don't shoulder all the liability and premiums and excess payments can be maintained at an affordable level[3]. This scheme does penalise new builds in flood prone areas but in the case of the changing delta landuses, penalties and restrictions might be waived for an initial period (10-20 years perhaps) and other incentives introduced in order to encourage development and flood preparedness. With the certainty of cover in the event of a flood, new forms of construction or infrastructural models able to cope with potential flooding might be more likely to be tested and employed.

1. See article on Dutch flood insurance practices, www.climatechangepost.com

2. See article in www.insurancejournal.com

3. Refer to www.floodre.co.uk

10.3 system limitations

As design is a speculative and subjective exercise, it is open to criticism and attempts to “back up the design” via a comprehensive analysis and the extraction of principal themes, interactions and processes, while absolutely necessarey, are also reductive. This is both a weakness and strength of combining research and design, particularly at the regional or (vastly more complicated) territorial scale. This thesis is unable to comprehensively describe the hydrological and ecosystemic functioning of the Dutch delta at present yet alone when the dams are removed and the estuary returned to a more naturalistic condition. As such, many assumptions are questionable and might not support the type and extent of new landuse mechanisms proposed. For this reason I chose to concentrate not on the functional characteristics of the estuarine processes but on the proposal’s spatial, cultural and connective implications. While this is important, I realise that a simplistic understanding of the estuarine processes is a potential weakness of the thesis and so have sought to reduce these risks by:

- a quantitive emphasis on the impacts of the proposals (such as the quantity of biomass produced, carbon sequestered or water filtered by these new systems
- identifying possible social, cultural and urban connections / networks
- suggesting potential terrestrial / aquatic synergies
- relating new landuse patterns to existing infrastructures, be they functional infrastructure (ports, bridges, flood defences etc.), social (historical centres, monuments, churches etc.) or landscape infrastructure (prominotories, habitat etc.)
- suggesting the manipulation of possible synergies (for example by coupling aquaculture with macroalgae or salt marsh meadows to balance nutrient exchange and needs) to manage impacts of changing system variables.

As previously mentioned, the principal systemic variables that determine the effect and the functioning of these systems in general (and the efficacy of the flood protection measures in particular), are nutrient levels, sediment supply and sea levels within the estuarine systems. The nutrient availability has been the most difficult to quantify and so, as mentioned, this thesis concentrates on mechanisms to minimise the risk of nutrient deficiencies by connecting the needs of industries that produce nutrient waste with landuses that might employ or absorb these nutrients. Extremes in the other two principal system variables though are more difficult to accommodate.

As discussed, sea level rise predictions vary from the Delta Commission’s 2008 range of 0.55m to 1.2m to Deltares’ suggested 2m rise by 2100: these equate to annual sea level rises of 0.6cm, 1.3cm and 2.4cm respectively. The advantage of ecosystem engineers such as oyster reefs and salt marshes is that they are either able to grow vertically (in the case of oysters) or encourage sedimentation and vertical accretion (as with salt marshes). Problems arise when sea level rises faster than the salt marshes can grow and while growth rates are highly variable, studies show average growth rates in the Westerschelde of 1.5cm per year and expected average growth rates of around 1cm elsewhere[1]. This suggests that salt marshes might match sea level rise of - and hence the fringe landscapes proposed here would function in - all but the most pessimistic projections. In other words, should sea level rise by much more than 1.2m (from 2018) on average by 2100, the salt marshes as proposed might no longer function as a long term flood defence and “land bank” mechanism and the salt marsh / oyster reef role would become redundant. This vertical accretion is also driven by sediment availability and although it is likely that sediments required for the salt marsh accretion could be naturally imported from the North Sea[2], too much or too little sediment would also be detrimental to system functioning. Based on average growth rates of 1cm per year, the total area of salt marshes proposed would require around **370,000m³** of sand per year (or 150 olympic swimming pools worth). So if enough sediment were not naturally available, the artificial introduction of sands into the system (nourishment) would cost €1.1-4.4 million per year[3] .

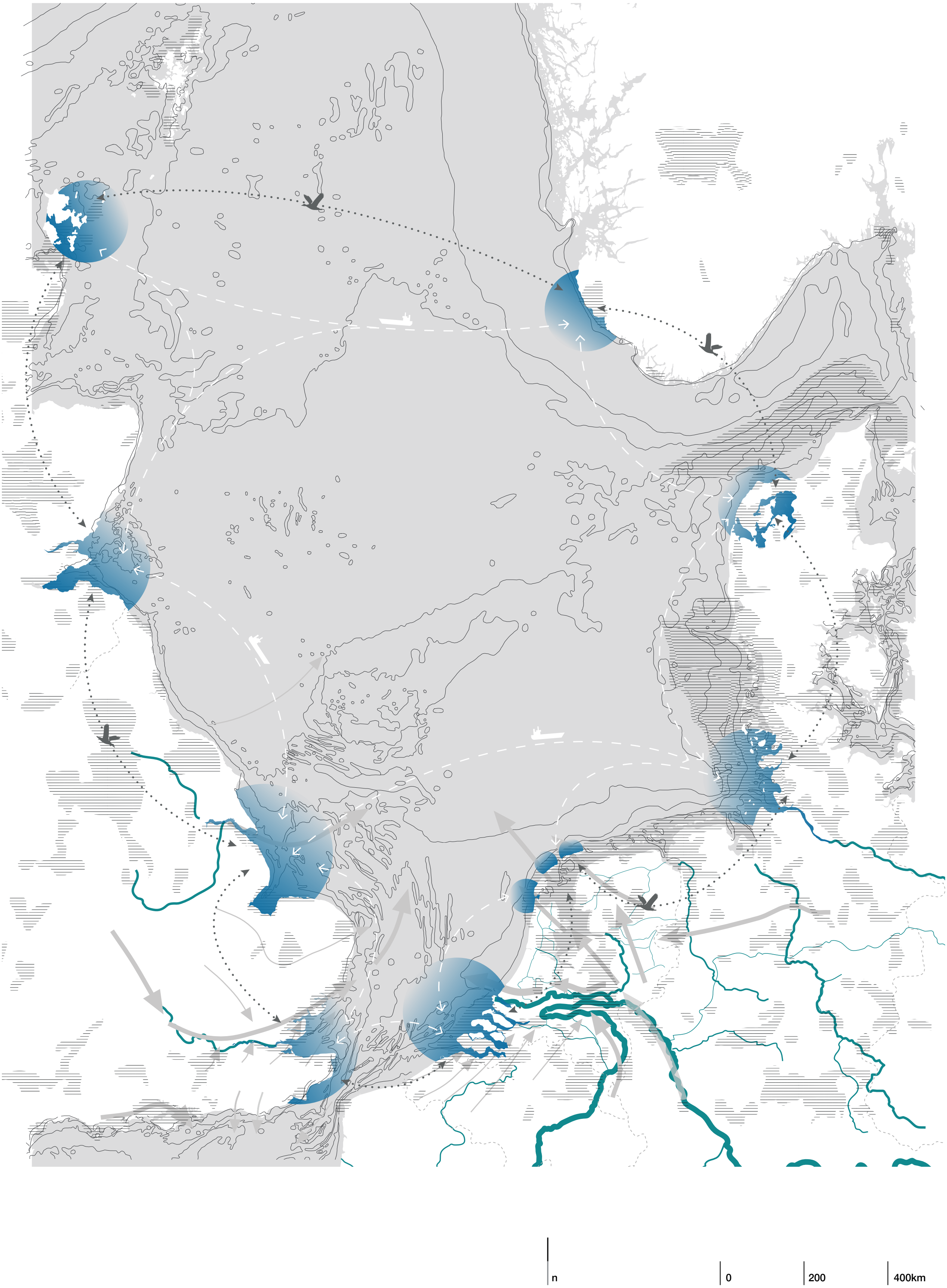
Sediment supply will also have to be balanced with the needs of the oyster reefs to ensure that they are not exposed to too much deposition and smothered. While oyster reefs do have the potential to rapidly accrete over time, the experiment conducted in the Oosterschelde did experience issues with excessive sediment and deposition rates burying and subsequently killing the animals[4]. These issues demonstrate some of the fragilities of these natural infrastructural ecosystems and the potential risks to their employment as a comprehensive coastal defence mechanism.

1. Wiersma et. al., 2014

2. See Wiersma et. al., 2014, appendix E: Results of expert sediment workshop

3. assuming costs of €3-12 per m³ as per Wiersma et. al., 2014

4. See www.publicwiki.deltares.nl



Figure, 52: Territorial application

The advantage of the system as a whole being made up of a series of (fairly) related constituent components, be they more protective (salt marsh meadows and their adjacent oyster reefs) or productive (the mussel pole fields and macroalgae plantations) is that the relative size of each component can be varied according to location. For example, the study area chosen has a significant tourism and shellfish focus and so these industries have provided the principal physical linkages between islands and communities. Were this system to be rolled out closer to a more industrial landscape (such as in the Westerschelde near Vlissingen or Terneuzen), the focus might be more on the remediative and biomass benefits to, as mentioned earlier, re-orient the Vlissingen refinery towards bio-fuels or the petro-chemical industrial complexes towards bio-based products and production for example. Were these new spatial typologies applied across the delta, their shared visual characteristics and the research, production, recreation and functional linkages they suggest, could connect towns and communities separated by more than simply a body of water (by creating broader networks that could be scaled up or down at will).

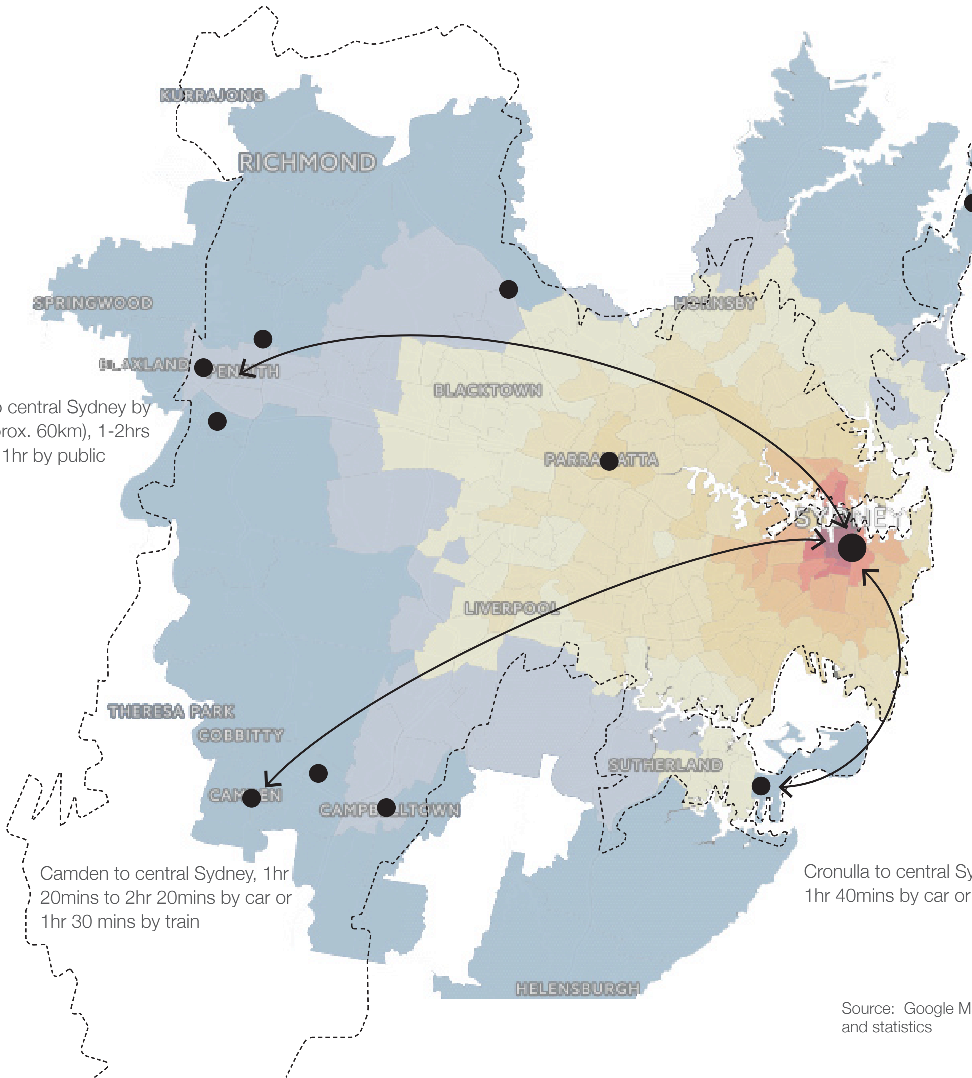
Another question also remains, what benefits might these locally applied infrastructures have for the broader region and beyond that, the North Sea territory? Apart from the bolstering of natural and habitat resources (that might aid birdlife, increase benthic capacity and boost fish and crustacean stocks) the benefits for the broader North Sea territory are more difficult to identify. The re-orientation of the delta is intended to both act as a generator of organic nutrients and as a filter of nutrient waste to mitigate nutrification issues in the North Sea. Again, this exchange will need to be monitored to ensure enough nutrients are being delivered into the oceanic systems through the delta and an increase in sediment import into the estuary will have implications further up the coast as more sand is needed to nourish beaches north of the delta (via the longshore drift of sediments from south-west to north-east).

The connective networks and synergies promoted by integrated systems such as these are likely limited in effectiveness to the regional scale (of the delta). There is no reason that this model might not be repeated across the North Sea territories (and indeed seaweed is cultivated from the UK to Norway and Denmark) and an algae driven bio-fuel network centred around the North Sea (and perhaps even distributed using existing oil pipelines) might be possible. This particular mix of infrastructures and spatial typologies might not be repeatable elsewhere though as climatic, flood risk or cultural conditions are likely not the same elsewhere. The broader impact of these proposals might be limited to the promotion of new local systemic networks that nevertheless benefit and help sustain traditional practices elsewhere (fishing etc.).

The fundamental difficulty is aligning these ecosystemic landuses and processes with our (traditionally rigid) notions of flood protection as well as (less rigid) economic and social infrastructures. The essay that provided the theoretical framework for this thesis discussed Marina Alberti's concepts of combined urban and natural systems (urban ecosystems as she called them), of which the proposals here represent an extreme example. The characteristics of her urban ecosystems were that they exhibit **emergent properties** in **non linear systems** where change is **path dependant** and **discontinuous**, and **multiple states of equilibria** are matched by a characteristic **spatial heterogeneity**.

The new productive landscapes and functional networks proposed in this thesis embrace these properties and fundamentally intertwine such notions with those of flood protection and social infrastructure. The ability of these systems to self-calibrate along with changing conditions (in water level for example) makes them more functionally resilient but what might be the impact of these changeable infrastructures on the economic and cultural processes (mussel harvesters or eco-tourism for instance) that come to depend upon them? One possible consequence might be that the same characteristics that define the urban ecosystems might be replicated in these economic and cultural systems. Producers, managers and operators would need to quickly respond to changes in the natural systems and these responses would be dictated by the system context. In other words, these new ecological landuses and the economies they promote might offer an alternative model to globalisation while still tapping global food and supply chains. Economies of scale might be replaced by economies of context as local operators would be best placed to understand system changes and smaller operations be best suited to make the changes required by shifting ecological and productive characteristics.

Figure, 53: Australia at night



Penrith to central Sydney by 9am (approx. 60km), 1-2hrs by car or 1hr by public transport

Camden to central Sydney, 1hr 20mins to 2hr 20mins by car or 1hr 30 mins by train

Cronulla to central Sydney, 45mins to 1hr 40mins by car or 57mins by public

Source: Google Maps, Sydney LGA's and statistics

Figure, 54: Sydney metro area showing employment activity and commuting times

10.4 thesis motivation, settlement patterns

The issues I am broadly interested in largely stem from the challenges posed by the urban expansion required in Australia over the next 30 years to cope with a likely dramatic rise in population. Currently around 24 million people live in the country but this is expected to double in the next 50 years... due largely to migration. Almost three quarters of these people are expected to live in the eight state capital cities (up from around two thirds at present) with 89% of these moving to the four largest state capital cities of Sydney, Melbourne, Brisbane and Perth[1].

The current urban sprawl that characterises Australia's cities - as well as issues around environmental impact, land, habitat and water degradation and the energy transition - renders them unlikely to be able to comfortably absorb this expected population growth whilst maintaining access to amenity, social inclusiveness, liveability and housing affordability. For instance, the population of greater Sydney is approximately 5 million and the city has an urban population density of around 1240 people per km^2.[2] The economic, cultural and employment activity though is overwhelmingly focused on a small area at the city's historic and CBD heart (see opposite page). One of the largest issues is the creaking infrastructure in these large cities that were planned and have expanded under the logic of private car ownership. Commuter suburbs (where housing is moderately affordable) now are sometimes over two hours drive from the central business districts and those able to access the rail network might still face commutes of up to 1.5 hours in each direction. This infrastructure is unlikely to be able to cope with a doubling of population let alone a shift in transport and usage patterns that might accompany the energy transition etc.

State and national planning bodies are proposing few alternatives for how the country might tackle this challenge and indeed, each city's planning bodies are proposing a continuation of "business as usual". There have though, been a few alternative suggestions from academia including the promotion of a number of networked urban regions connected by high speed rail and bolstering the existing regional infrastructure and populations.[3] As such, one approach might be to follow Europe's lead and develop networked regions of smaller cities that could revitalise shrinking regional towns, result in more liveable and sustainable cities and reduce further landscape and habitat degradation. Indeed, the Randstad area is broadly commensurate with the Sydney basin and commuting times and distances from Rotterdam to Amsterdam for example are very similar to those from the west of Sydney. The difference is though, that the Randstad has a population of around 7.8 million people (roughly double Sydney's) and an average urban density of around 4000 people per km2 in urban areas (almost four times that of Sydney).[4] The fragile, yet ever present and hugely complex landscape and ecological systems in Australia will also have a huge impact on this expansion and could offer potential for new forms of ecological or landscape driven settlement. Most Australian capital cities are also bordered by national parks, areas of high biodiversity or ecologies that are easily damaged and have huge implications for settlement (such as erosion, salinity, flooding, water pollution and scarcity etc.).

The webs of well-connected, small (and liveable) cities in Northern Europe, and the Netherlands in particular – especially those located close to naturalistic systems be it coastline, river valley or delta – might provide a relevant model for how Australia might become more urbanised without further compromising its natural heritage. This is not to infer that The Netherlands has established a perfect balance between the urban and the natural, far from it. The Dutch landscape is, in effect, a constructed one where the management of natural processes necessarily place huge restrictions on hydrological and ecological systems. A number of factors have lately resulted in a review of this traditional approach and a growing appreciation for both the fragility of these systems and of their potential to alleviate urban problems (ecosystem services).

The managed Dutch landscape might represent an extreme in the rationalisation of natural systems to support our urban, economic and social needs but this process obviously also occurs in Australia's sprawling suburbs (though water management is generally concerned with scarcity rather than an excess of water). The beginnings of a Dutch shift away from their history of absolute landscape manipulation in order to ensure conditions condusive to urbanisation, is perhaps reflective of a broader realisation of the planetary environmental impacts of our occupation patterns.

1. Australian Bureau of Statistics

2. http://www.cityofsydney.nsw.gov.au/learn/research-and-statistics/the-city-at-a-glance/greater-sydney

3. Weller et. al., 2013

4. Randstad population densities

Predominant condition of Australian sub-urbanity

Housing, industrial and natural areas sharply delineated

In the Netherlands industry, agriculture (the countryside) and urban areas more intermingled but highly managed

Figure, 55: Australian urban landscapes comparison

10.5 urban / natural interface

Urban actions and cultures absolutely shape our environments and so too - as is again evident in the Dutch case - do our environments absolutely shape our urban (as well as national) cultures. It might follow then, that techniques for multiplying the ecological, social and economic efficacy of the (already pliable) Dutch landscape could offer instruction for a more versatile and nuanced approach to Australian urbanism and sprawl. These issues in Australia are currently not being tackled in a coordinated fashion at the larger scale and the North Sea Studio's focus on merging ecological, social and economic priorities and processes at the territorial as well as the local scale offers an opportunity to explore these issues in a different cultural and landscape context than Australia's.

The inference is that binary notions of urban or rural, artificial or natural are losing their authority in our contemporary urban ecosystems. This thread runs through the whole of this thesis and aligns with the studio themes of performative landscapes and a focus on symbiosis between urban and natural systems. So too, is the shared position (of studio and thesis) that the scale at which these issues need to be addressed is at the systems and regional scale, rather than (or as well as) the city or neighbourhood scale.

As such, this thesis has responded to these topics in an unashamedly explorative way, as an opportunity to personally inhabit an alternate urban and landscape, culture and context. The theoretical framework (driven by a review of various approaches to the combination of natural and urban systems) also suggested an intuitive approach given the complexity of interactions between these systems. The methodology employed therefore, attempted to be rigorous and systematic in the analysis of each particular area of interest as focus moved down the scales...from terrestrial to regional to sub-regional to the specific interventions. The hope was that new and interesting synergies and patterns might fall out of the design process that are nevertheless supported by a clear distillation of the themes, infrastructures and processes predominant at each scale.

This approach of identifying and relating the functional, social and administrative components of new natural and productive infrastructures all within a spatial framework might be applicable to other contexts as a way to balance flows but (critically) also to cultivate cultural connections and adaptive urban ecosystems (in the Alberti sense).

Clearly the Australian context is not the same as that of the Netherlands and indeed, it might be argued that they are polar opposites (with respect to landscape scale, infrastructural focus, weather patterns etc. in any case). And while the issues addressed and solutions proposed within this thesis derive from a particular North Sea, Dutch and delta condition, the strategic relation of context driven ecological infrastructures in a shared spatial organisational matrix might potentially be applied to another context. This might be more difficult in Australia where the cultural connections to landscape are very different though the functional and administrative components are likely very similar. The point would be to identify the potential for a new urbanisation logic based on Australian spatial identities to unify disparate infrastructural systems and make explicit the urban, productive, cultural and natural interconnections that might sustain Australia's social, economic and environmental landscapes.

Figure, 56: A new terrestrial edge

10.6 conclusion

While the heart of the delta is clearly suffering from environmental and demographic decline and (physically at least in terms of transport links) is poorly connected to regional and global networks, the peripheral port and industrial complexes are absolutely defined by their global positions. As their profitability is challenged and the energy transition impacts fossil fuel based industries, the economic and social contribution of these global complexes to the delta might also decline. Throughout its history, the delta's particular geographic and geomorphological characteristics have determined the success of its communities and economic practices. This thesis intends to suggest another site specific set of infrastructures that improve local conditions as well as help to position the delta in global agro-food supply chains, as a biodiversity hotspot and natural resource.

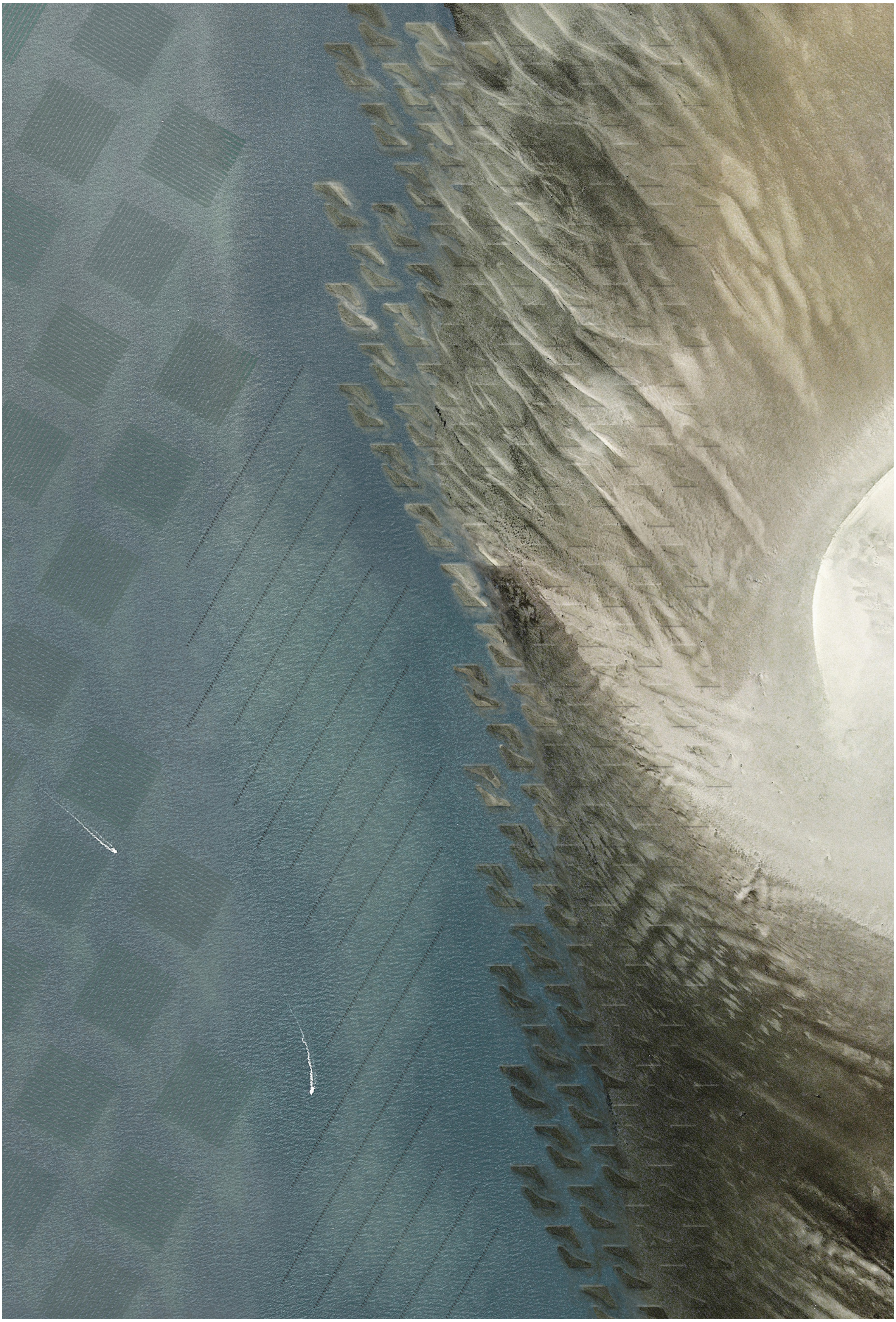
The main research question asked whether these new ecological infrastructures could help shift the natural, social and economic focus of the delta as well as boost its productivity (in terms of habitat as well as product) and promote connectivity. While there remain a huge amount of unanswered questions as to the functioning, synergies and limits of these particular new systems, this approach to group and interlink productive, protective and natural infrastructures does have the potential to multiply benefits as well as minimise cost, waste and vulnerability to systemic shocks. The particular landuse typologies proposed and their individual design rationales might also meet the requirements of the stated design goals but it is the broader theoretical approach that is perhaps more transferable to other contexts: the adoption and designed application of local spatial relationships and typologies.

So in summary, this thesis has sought to co-opt and adapt a series of ecologies or landuse typologies already present in the delta (or nearby) to suggest new synergies and spatial relationships that could have multiple social, cultural, economic, natural and infrastructural benefits. Context specific functional, spatial and locational principles have guided the design of these multi-functional landscapes, their application mapped on the sub-regional and local scales and their benefits identified and quantified, where possible using tools that value ecosystem services provision.

The application and design of these typologies intentionally suggested a strong series of spatial characteristics as a nod to traditional Dutch landscape structures but also to promote a cultural identity shared across the islands and settlements within the archipelago and focused on the element that unites them all, the estuary. The productive capacities of these new infrastructural typologies are also intended to build on existing aspects of local cultural identity and practice (a culinary focus on aquaculture and agricultural production as well as water and nature based recreation and tourism) to boost their potential to further characterise the delta, spread the benefits and encourage settlement and investment. How this would be received by the delta's inhabitants though is still an open question.

Relevance
With the advent of the (almost) formal recognition of the Anthropocene as a new geological epoch and the accompanying realisation that our actions affect planetary and geological change, a whole series of problems converge and play out in the urban sphere. These range from the likely impacts of climate change (sea level rise, altered weather and storm patterns etc.), implications of the energy transition away from fossil fuels (renewable sources, shifting industrial models etc.), the degradation of habitat (impacting biodiversity, nature-based recreation, biotic ecosystem services etc.), water management issues (flood protection, run-off management and water provision) to the compromising of natural landscapes (through resource depletion, nutrient runoff and pollution etc.).

So from a societal and ethical point of view, it would seem obvious that we should address these (likely) existential problems in the urban areas where the majority of us live and where concentrations of people, industries and agricultures likely contribute to many of these now global issues. In an era where our assumptions for how we manage our urban systems (transport, energy provision, water management, food provision etc.) are changing...surely the fundamental relationships between urban and ecological systems might also be questioned towards achieving a greater parity between the needs of the two. By the same token, and particularly in the Dutch



Figure, 57: A new estuarine field

context, current conceptions of the role of the countryside (in terms of a venue for recreation or agricultural / economic production) might also be shifting. The declining economies of agriculture and greater emphasis on tourism and recreation might offer an opportunity to reconfigure these spaces that make up the field within which our urban areas are set.

The relevance of this paper from a scientific perspective is more difficult to establish at this stage. The abundance of theories over the incorporation of ecological drivers for urban design processes[1] and the varying terms employed (landscape urbanism, ecological urbanism, infrastructural urbanism, regenerative urbanism etc.) do muddy the waters somewhat. This is perhaps a result of the relatively short amount of time that these topics have been a part of academic discourse but this also might infer that there are fewer examples of their practical application. The Southwest Delta too has been the subject of intense governmental, academic and professional scrutiny, including looking at the implications of an open delta model that promotes a return to a more naturalistic system[2]. The particular focus of this thesis on ecosystem services that might benefit adjacent urban areas, a broader interpretation of territorial systems as well as to suggest new cultural relations to (and uses for) countryside areas, might offer a slightly different perspective of viewing the delta as a habitat and cultural resource on top of its current economic and logistical significance.

At the same time, and as discussed above, traditional reductionist interpretations and static mapping of urban ecosystems are perhaps unable to adequately represent the complex combination of natural, social and economic processes inherent in the contemporary urban setting. Traditional planning that seeks an ideal masterplanned solution is being superceded by a greater recognition of the systemic and complex nature of urban processes as well as the breadth of spatial and temporal scales across which they operate. In this context, one of the roles of any design exploration (such as this thesis) should be to proffer alternative combinations of, and links between, these natural, social and economic processes. As a single masterplanned solution can only respond to a limited set of conditions and likely changes...the broadest possible suite of design possibilities, process synergies and spatial patterns can naturally better respond to the systemic changes inherent in both our urban landscapes and the natural processes that help shape them.

This thesis then, could be seen as making a small contribution to the exploration of potentials and possible relationships between natural and urban processes within the context of the Southwest Dutch Delta as well as new (essential) cultural and spatial approaches to augmented ecologies. These ecologies are also becoming more prevelant in the light of increasing natural disasters and preparations for climate change and sea level rise as seen in programs such as SCAPE's "Oystertecture" proposals as part of Rebuild by Design in New York after Hurricane Sandy.[3]

There is clearly much work required to determine the efficacy, suitability and potential of these infrastructural ecologies particularly as their operation is so determined by local conditions and context. Multiple applications of systems relations and synergies between previously unconnected traditional infrastructures[4] as well as experiments with tools such as ecosystem engineers (as is the case with those conducted by SCAPE and in the Oosterschelde) are being explored. This suggestion to combine the two within a distinct designed spatial framework is a fairly naive leap that would require enormous amounts of further research into areas including:

- the carrying capacity and functional dynamics of estuarine systems for the landuses
- how synergies between infrastructures might practically function and be scaled
- what planning, policy, insurance and administrative mechanisms might be required to implement and maintain these systems
- how this natural system support and monitoring roles could be spread amongst private, public and community interest stakeholders
- how might the residents of the archipelago respond to the changes proposed
- implications for those ecosystems and habitats already present in the delta

All in all though, the proposals as presented might provide the means for a fundamental re-orientation of the natural, visual and social landscapes within the delta using mechanisms that champion natural processes yet foster community and economic connections while able to adapt to changing physical and cultural climates.

1. Waldheim 2016, Belanger 2013, Alberti 2008 etc.

2. Meyer et al 2012, 2015

3. Wakefield et al, (in press)

4. As described by Brown, 2014

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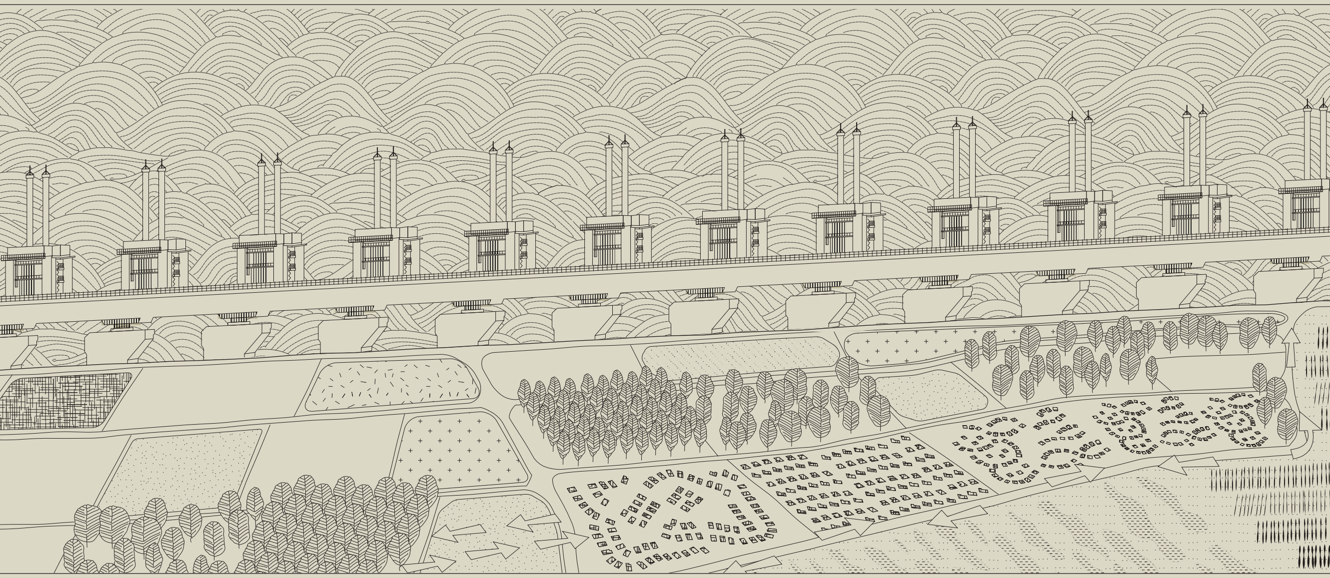
a non-straightforward archipelago

appendix



contents


THE LOBSTER
NEW EN SUITE B&B ACCOMMODATION
THE LOBSTER
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FREE WI-FI
FRESH COFFEE
Locally Caught
Doggy Bags

Approaching Urban Ecosystems:
A theoretical framework for designing with nature

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Abstract
In *Design With Nature*, Ian McHarg relates an anecdote of NASA experiments with self-sustaining environments in order to support lunar missions[1]. Within these environments, algae and bacteria would be employed to consume the waste products produced by the astronaut (CO2 and bodily wastes) and in turn the astronaut would subsist on the elements produced by these processes (condensed water, oxygen and protein). This limited example of absolute interdependence between ecological and human processes perhaps reflects a certain romanticism on McHarg's part when it came to natural as opposed to urban processes, referring as he did to cities as 'God's Junkyard'[2].

The inherent interrelation in the above example is expanded and made explicit in Marina Alberti's book, *Advances in Urban Ecology*, where she calls for a new branch of study (urban ecology) that recognises this interdependence and could inform 'alternative development patterns [that] can simultaneously support ecological (i.e., bird diversity, water quality) and human function (housing and water supply)'[3].

This evolution of approach, from natural and urban systems as essentially independent layers with discreet interactions, to viewing these as simultaneous processes that evolved together and exert continuous influence over each other, is taken one step further by Pierre Belanger. His PhD thesis advocated that the employment of these ecological systems 'be designed as infrastructures that shape contemporary urban economies.'[4]

This paper will seek to synthesise and compare these texts with a view towards building a theoretical framework for approaching urban design in hybrid ecological/ urban systems. This framework should prioritise resilience within both human and ecological processes and therefore, within the urban landscapes they go together to comprise.

Key words
Urban ecosystems, theoretical framework, HcHarg, Alberti, Belanger

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1 McHarg, 1971. P.44
2 McHarg, 1971. P.23
3 Alberti, 2008
4 Belanger, 2013

Introduction
Today's urban landscapes are a complex field occupied by a multitude of inter-related systems (ecological, social, infrastructural, economic and logistic etc.) that influence each other's form and function to a greater or lesser degree and in ways that are at times obvious and at other times, all too obscure. It is these inter-relations that determine the patterns and flows of our urban systems. Understanding and seeking to direct the progression and form of these urban systems has been a project existing as long as cities themselves, driven by both the philosophy of "the designer" and the aspirations of the community or culture that will inhabit a space.[1]

The question is, particularly in the Dutch context of an absolutely managed naturalistic landscape (the systems of polders and dikes) and an urban landscape fundamentally aware of natural processes (riverine, delta and coastal processes), how does one approach the design of urban systems? The contemporary awareness of both the importance of natural systems (climate processes, habitat and biodiversity, geophysical processes etc.) and our (overwhelmingly detrimental) impact upon these systems is reflected in the positions taken by urban theorists as they attempt to reconcile urban and ecological systems.

This essay intends to track the evolution of this reconciliation through the work of three theorists and urban practitioners, Ian McHarg, Marina Alberti and Pierre Belanger. Each of the three places natural mechanisms in a prominent position within the urban planning process but they vary in terms of the agency they instil in ecological systems and in the design practices they suggest be employed. The hope is that this literature review might provide a contemporary theoretical framework for approaching complex urban landscapes in the South-West Delta region of The Netherlands, in particular with a view towards re-empowering natural processes in an area where they have been largely negated by the Deltaworks of last century.

The McHargian project
McHarg's intent for 1969's *Design With Nature* was, in part at least, to encourage a greater appreciation of the - in his view all too fragile - natural world.[2] Perhaps more significant for the urban planning and landscape architecture professions was McHarg's goal of outlining a practical and systematic approach to urban and sub-urban design that could counteract piecemeal, ill-informed and myopic destruction of natural values for urban development: ' We need, not only a better view of man and nature, but a working method by which the least of us can ensure the product of his works is not more despoliation.'[3]

In essence then, his ecological planning method was a reaction against the imposition of engineered and urban developments with little regard for, or indeed understanding of, the natural systems that underlie a particular place or context. He called for the recognition of natural values and systems as well as their integration into the planning process as a key determinant for allocation of functions as well as regional and local decision-making. McHarg's admiration for Dutch planning traditions and their employment of naturalistic techniques of flood protection[4] may have caused him to overestimate their acceptance of natural processes. Nevertheless, the Dutch coordinated and regional response to urban and planning tasks as well as their foundation upon an excellent understanding of natural processes and tendencies, provided McHarg with the antithesis of the practices then deployed in the United States.

It was these practices, ruled over as they were by cost-benefit analysis, that McHarg's progressive vision set out to oppose, presented in a comparable language as a 'method [that] requires that we

[1] Bacon, 1974.
[2] 'This book is a personal testament to the power and importance of sun, moon, and stars, the changing seasons, seedtime and harvest, clouds, rain and rivers, the oceans and the forests, the creatures and the herbs.' McHarg, 1971. P.05
[3] McHarg, 1971. P.05
[4] Replication of dunal systems, land management techniques to maintain dune vegetation and flexible dike foundations etc.

obtain the most benefit for the least cost but that we include as values social processes, natural resources and beauty.'[1] This championing of the values inherent in natural processes was likely a huge shift at the time of publication and was the mechanism through which McHarg could distil dynamic physical and biological processes into a form or language that could be presented and equated by landscape planners.

> *'Land, air and water resources are indispensable to life and thus constitute social values… A recognition of these social values, inherent in natural processes and that these processes, must precede prescription for the utilisation of natural resources.'*[2]

McHarg's representation of natural processes and patterns
Like Alberti, McHarg recognised that natural processes directly impact urban systems and represent opportunities for, or place limitations on, land-use and settlement patterns. His method advocated the simplification of these changeable natural processes into scales of social value that could be represented as a map overlay. As such, physical or biotic processes (geological or climatic systems for example) could be represented spatially and equated with patterns of urban settlement and use as well as with natural processes that have a spatial component (vegetation community makeup and distribution for example).

For each project, aspects of these natural processes and patterns (such as the soil profiles across an area) were ascribed a value according to its suitability for a particular land-use or social function (such as compressive strength for building foundations). These values were made explicit by shading areas of highest significance - or those that represented a constraint - the darkest and those of least significance, in the lightest shade. The intention was that these natural values (such as hydrology) could be measured, represented and overlaid alongside economic and social values (such as agricultural land productivity and scenic value etc.) without prejudice. The areas of least significance across a number, or all, of the values overlaid would then appear in the lightest shade and therefore begin to direct where interventions (such as a new highway or urban expansion) could occur with the least impact on the values identified.

In more comprehensive or complicated iterations of his method, McHarg overlaid a whole suite of a site's physical, geological, hydrological, societal and ecological characteristics in order to establish any opportunities or constraints for urban occupation or use… essentially the site analysis procedure broadly familiar to modern day Landscape Architects and Urbanists. Again, a social value range was ascribed to each of these categories that were then placed in a hierarchy according to the requirements of a particular land-use, be it conservation, recreation or urbanisation etc. These could then be overlaid onto a single "Suitability Synthesis Map" (see Fig. 01 below) that would allow an easier comparison of land-use suitability as well as any synergies or conflicts between proposed land-uses. The corollary of this would be its use in determining the most beneficial use (or mix of uses) that a region could be put to as well as the compatibility of these uses.

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[1] McHarg, 1971. P.34
[2] McHarg, 1971. P.104

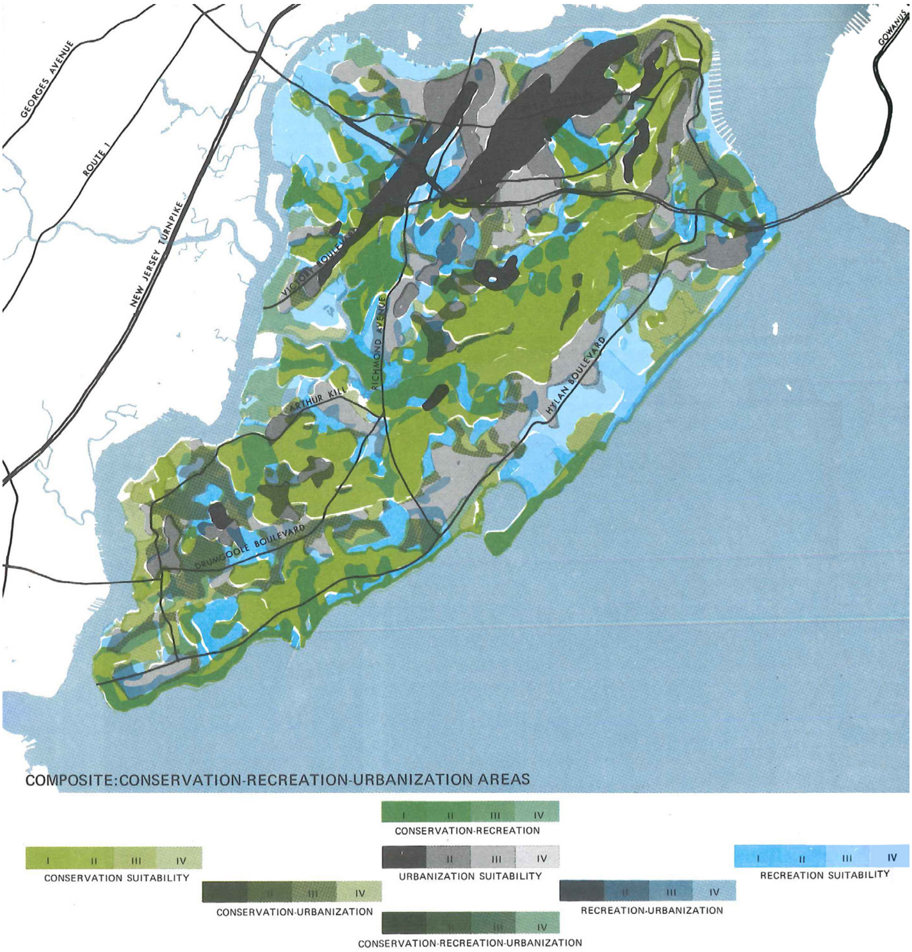

Fig. 01: Land-use suitability composite map for Staten Island (p.114 of McHarg, 1971)

Representational short-comings

While this method has lost little of its potency for landscape planners over the last 50 years, it does - not unreasonably - contain some inherent limitations. The minute you represent dynamic processes as a static patterns (on a map overlay for example), the ever-evolving process leaves the pattern description behind and these snapshots of a dynamic process are immediately obsolete. The recognition of potential feedback loops as existing and new patterns interact is also negated in this process… until the next series of overlays is created for the next project. The other problematic aspect of reducing natural processes to a suite of social values is that these values are not culturally universal and, like the natural processes they seek to represent, are subject to constant change.

McHarg certainly recognised that his methods represented an over-simplification of natural processes but the intent was to nevertheless translate or represent these processes in a planning and political arena dominated by economic rationalism, 'Gross National Product does not measure health or happiness, dignity, compassion, beauty or delight'[1]. He formulated a means of viewing, and ultimately ordering, the natural world such that an ecologically based planning method could be rationally communicated and defended to developers and politicians. But it is this reductionism

[1] McHarg, 1971. P.23

that is most frequently the target of contemporary criticism, including by his former students such as James Corner who lamented 'The failure of earlier urban design and regionally scaled enterprises was the oversimplification, the reduction, of the phenomenal richness of physical life.'[1]

The rationality of his standardised approach to place was formalised in Global Information Systems (GIS) and, depending on your point of view, both the strength and weakness of its presentation of design decisions as the logical conclusion of a series of mapping overlays, is that it allows the negation of "the designer". While McHarg suggested that his method 'is an indispensible ingredient to a plan, but is not the plan itself'[2], it sought to minimise subjective design decisions, artfulness and arguments that cannot be empirically defended with the insinuation that '… if the process were correct, the consequent form would be good, almost as if objective study automatically gave rise to an appropriate aesthetic.'[3] In essence, in its search for certainty of representation (perhaps necessary at the time to ensure natural values be incorporated in the planning process), ambiguity was rejected and (likely) variable values were expressed as finite, pattern overlays.

Aesthetics aside, it is striking that such an absolutely rational method for defensible and objective planning outcomes was borne of what is a highly personal book, written from a stridently subjective perspective and railing against 'the squalid city and the pathetic subdivision, suitcase agriculture and the cynical industrialist, the insidious merchant, and the product of all these in the necklace of megalopolis around the continent, their entrails coalescing.'[4]

From natural vs urban systems to urban ecosystems

The practical application of McHarg's personal bias towards natural systems set in opposition to human patterns and planning processes, generally constitutes a thoroughly deterministic and binary method that – while the apportioning of value to various natural or urban patterns might vary from practitioner to practitioner – promises a single (or limited set of) solution/s. The conclusion of Marina Alberti's book is quite the opposite. Her understanding suggests that the interaction of human and natural patterns and processes over time (and at varying scales) are so complex that current models and even disciplines, are unable to adequately describe, let alone predict, the confluence of these ecosystems. This is particularly the case where (as seems inferred in McHarg's work) a fixed, "correct" outcome is sought. Indeed 'Planning and management strategies that aim to achieve a stable state are likely to make the system less resilient and reduce the options for sustaining human and ecological functions simultaneously.'[5]

Design With Nature has also been criticised for promoting the dichotomy between natural and urban systems, of creating a false separation of the two and reinforcing the mind-set of their operating at opposite poles.[6] Indeed, despite advocating against this partition of man and nature, one suspects McHarg's suitabilities synthesis maps are intended not to bring the natural and the urban together in a sustainable fashion, but to maintain their separation. This is pointedly not the case with Alberti's thesis. For her, 'urban landscape patterns are hybrid phenomena emerging from the interplay of human and ecological processes acting on multiple temporal and spatial scales.'[7] One can no longer analyse, describe or predict outcomes in urban ecosystems without a comparable understanding of natural systems (at the local, regional and global scales). Indeed, these systems are so intertwined that a new branch of study is required, that of urban ecology, 'the study of the coevolution of human-ecological systems, not separate studies of the human habitat and of the ecosystems upon which humans depend'.[8]

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[1] Corner, 2006. P.32
[2] McHarg, 1971. P.127
[3] Treib, 1999. P.31
[4] McHarg, 1971. P.29
[5] Alberti, 2008. P.270
[6] As noted by Weller, 2006 and Waldheim, 2016.
[7] Alberti, 2008. P.13
[8] Alberti, 2008. P.252

Alberti's urban ecology would treat anthropomorphic and natural systems as not representing polar positions that need to be reconciled but as simply two sets of drivers that combine to influence the makeup and functioning of our urban areas. She sees these two sets of drivers as being made up of both process (characterised by flux) and pattern (their spatial manifestation) that combine to make up urban ecosystems, exhibiting 'unique properties, patterns and behaviours that arise from a complex coupling of human and ecological processes.'[1]

Here urban ecosystems are viewed as a whole, the product of inherently complex and dynamic, natural and urban, patterns and processes that fundamentally influence and change each other in feedback loops from the micro to planetary scales. As much as urban settlement patterns are initially dictated, or at least influenced by, natural processes (climate, geological and hydrological conditions etc.), there is no doubt that 'In urbanising regions, humans affect ecosystem function through direct and subtle changes in biophysical and ecological processes.'[2] Ecosystem function in turn, 'directly supports the human population in non-urbanised areas and indirectly supports human function in urbanised areas.'[3] This interdependency and influence, the coupling of natural and urban processes is characterised by Alberti's notion of resilience in urban ecosystems as 'defined by the system's ability to maintain human and ecosystem functions simultaneously.'[4]

A new approach

As compared to McHarg, Alberti is advocating a fundamental shift in the way we view these urban ecosystems for the purposes of landscape planning and management. This applies to how we approach natural ecosystems in urban planning but also to what our ultimate aims for these planning processes should be. Our traditional approach to natural ecosystems (and likely also to urban patterns and processes and therefore, also to urban ecosystems) is that they are 'predictable and behave in a linear way, that their behaviour is consistent over time and space and invariant to scale, and that change is continuous.'[5] She suggests that we can no longer operate under this misapprehension and, as discussed previously, planning policies directed towards achieving a single static outcome or to achieving a state of continuance, do not incorporate the inherent characteristics of urban and natural ecosystems and are therefore destined to fail.

It is worthwhile here to briefly outline Alberti's stated characteristics of these urban ecosystems that make them so difficult to incorporate within a planning process (traditional or not). These she describes as the following[6]:

- These systems exhibit **emergent properties** that do not characterise any of their constituent parts.
- The also exhibit **multiple** states of **equilibria** in that functionally different states might be possible within one system… there is no single state of equilibrium.
- **Non-linearity** infers that change, and the impacts of change, are not predictable.
- Changes within a system are **path dependant**, i.e. changes caused by certain driving forces might in turn have an impact upon, and alter, the forces themselves.
- Change in these systems is also episodic or **discontinuous**, it occurs neither gradually or randomly but suddenly, once a particular system threshold has been crossed.
- **Spatial heterogeneity** infers events, processes and functions are not uniformally distributed over space but occur in patches.
- As already mentioned, **resilience** is applied to an ecosystem's ability to support both ecological and human functions.

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[1] Alberti, 2008. P.17
[2] Alberti, 2008. P.62
[3] Alberti, 2008. P.234
[4] Alberti, 2008. P.22
[5] Alberti, 2008. P.21
[6] Alberti, 2008. From p.258

So McHarg's belief that we should ascribe value to natural processes and incorporate both these processes (in their impacts on urban patterns) and values (simplified so as to allow communication with social or economic values) within the landscape planning process still (partly) holds true. The scale of this previous imbalance that he was seeking to redress though is less profound today as there is a much greater recognition of our reliance upon natural systems but also of the significant influence urban processes have on these same ecological systems (as discussed by Alberti).

Advances in Urban Ecology makes it clear that we cannot separate human and ecosystem processes, particularly as they apply to urban areas as Alberti's urban ecosystems. It is also clear that these urban ecosystems are fundamentally complex, unpredictable, non linear and non scalable (temporally, spatially and in terms of isolating component systems as a means of understanding the whole). Indeed, Alberti concludes that numerous models for analysis and prediction of these urban ecosystems and their interactions (complex systems theory, urban patch dynamics, gradient theory etc.) across multiple disciplines (social and natural sciences, urban planning etc.) '…still cannot effectively take into account the complex interactions between humans and ecology.'[1]

From a design perspective then, while the mapping of natural and urban systems and patterns remains important to understand a site's context, it cannot represent either the complexity or the multiple values (cultural, economic, habitat, functional etc.) attached to each aspect of these systems. Indeed, the way we fundamentally view urban landscapes should change to reflect the indivisibility of natural, urban, infrastructural and social systems in combining to create one urban ecosystem. Also, our means of representation and modelling should reflect the likelihood that all aspects of this complex system cannot be mapped in the traditional, empirical fashion championed by McHarg.

Designed systems and synergies

This shift away from the categorisation and indexation of patterns is tracked in Pierre Belanger's work as 'linear, fixed, and closed mechanisms of the industrial economy are quickly fading in the background of more flexible, circular, and networked systems of urban economies.'[2] Belanger suggests that the primacy of the McHargian paradigm has diminished as urban spatial and management patterns have moved away from traditional centralised models (including the urban gradient theory mentioned above) and that infrastructure at the scale of the landscape (spatially, temporally and from a systems perspective) is better able to relate to natural – and therefore urban – ecosystems.

> *' Transcending jurisdictional boundaries, the integrative and horizontal enterprise of landscape of landscape infrastructure enlists geographic zoning, boundary realignments, strategic design, subsurface programming, sectional thickening, and ecological engineering as some of the most influential mechanisms in the structural transformation of urban regions to effect change on the large-scale operational and logistical aspects of urbanisation.'*[3]

Belanger suggests that approaches toward this landscape infrastructural point of view (as in Alberti's summation of the distinct characteristics of urban ecologies) will need to recognise a number of distinct design processes and planning practices, such as[4]:

- Classical divisions of land use zoning, geo-physical characteristics, construction methods and maintenance regimes will need to become more **flexible**.
- **Synergies** must be promoted between urban, economic, engineered and logistical infrastructures and biophysical and ecological infrastructures and processes to maximise functionality across jurisdictional (and cultural) boundaries.
- Solutions must come from **cross-collaborations** between disciplines.

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[1] Alberti, 2008. P.252
[2] Belanger, 2013. P.309
[3] Belanger, 2013. P.301
[4] Belanger, 2013. From p.305

- These infrastructures and systems will operate at different **speeds and scales** than traditional infrastructures.
- They will also operate in the realm of **distribution and disaggregation** that characterise natural and, increasingly, urban systems.
- This then infers that **regionalisation** will become a dominant paradigm as the distinctions between urban centre and periphery and well as between urban and rural land uses, begin to disappear.

For both authors then, landscape becomes the field of operation upon which these urban ecosystem interactions (for Alberti[1]) and new constructed ecologies (for Belanger[2]) will play out. The question remains, if the compartmentalisation and reductive rationalism of McHarg's model can only express a very small part of the complexity inherent in the urban ecosystem, how do we communicate, operationalize and narrate this new paradigm?

Mapping as process

Belanger see a renewed role for the designer - one eroded via McHarg's method - in the visualisation (via flow, strategy and sequence diagramming, use of the section etc.) and mapping of the characteristics, dynamics and possible synergies of and between these complex urban and ecological systems. This new design role moves from an informed determination of the end state for a particular urban landscape to the communication of possible system processes and interactions between systems (both urban and natural) that might combine to comprise an eco-systemic relationship, a new sequence of states or inter-relations. The renewed significance of - albeit unconventional and speculative - mapping is echoed by James Corner in his call for a broadening of mapping techniques to communicate site characteristics and possibilities other than simple pattern overlays. 'Mapping acts may emancipate potentials, enrich experience and diversify worlds.' He writes, and mapping's 'agency lies in neither reproduction nor imposition but rather in uncovering realities previously unseen or imagined'[3]

Corner suggests a variety of mapping techniques – some incorporating Alberti's expressed preference for using scenarios to plan for complex systems while accounting for their inherent uncertainties – that are all intended to reveal, superimpose and suggest characteristics, relationships and synergies inherent to (or lying as potentials within) urban and landscape systems and infrastructures.

The inference then, is that today's urban planning and design project should concern itself with the visualisation and mapping of process and relationships within urban ecosystems (in the holistic sense Alberti intends). With the exhaustive overlaying, decomposing and reconstructing, abstracting and personalising, diagramming and flowcharting urban systems and interactions across spatial and temporal scales. Not with a view towards a single planning outcome or even a comprehensive representation of the landscape in question, but towards establishing potentially unexpected associations and synergies between social, ecological, infrastructural and economic systems that combine to make up the urban landscape. The products distilled from this design project should incorporate Belanger's landscape infrastructural planning practices and bear in mind Alberti's characteristics of urban ecosystems to ensure that the synergies, processes and relationships identified could play a role in the continued resilience of these urban ecosystems. In a sense, the mapping of landscape becomes a process in and of itself… a visual representation of potentials rather than patterns and an evocative echo of the processes playing out within our

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[1] 'The dynamics of land use and land cover are at the core of urban ecosystem change.' Alberti, 2008. P.49

[2] 'The horizontal nature of the field of landscape avoids disciplinary cul-de-sacs, rendering irrelevant the historical oppositions between concepts such as city and country, rural and urban, natural and human, modern and historic.' Belanger, 2013. P.284

[3] Corner, 1999. P.213

urban systems that might nevertheless, propose new (conjoined) urban and natural infrastructures at the scale of the landscape.

Conclusion

McHarg's reductionist mapping was borne of a need to equate natural, engineering, social, economic and urban processes into the same value system and towards an optimal state or solution. Alberti's thesis is that these systems and processes cannot be separated, that we should view them as one overarching urban ecosystem whose complexities and interactions cannot be quantified and mapped in the McHargian sense and indeed, to attempt to do so would obscure their likely inherent suite of potential states and relationships. The shift in practice recommended in Belanger and Corners' writings suggest that less rational but more revealing forms of mapping and representation are required to not only visualise the complex systems at work in urban landscapes, but to elicit new and multiple functional associations, systemic mechanisms and cultural meaning ascribed to that landscape.

The understanding of the characteristics, suggested practices and evolution of these theories then underpins the theoretical framework for approaching urban landscapes within the South-West Delta. Multiple, explorative as well as descriptive mapping techniques should be employed, making no distinction between natural, urban, infrastructural and social processes but should seek to understand, uncover and represent relationships and synergies (existing or potential) between system components through spatial and temporal scales. Rather than seeking one optimal state or condition, multiple forms of representation and investigation should be employed to explore the capacity of these relationships and synergies to form new complex, interrelated natural and urban infrastructures and component mechanisms that can improve the resilience of the urban ecosystem as a whole.

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problem summary, territorial

As a body and ecosystem of interacting natural processes, the North Sea is vulnerable to the effects of global warming and climate change such as ocean warming, acidification, oxygen depletion etc.

At the same time these natural ecosystems are under enormous pressure of overuse

The compartmentalisation of the North Sea is at odds with the territorial approach required to address threats that span national boundaries and jurisdictions

Processes of exchange indelibly connect the sea with surrounding terrestrial areas, particularly within the deltas

The delta funtions that operate as fish nursery, sediment source, biotic habitat and generator of biodiversity for the whole of the North Sea are being curtailed

Nutrient imbalances are being exacerbated by agricultural and other waste runoff further damaging habitat and biodiversity indicators

problem summary, regional

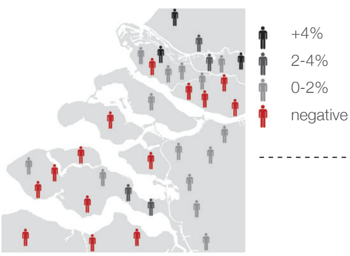
A landscape previously defined by, and deriving its vitality from, change and flux has been fixed and made static with a corresponding decline in natural ecosystem health

Estuarine processes that promote habitat formation and aquatic health are stalling, with attendant adverse impacts on biodiversity

Deltaic communities' connection with their landscape has potentially been lost with a life lived behind protective dikes. These same communities are nevertheless still potentially threatened by increasing sea level rises caused by the effects of climate change

Monofunctional and threatened agricultural landuses dominate the landscapes while providing marginal economic benefit at the expense of likely more sustainable, multi-faceted and profitable landuses (such as recreation and tourism) whose efficacy is restricted by the curtailed estuarine processes

Pop^n growth by municipality, 2011-2016

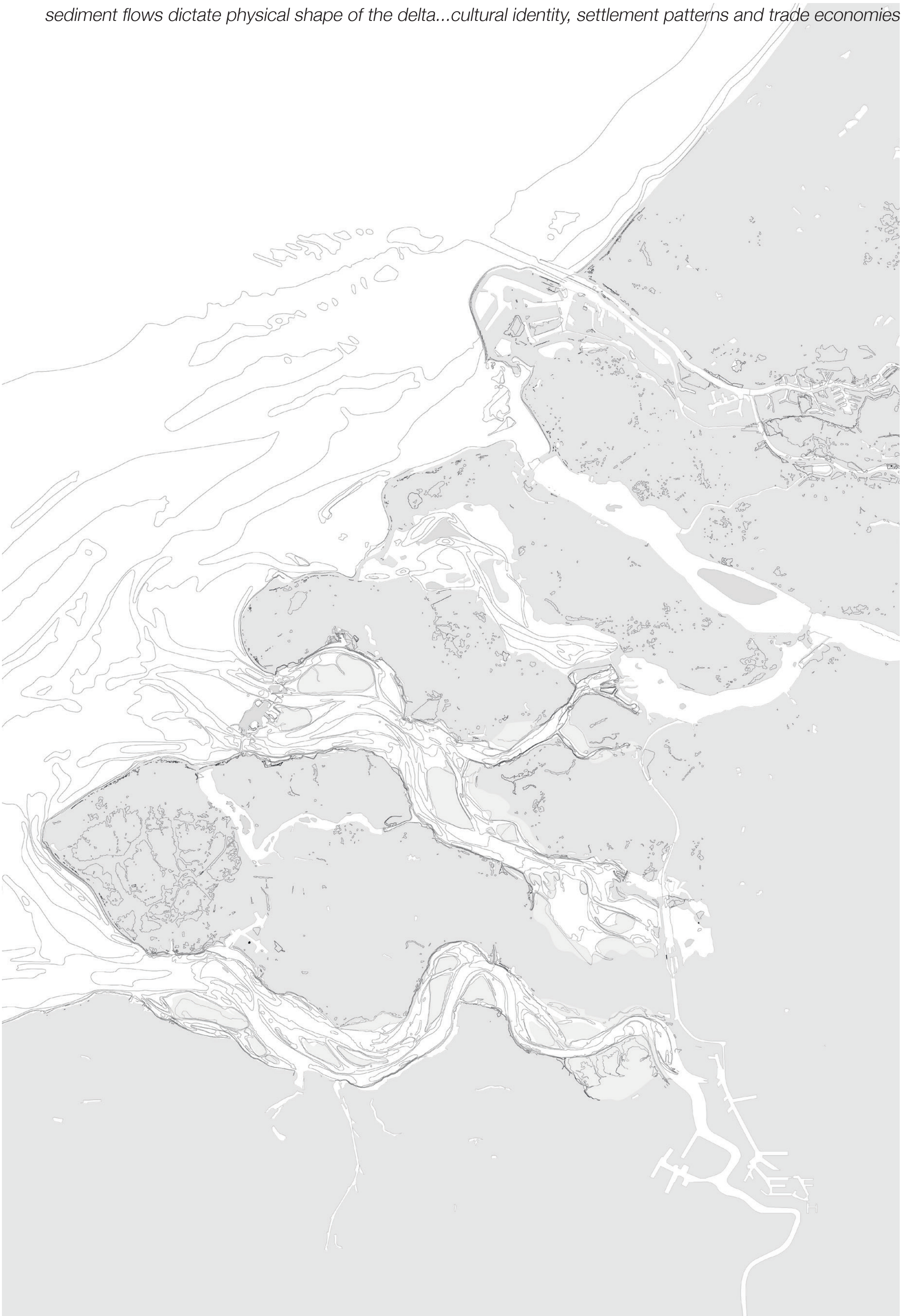


The population of the delta is declining yet is located adjacent to a belt of highly urbanised and prosperous urban areas

In the light of the energy transition, a reliance on petrochemical industries is likely not sustainable


socio-spatial evolution of the Southwest Delta
Source: Google Earth

sediment flows dictate physical shape of the delta...cultural identity, settlement patterns and trade economies



Pre 11th Century, island settlements

Key	A Landscape in Flux

Approx. extents, 12th Century	Oldest settlements, pre 12th C.

n 0 10 20km

Sources: http://www.topotijdreis.nl. H. Hettema (1947), Grote Historisch Schoolatlas. R. Rutte (2013), Four hundred years of urban development in the Scheldt estuary.

Sources: http://www.topotijdreis.nl. H. Hettema (1947), Grote Historisch Schoolatlas. R. Rutte (2013), Four hundred years of urban development in the Scheldt estuary.

Sint-Catherine Day flood, 1490

pre 11th Century

11th Century

12th Century

15th Century

17th Century

18th Century

19th Century

20th Century

present day

source: https://risingwatersrr.wordpress.com/page/13/

16th Century, trading routes shift north and east

Key A Landscape in Flux

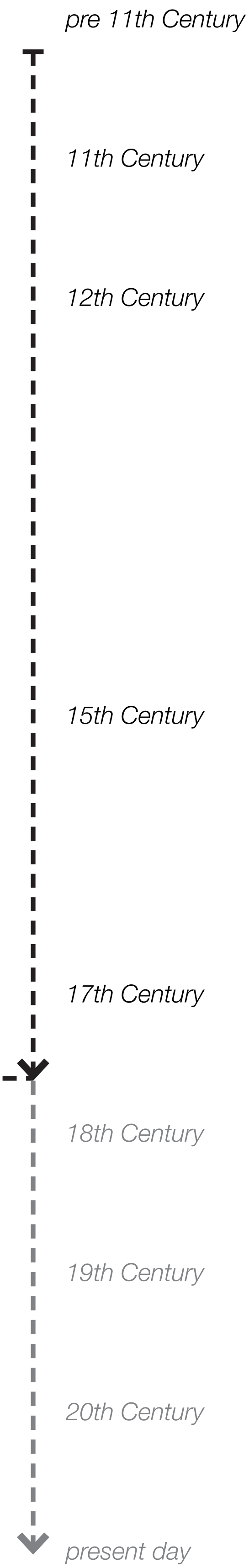
Approx. extents, 12th Century
15th Century

Oldest settlements, pre 12th C.
New ports, 12th to 13th C.
Eastern Scheldt ports, 14th C.

n 0 10 20km

Sources: http://www.topotijdreis.nl. H. Hettema (1947), Grote Historisch Schoolatlas. R. Rutte (2013), Four hundred years of urban development in the Scheldt estuary.

Timber dike construction, c.1705



source: https://repository.tudelft.nl/search/MMP/?q=zeeland

17th Century, Vlissingen prospers as centre of fishing trade, gateway to Antwerp and...

Sources: http://www.topotijdreis.nl. H. Hettema (1947), Grote Historisch Schoolatlas. R. Rutte (2013), Four hundred years of urban development in the Scheldt estuary.

pre 11th Century

Kasteel Rammekes, c.1785

11th Century

12th Century

15th Century

17th Century

18th Century

19th Century

20th Century

present day

source: https://repository.tudelft.nl/search/MMP/?q=zeeland

...18th Century, privateering base while sedimentation processes relegate other ports inland

Key A Landscape in Flux

Approx. extents, 12th Century

15th Century

17th Century

18th Century

Oldest settlements, pre 12th C.

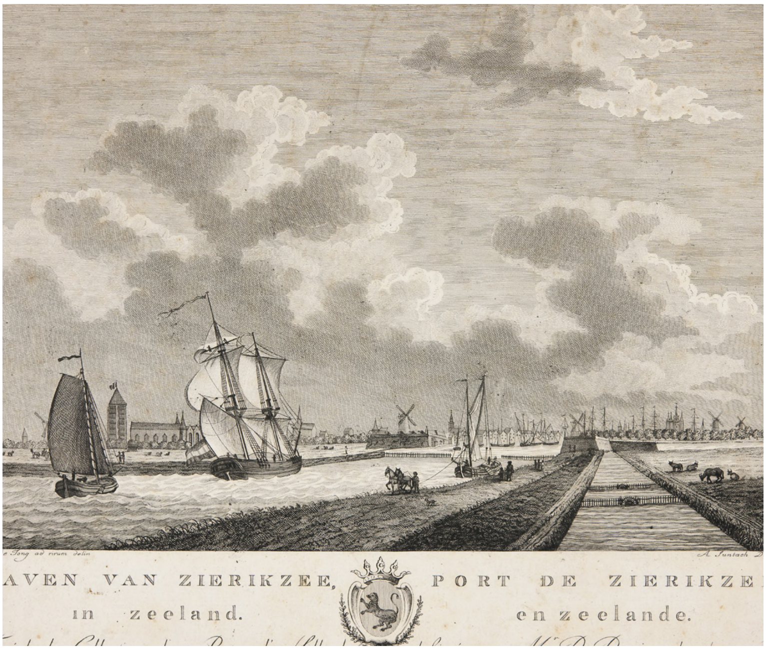
New ports, 12th to 13th C.

Eastern Scheldt ports, 14th C.

n 0 10 20km

Sources: http://www.topotijdreis.nl. H. Hettema (1947), Grote Historisch Schoolatlas. R. Rutte (2013), Four hundred years of urban development in the Scheldt estuary.

Zierikzee harbour canal, c.1825



pre 11th Century

11th Century

12th Century

15th Century

17th Century

18th Century

19th Century

20th Century

present day

source: https://repository.tudelft.nl/search/MMP/?q=zeeland

19th Century, port activities consolidated in Rotterdam and Nieuwe Waterweg redirects river outflows

Key	A Landscape in Flux		
	Approx. extents, 12th Century	●	Oldest settlements, pre 12th C.
	15th Century	○	New ports, 12th to 13th C.
	17th Century	●	Eastern Scheldt ports, 14th C.
	18th Century		
	19th Century		

n 0 10 20km

Sources: http://www.topotijdreis.nl. H. Hettema (1947), Grote Historisch Schoolatlas. R. Rutte (2013), Four hundred years of urban development in the Scheldt estuary.

pre 11th Century

Dreischor in flood, 1953

11th Century

12th Century

15th Century

17th Century

18th Century

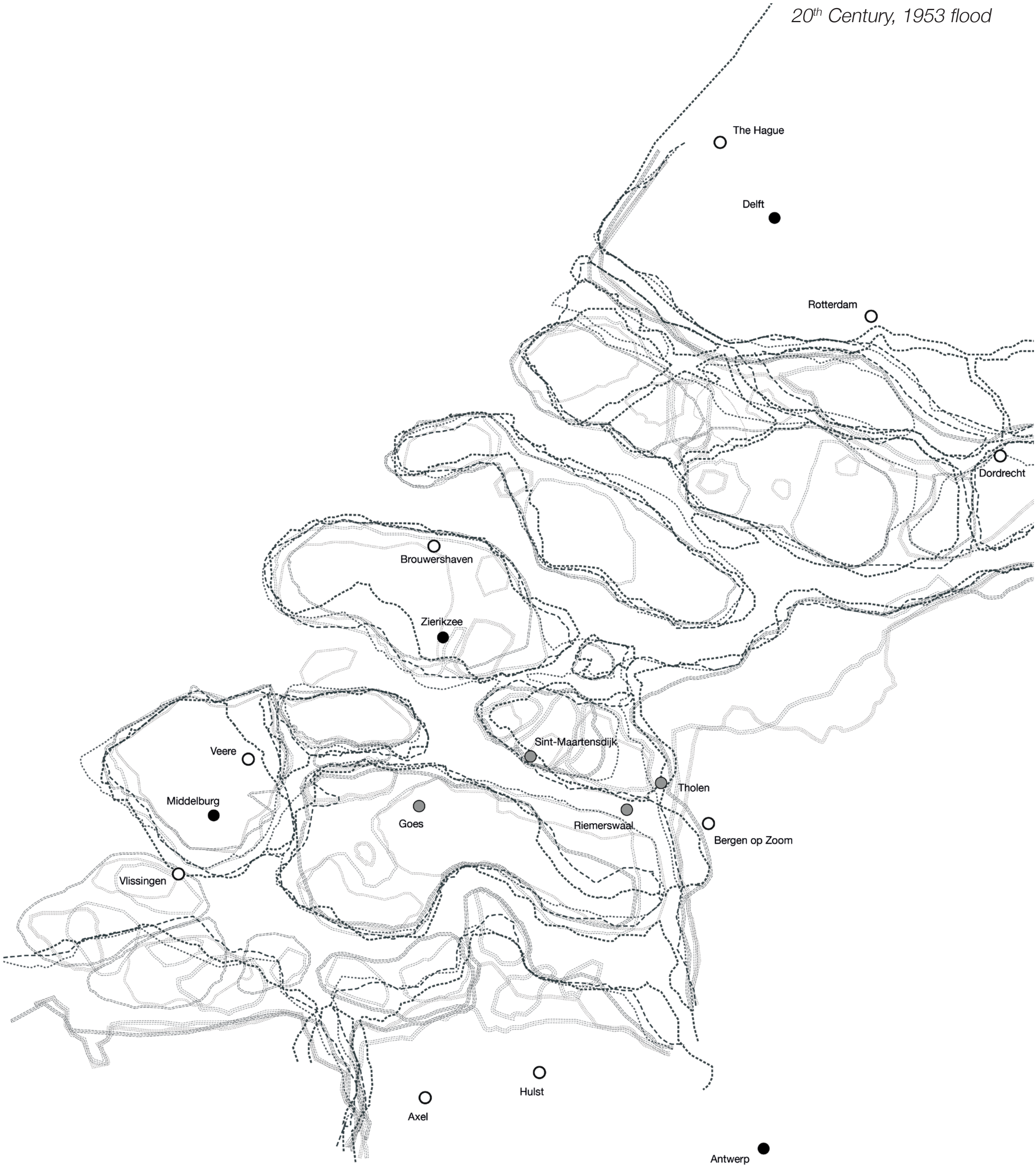
19th Century

20th Century

present day

source: https://www.entoen.nu/nl/watersnood

20th Century, 1953 flood



Key
A Landscape in Flux

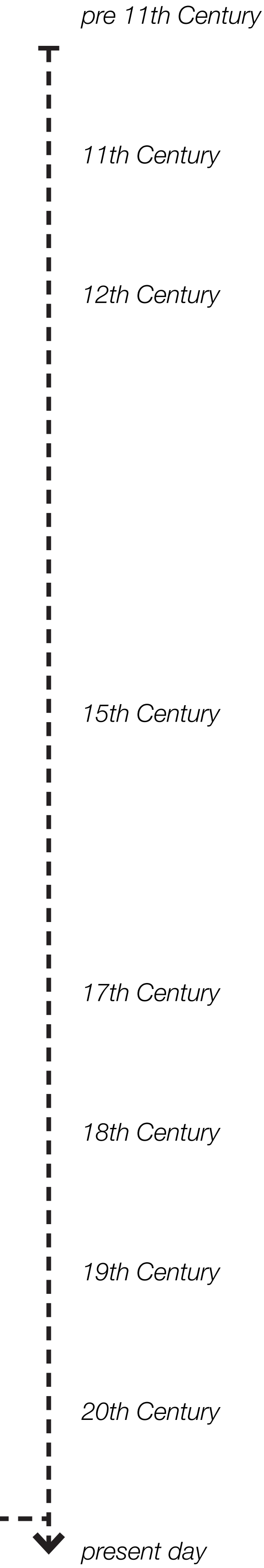
Approx. extents, 12th Century
15th Century
17th Century
18th Century
19th Century
Mid 20th Century

Oldest settlements, pre 12th C.
New ports, 12th to 13th C.
Eastern Scheldt ports, 14th C.

n 0 10 20km

Sources: http://www.topotijdreis.nl. H. Hettema (1947), Grote Historisch Schoolatlas. R. Rutte (2013), Four hundred years of urban development in the Scheldt estuary.

Modern life behind the dikes, Edwin Zwakman



source: http://www.edwinzwakman.nl/suburb-3.htm

Present day, Deltaworks fix a landscape historically defined by flux

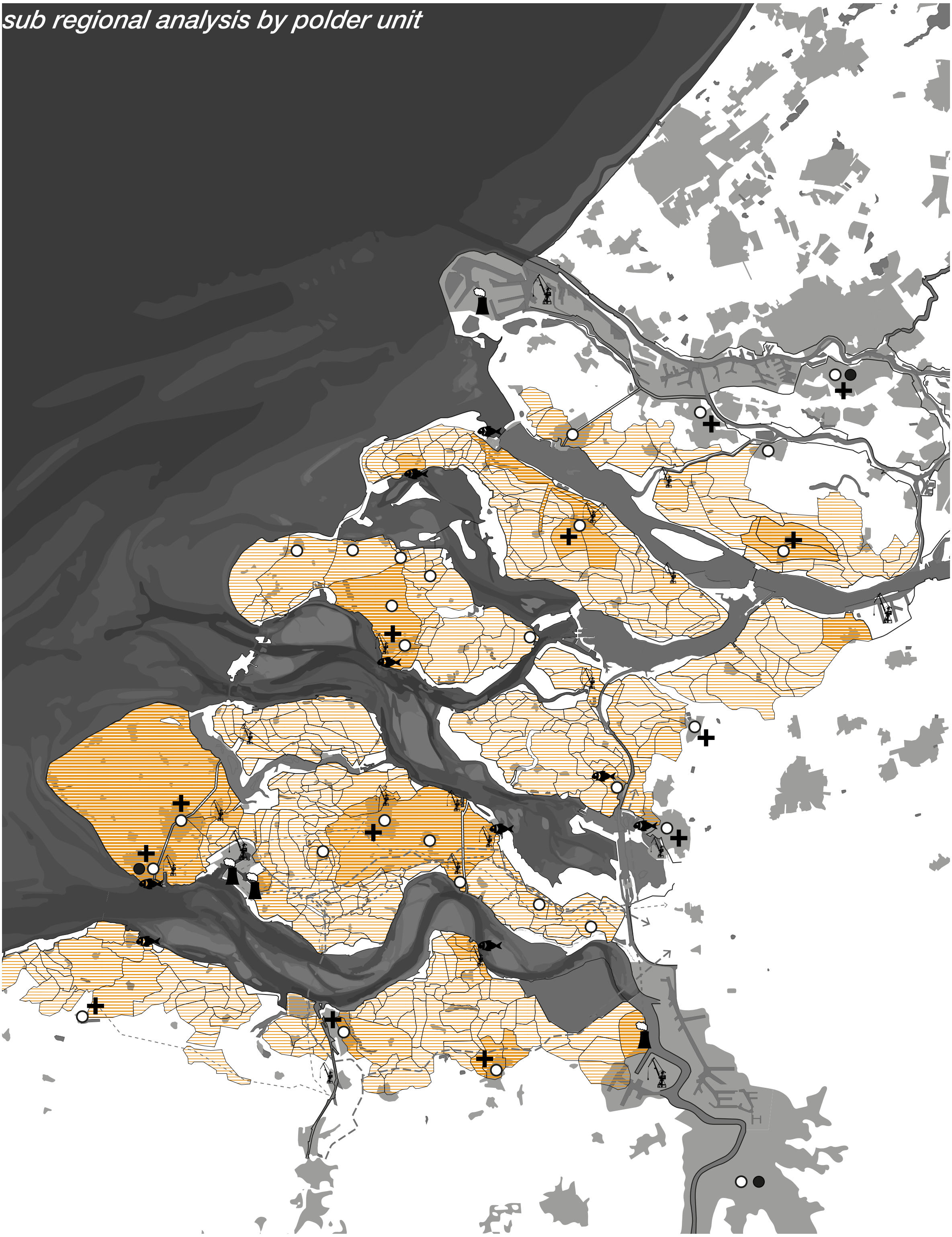
Key — A Landscape in Flux

- Approx. extents, 12th Century
- 15th Century
- 17th Century
- 18th Century
- 19th Century
- Mid 20th Century

- Oldest settlements, pre 12th C.
- New ports, 12th to 13th C.
- Eastern Scheldt ports, 14th C.

n | 0 | 10 | 20km

Sources: http://www.topotijdreis.nl. H. Hettema (1947), Grote Historisch Schoolatlas. R. Rutte (2013), Four hundred years of urban development in the Scheldt estuary.

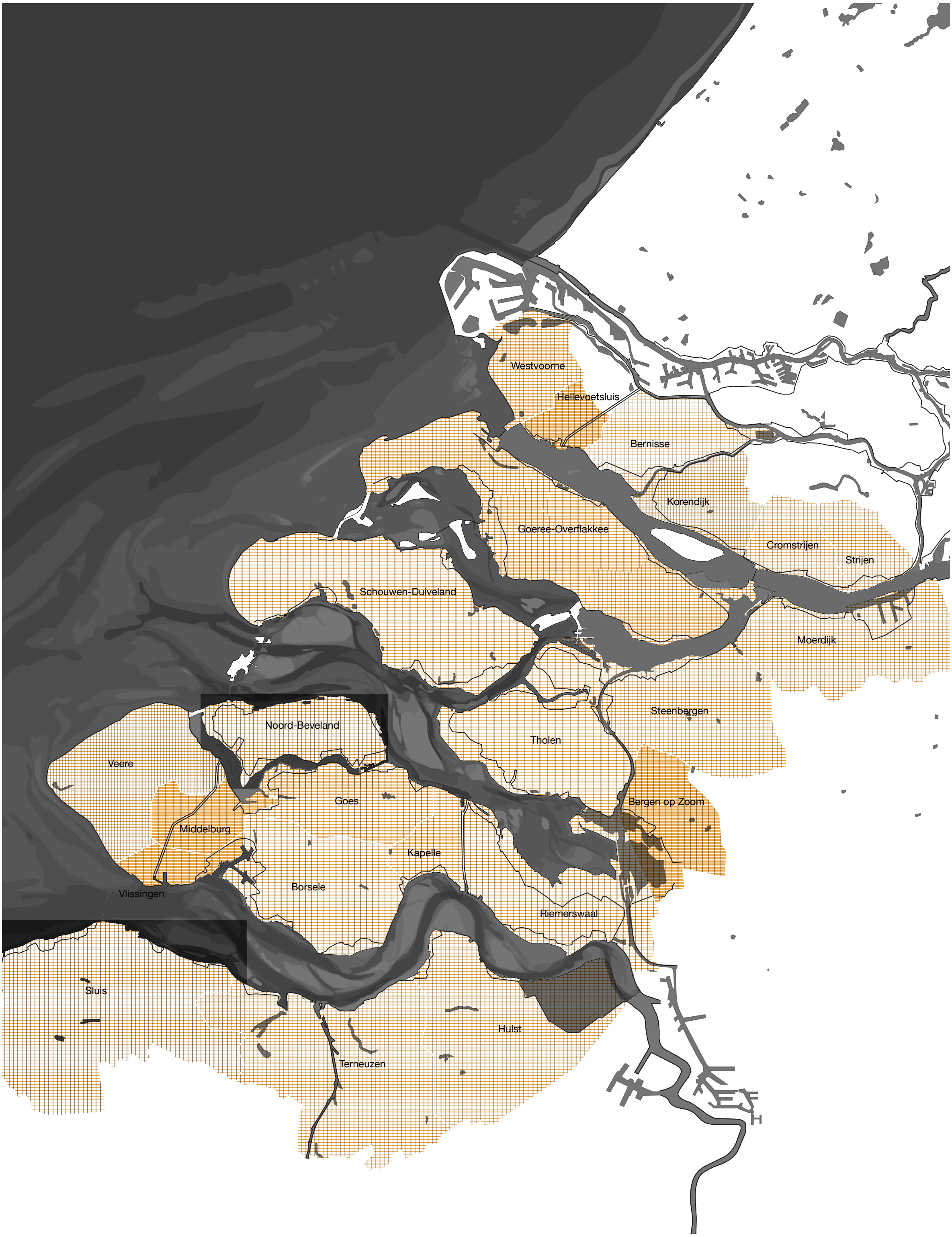


Key
Critical and social infrastructure
High schools and univertities
Power stations
Fishing ports
Hospital
Commercial and industrial port
Pipelines and HV cables (380/150kV)

Highly serviced (or critical)
Moderately serviced
Poorly serviced
Very poorly serviced
Urbanised areas

n 0 10 20km

Source: www.googlemaps.com. TUDelft Kaartenkamer. H. Meyer Et. Al. (2015), New perspectives on urbanizing deltas. Omgevingsplan Zeeland, 2010-2018



Key Population demographics by municipality

Population growth, 2010-2025

Growth (2.5% to 10%)

Relatively stable (-2.5% to 2.5%)

Decline (-10% to -2.5%)

Strong decline (-10% or less)

Population density, inhabitants/km^2

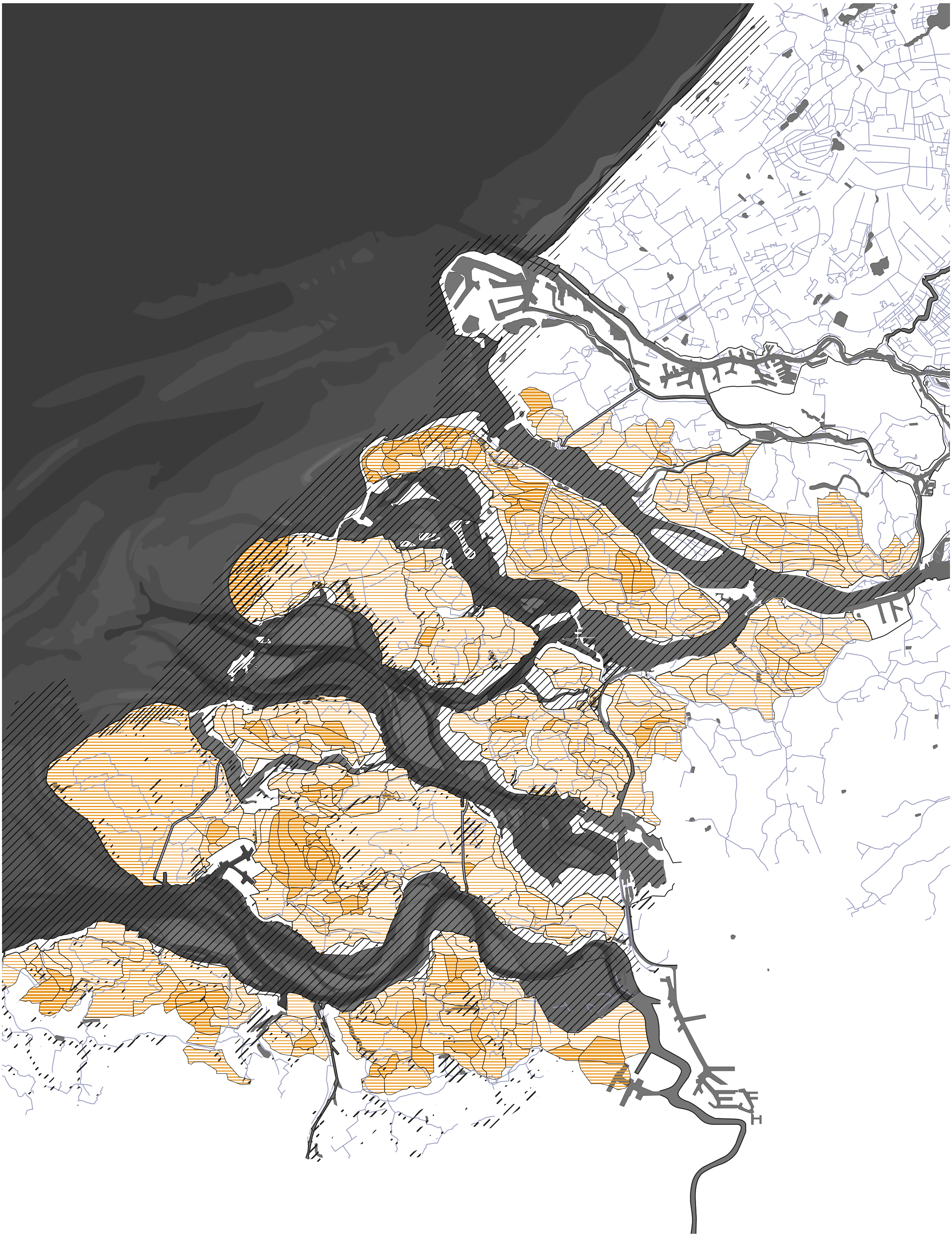
Highest (over 950/km^2)

Moderate (250-950/km^2)

Low (100-250/km^2)

Very low (below 100/km^2)

Source: Population densities from www.statline.cbs.nl. Population projections from www.pbl.nl/node/56032.



Key Natural values and access to water

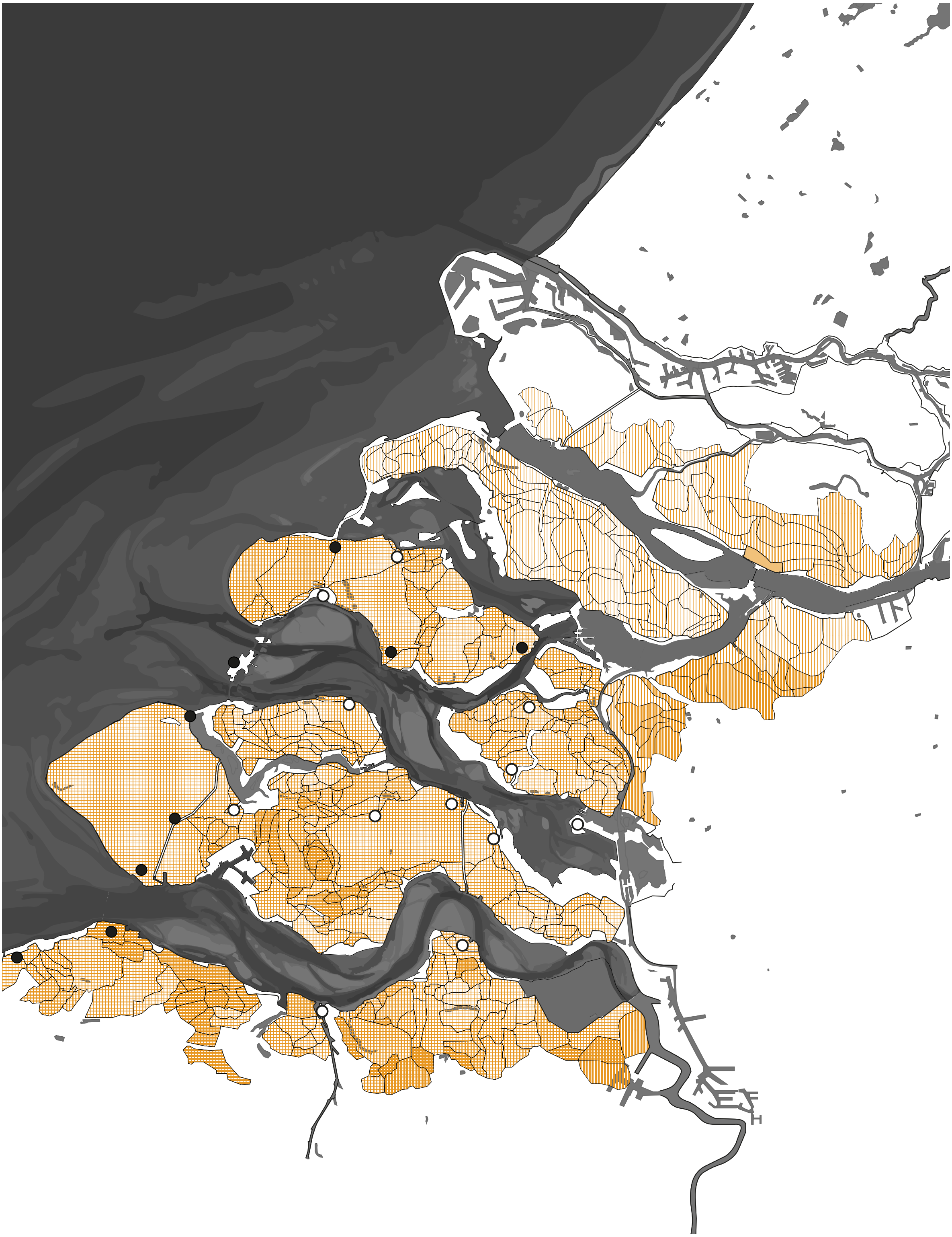
Landuse and hydrology
- Natura 2000 designation
- Ecologische hoofdstructuur (EHS)
- Waterways

Proximity to water
- Minimal connection to waterways or natural areas
- Adjacent to inland waterways
- Adjacent to estuarine connections
- Adjacent to estuarine areas

n 0 10 20km

Source: Omgevingsplan Zeeland, 2010-2018.

Polder proximity to water and natural areas



Key

Landuse indicators

Costs of development (Zeeland only)

- Low
- Normal
- High
- Very high
- Tourist hotspot/ regional devt. significance

Soil salinity levels

- No soil salinity issues
- Mostly moderate (15 m-hv to 50 m-hv)
- Areas of both high and moderate salinity
- Mostly high (0 m-hv to 15 m-hv)

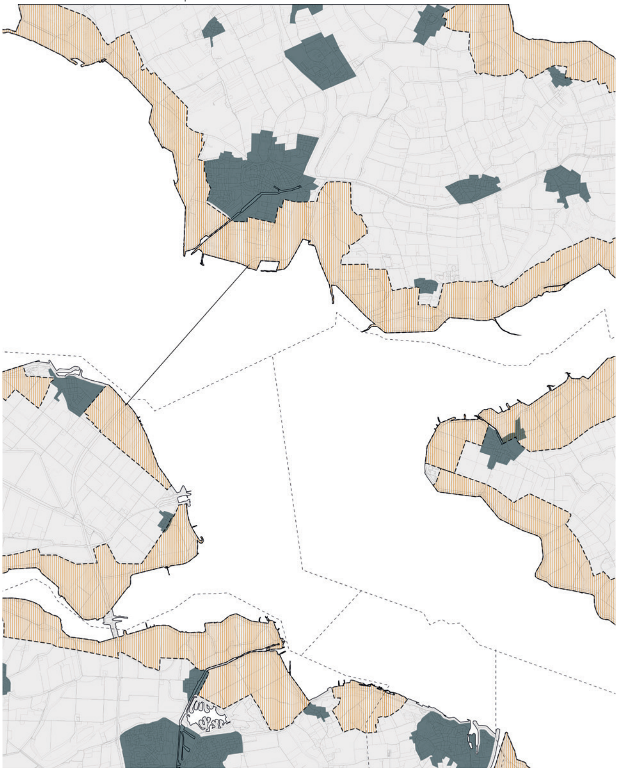
n 0 10 20km

Source: Soil salinity from H. Meyer Et. Al. (2015), New perspectives on urbanizing deltas. Devt. costs and tourism info from Omgevingsplan Zeeland, 2010-2018.

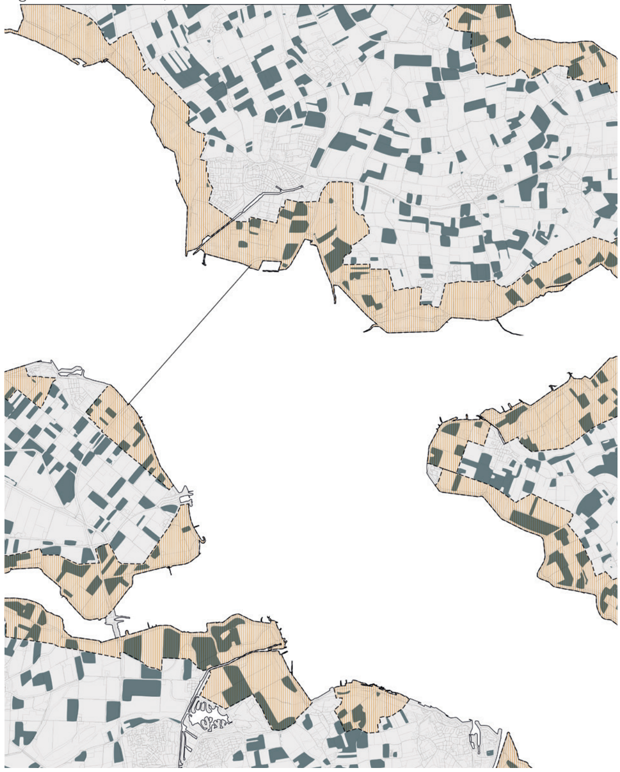
sub regional landuse

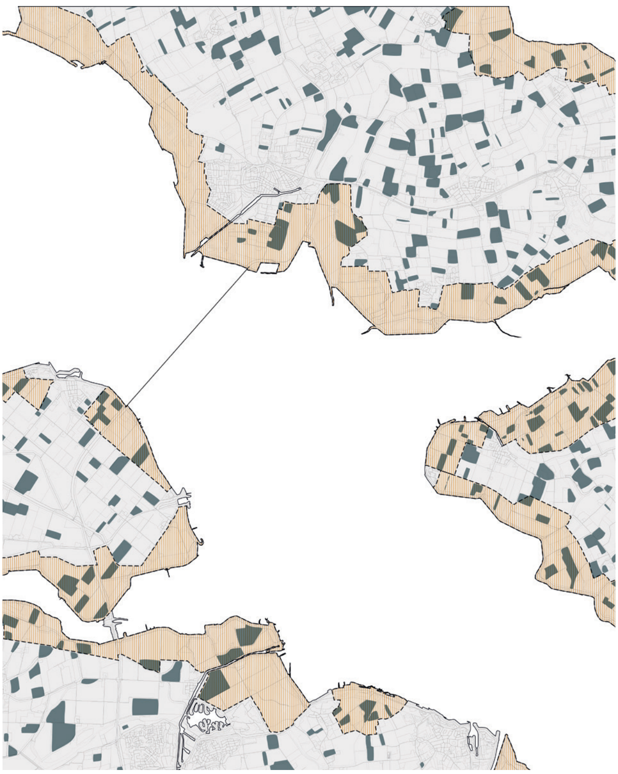
Landuse patternation with depoldered areas

Urban landuse with depoldered areas

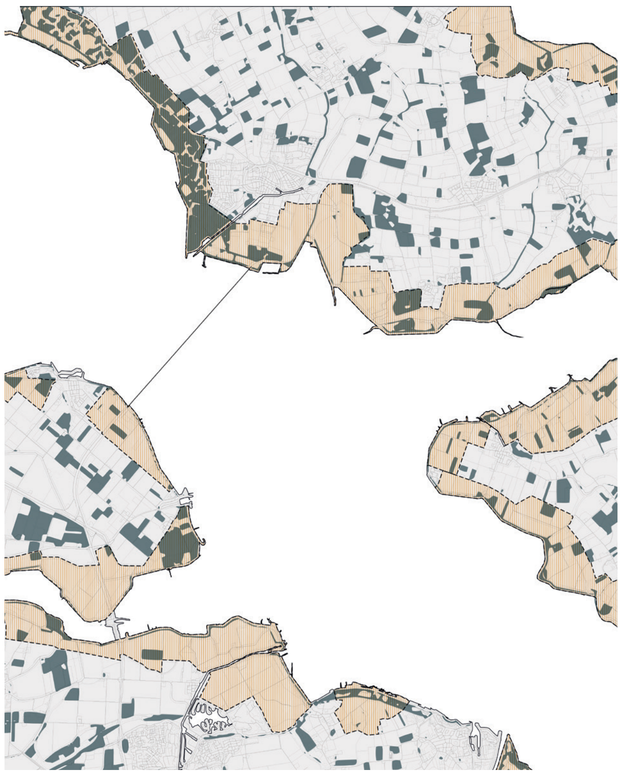


Agricultural landuse, cereals



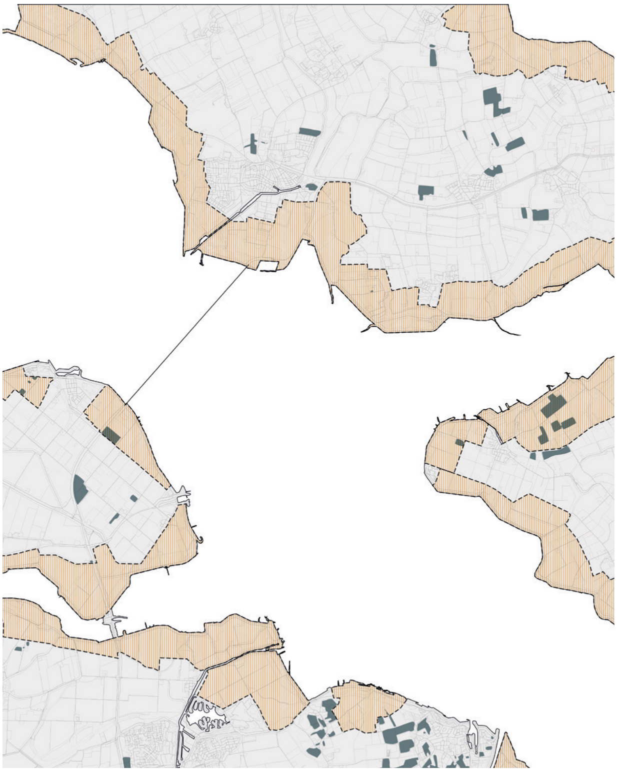


Potatoes

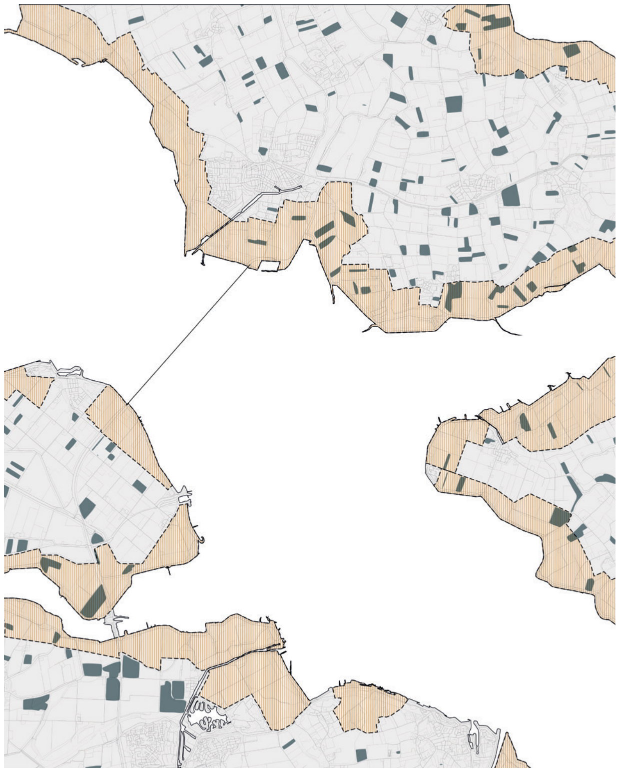


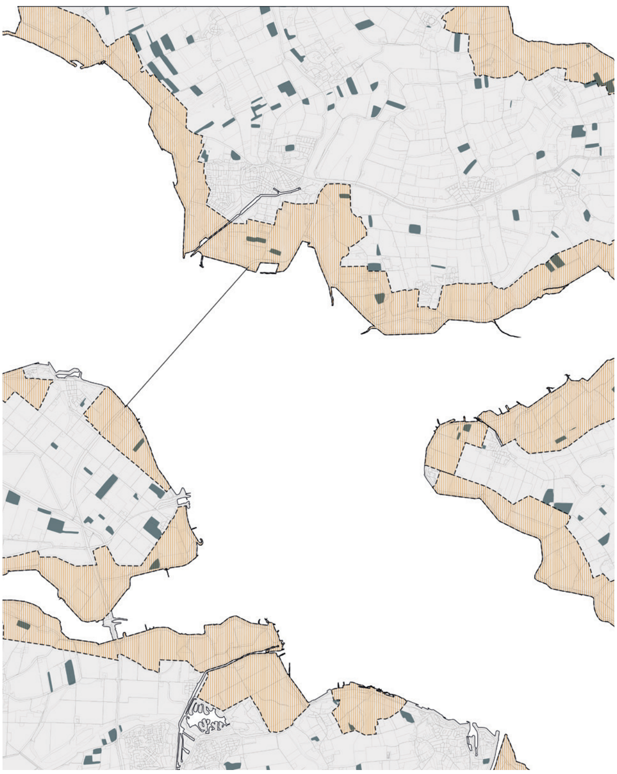
Grassland

Fruit

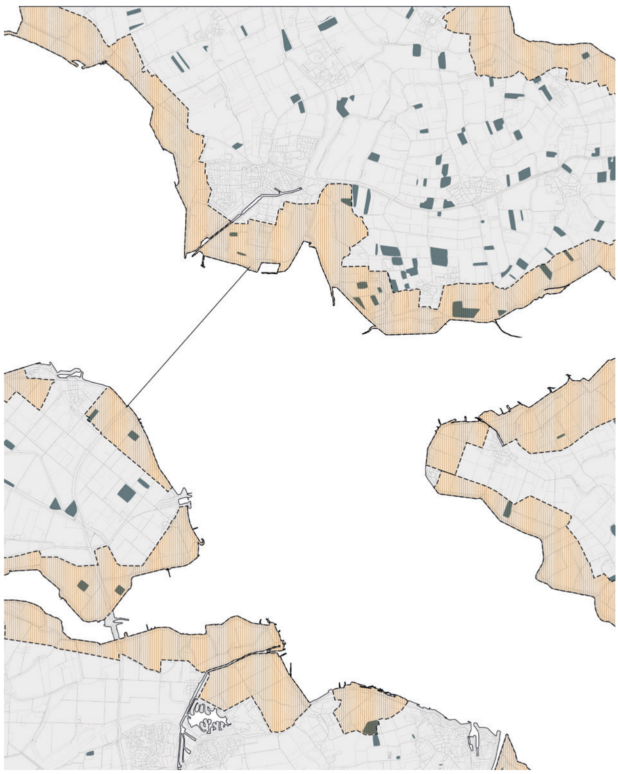


Onions





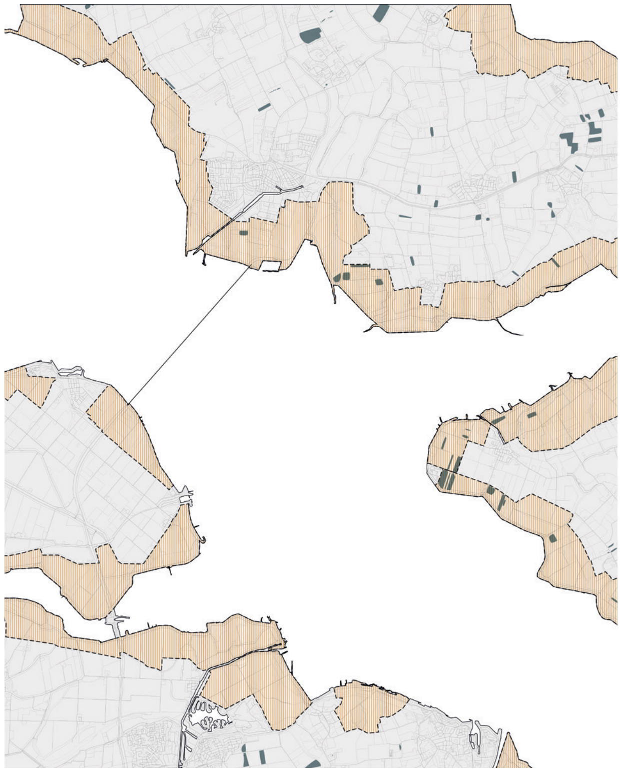
Corn

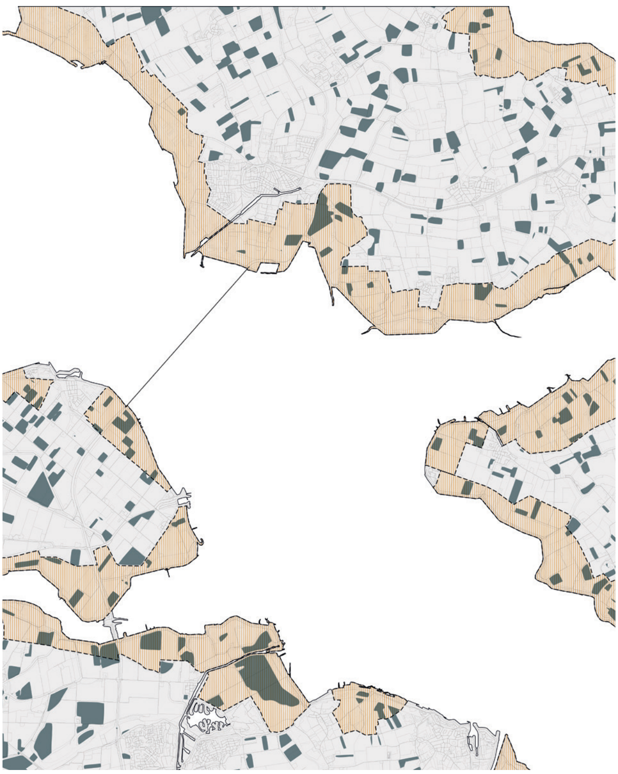


Vegetables

Legumes

Flowers and seeds





Remaining landuse

sub regional statistical data

SUB REGIONAL STATISTICS EXTRACTED FROM http://pdokviewer.pdok.nl/

e_code	BK01512							
Core_name	Kats	BK01473		BK01421		BK01454		BK01431
Prov_code	PV29	Core_name	Colijnsplaat	Kern_naam	Zierikzee	Kern_naam	Ouwerkerk	Core_name
Bkgr_code	BKGR01	Prov_code	PV29	Prov_code	PV29	Prov_code	PV29	Prov_code
X_gba	50864	Bkgr_code	BKGR03	Bkgr_code	BKGR06	Bkgr_code	BKGR01	Bkgr_code
Y_gba	398761	X_gba	48437	X_gba	53058	X_gba	57745	X_gba
popn centres	1	Y_gba	402170	Y_gba	407863	Y_gba	405035	Y_gba
popn total	285	Numbers01	1	Aantkern01	1	Aantkern01	1	Numbers01
Gemlft	44	Bev11tot	1350	Bev11tot	10435	Bev11tot	430	Bev11tot
Bev_t0_14	35	Gemlft	46	Gemlft	44	Gemlft	45	Gemlft
Bev_t15_24	25	Bev_t0_14	200	Bev_t0_14	1600	Bev_t0_14	60	Bev_t0_14
Bev_t25_44	75	Bev_t15_24	105	Bev_t15_24	1045	Bev_t15_24	35	Bev_t15_24
Bev_t45_64	100	Bev_t25_44	335	Bev_t25_44	2495	Bev_t25_44	110	Bev_t25_44
popn working age	200		640		5140		205	
unempl by municip %of popn over 15 not working at end of 2011???		42%		42%		41%		41%
Bev_t65pl	55	Bev_t45_64	380	Bev_t45_64	3130	Bev_t45_64	135	Bev_t45_64
Bev_man	150	Bev_t65pl	330	Bev_t65pl	2165	Bev_t65pl	90	Bev_t65pl
Bev_vrw	135	Bev_man	655	Bev_man	5035	Bev_man	215	Bev_man
# in households tot	285	Bev_vrw	695	Bev_vrw	5400	Bev_vrw	215	Bev_vrw
Ppart0_14	35	Ppart_tot	1265	Ppart_tot	10125	Ppart_tot	430	Ppart_tot
Ppart15_24	25	Ppart0_14	200	Ppart0_14	1600	Ppart0_14	60	Ppart0_14
Ppart25_44	75	Ppart15_24	105	Ppart15_24	1035	Ppart15_24	35	Ppart15_24
Ppart45_64	100	Ppart25_44	335	Ppart25_44	2465	Ppart25_44	110	Ppart25_44
Ppart65pl	55	Ppart45_64	380	Ppart45_64	3085	Ppart45_64	135	Ppart45_64
Up to_a	55	Ppart65pl	245	Ppart65pl	1940	Ppart65pl	90	Ppart65pl
single person households15_24	0	Up to_a	240	Tot_eenp	1685	Tot_eenp	55	Up to_a
Eenp25_44	15	Eenp15_24	5	Eenp15_24	65	Eenp15_24	0	Eenp15_24
Eenp45_64	25	Eenp25_44	65	Eenp25_44	450	Eenp25_44	15	Eenp25_44
Eenp65pl	15	Eenp45_64	85	Eenp45_64	490	Eenp45_64	15	Eenp45_64
Tot_multi person households w kid:	105	Eenp65pl	85	Eenp65pl	675	Eenp65pl	25	Eenp65pl
Mp_mk0_14	35	Tot_mp_mk	625	Tot_mp_mk	5250	Tot_mp_mk	230	Tot_mp_mk
Mp_mk15_24	15	Mp_mk0_14	200	Mp_mk0_14	1585	Mp_mk0_14	60	Mp_mk0_14
Mp_mk25_44	30	Mp_mk15_24	95	Mp_mk15_24	860	Mp_mk15_24	30	Mp_mk15_24
Mp_mk45_64	25	Mp_mk25_44	205	Mp_mk25_44	1525	Mp_mk25_44	80	Mp_mk25_44
Mp_mk65pl	0	Mp_mk45_64	120	Mp_mk45_64	1210	Mp_mk45_64	50	Mp_mk45_64
Tot_multi person households no kic	120	Mp_mk65pl	10	Mp_mk65pl	70	Mp_mk65pl	10	Mp_mk65pl
Mp_zk0_14	0	Tot_mp_zk	400	Tot_mp_zk	3190	Tot_mp_zk	145	Tot_mp_zk
Mp_zk15_24	5	Mp_zk0_14	0	Mp_zk0_14	10	Mp_zk0_14	0	Mp_zk0_14
Mp_zk25_44	30	Mp_zk15_24	10	Mp_zk15_24	110	Mp_zk15_24	5	Mp_zk15_24
Mp_zk45_64	50	Mp_zk25_44	65	Mp_zk25_44	490	Mp_zk25_44	20	Mp_zk25_44
Mp_zk65pl	35	Mp_zk45_64	175	Mp_zk45_64	1385	Mp_zk45_64	65	Mp_zk45_64
Tot_ongeh	45	Mp_zk65pl	150	Mp_zk65pl	1190	Mp_zk65pl	55	Mp_zk65pl
Tot_ong_mk	15	Tot_ongeh	190	Tot_ongeh	1290	Tot_ongeh	65	Tot_ongeh
Tot_ong_zk	35	Tot_ong_mk	115	Tot_ong_mk	705	Tot_ong_mk	35	Tot_ong_mk
Until married	155	Tot_ong_zk	80	Tot_ong_zk	585	Tot_ong_zk	30	Tot_ong_zk
Tot_geh_mk	70	Until married	755	Tot_gehuwd	6335	Tot_gehuwd	285	Until married
Tot_geh_zk	85	Tot_geh_mk	435	Tot_geh_mk	3760	Tot_geh_mk	170	Tot_geh_mk
Up to one	20	Tot_geh_zk	320	Tot_geh_zk	2570	Tot_geh_zk	115	Tot_geh_zk
Tot_samenw	5	Up to one	80	Tot_eenoud	780	Tot_eenoud	25	Up to one
Tot_instit	0	Tot_samenw	0	Tot_samenw	35	Tot_samenw	0	Tot_samenw
Kn_autoch	265	Tot_instit	85	Tot_instit	310	Tot_instit	0	Tot_instit
Kn_allo_w	15	Kn_autoch	1190	Kn_autoch	9355	Kn_autoch	395	Kn_autoch
Kn_allo_nw	5	Kn_allo_w	120	Kn_allo_w	735	Kn_allo_w	35	Kn_allo_w
P_lagopl15	-99999	Kn_allo_nw	40	Kn_allo_nw	350	Kn_allo_nw	0	Kn_allo_nw
P_midopl15	-99999	P_lagopl15	-99999	P_lagopl15	43	P_lagopl15	-99999	P_lagopl15
P_hogopl15	-99999	P_midopl15	-99999	P_midopl15	40	P_midopl15	-99999	P_midopl15
working popn_15-24	8	P_hogopl15	-99999	P_hogopl15	18	P_hogopl15	-99999	P_hogopl15
P_wbv_25-44	29	P_wbv_1524	9	P_wbv_1524	11	P_wbv_1524	6	P_wbv_1524
P_wbv_45-54	43	P_wbv_2544	31	P_wbv_2544	30	P_wbv_2544	29	P_wbv_2544
P_wbv_55-64	16	P_wbv_4554	40	P_wbv_4554	41	P_wbv_4554	42	P_wbv_4554
P_wbv_65-74	4	P_wbv_5564	18	P_wbv_5564	17	P_wbv_5564	21	P_wbv_5564
% employed by industry								
Agriculture, forestry and fishing	1	P_wbv_6574	2	P_wbv_6574	1	P_wbv_6574	2	P_wbv_6574
industry %	19	P_wrk_lndb	2	P_wrk_lndb	1	P_wrk_lndb	2	P_wrk_lndb
Commercial services	33	P_wrk_nijv	23	P_wrk_nijv	21	P_wrk_nijv	22	P_wrk_nijv
non Commercial services	32	P_wrk_cmd	29	P_wrk_cmd	31	P_wrk_cmd	38	P_wrk_cmd
Other	12	P_wrk_ncmd	31	P_wrk_ncmd	31	P_wrk_ncmd	26	P_wrk_ncmd
unknown	3	P_wrk_ov	13	P_wrk_ov	14	P_wrk_ov	12	P_wrk_ov
Bev01tot	300	P_wrk_onb	2	P_wrk_onb	2	P_wrk_onb	1	P_wrk_onb
Balance_bin	-15	Bev01tot	1280	Bev01tot	10380	Bev01tot	455	Bev01tot
Balance_bout	0	Balance_bin	170	Saldo_bin	495	Saldo_bin	-30	Balance_bin
Tothh_eenp	55	Balance_bout	25	Saldo_buit	115	Saldo_buit	-5	Balance_bout
Tothh_mpmk	30	Tothh_eenp	240	Tothh_eenp	1685	Tothh_eenp	55	Tothh_eenp
Tothh_mpzk	60	Tothh_mpmk	175	Tothh_mpmk	1490	Tothh_mpmk	70	Tothh_mpmk
Tothh_t	150	Tothh_mpzk	200	Tothh_mpzk	1590	Tothh_mpzk	75	Tothh_mpzk
Tothh_1	55	Tothh_t	615	Tothh_t	4760	Tothh_t	200	Tothh_t
Tothh_2	70	Tothh_1	240	Tothh_1	1690	Tothh_1	55	Tothh_1
Tothh_3	10	Tothh_2	215	Tothh_2	1755	Tothh_2	85	Tothh_2
Tothh_4	10	Tothh_3	65	Tothh_3	580	Tothh_3	25	Tothh_3
Tothh_5	0	Tothh_4	75	Tothh_4	560	Tothh_4	25	Tothh_4
Tothh_6pl	0	Tothh_5	15	Tothh_5	145	Tothh_5	5	Tothh_5
House11	170	Tothh_6pl	5	Tothh_6pl	35	Tothh_6pl	0	Tothh_6pl
Housing01	170	House11	720	Woning11	4830	Woning11	205	House11
Won_prc_e	81	Housing01	700	Woning01	4320	Woning01	200	Housing01
Won_prc_h	19	Won_prc_e	65	Won_prc_e	52	Won_prc_e	71	Won_prc_e
Won_prc_o	0	Won_prc_h	34	Won_prc_h	46	Won_prc_h	29	Won_prc_h
Won_bez_t	1.9	Won_prc_o	1	Won_prc_o	3	Won_prc_o	0	Won_prc_o
Won_bez_e	2	Won_bez_t	2.1	Won_bez_t	2.1	Won_bez_t	2.2	Won_bez_t
Won_bez_h	1.7	Won_bez_e	2.2	Won_bez_e	2.4	Won_bez_e	2.4	Won_bez_e
Won_woz_t	171000	Won_bez_h	1.8	Won_bez_h	1.8	Won_bez_h	1.7	Won_bez_h
Won_woz_e	175000	Won_woz_t	167000	Won_woz_t	199000	Won_woz_t	218000	Won_woz_t
Won_woz_h	158000	Won_woz_e	190000	Won_woz_e	243000	Won_woz_e	242000	Won_woz_e
Living unit	0	Won_woz_h	131000	Won_woz_h	148000	Won_woz_h	161000	Won_woz_h
Recrwon	0	Living unit	0	Wooneenh	15	Wooneenh	0	Living unit
Distance to GP	5.3	Recrwon	0	Recrwon	20	Recrwon	0	Recrwon
Av5_haprak	0	Afs_haprak	0.4	Afs_haprak	0.7	Afs_haprak	4.1	Afs_haprak
Afs_hapost	12	Av5_haprak	1	Av5_haprak	4	Av5_haprak	1	Av5_haprak
Distance to hospital	12	Afs_hapost	12.3	Afs_hapost	1.7	Afs_hapost	6.5	Afs_hapost
Afs_apoth	5.3	Afs_ziekhs	12.3	Afs_ziekhs	1.7	Afs_ziekhs	6.5	Afs_ziekhs
Afs_bsop	0.2	Afs_apoth	0.4	Afs_apoth	1.1	Afs_apoth	4.1	Afs_apoth
Afs_kdvblf	0.2	Afs_bsop	0.4	Afs_bsop	0.6	Afs_bsop	0.2	Afs_bsop
Afs_basond	0.2	Afs_kdvblf	0.4	Afs_kdvblf	0.5	Afs_kdvblf	3.9	Afs_kdvblf
Afs_vmbo	9.1	Afs_basond	0.4	Afs_basond	0.5	Afs_basond	0.2	Afs_basond
Afs_havwo	9.1	Afs_vmbo	12.4	Afs_vmbo	1.3	Afs_vmbo	7.8	Afs_vmbo
Distance to large supermarket	5.4	Afs_havwo	12.4	Afs_havwo	1.3	Afs_havwo	7.8	Afs_havwo
Distance to shops other daily foods	5.3	Afs_super	0.4	Afs_super	0.7	Afs_super	3.8	Afs_super
Number of stores other daily foods	0	Afs_ovlevm	0.4	Afs_ovlevm	0.7	Afs_ovlevm	0.2	Afs_ovlevm
Distance to the main road	2.3	Av5_ovlevm	3	Av5_ovlevm	19.3	Av5_ovlevm	4.1	Av5_ovlevm
Opptot	8	Afs_oprit	2.2	Afs_oprit	1	Afs_oprit	2.3	Afs_oprit
Land area 2010 ha	8	Opptot	41	Opptot	378	Opptot	15	Opptot
surface water area 2010 ha	0	Landn	41	Landn	367	Landn	15	Landn
density in addresses per square kil	71	Watern	0	Water	11	Water	0	Water
Sted	non urban, less th:	Oad	258	Oad	1051	Oad	108	Oad
Geom_valid	TRUE	Sted	non urban, less th:	Sted	Moderately urban	Sted	non urban, less th:	Sted
		Geom_valid	TRUE	Geom_valid	TRUE	Geom_valid	TRUE	Geom_valid

	BK01429		BK01495		BK01574		BK01564		
Nieuwerkerk	Core_name	Oosterland (Z.)	Core_name	Stavenisse	Kern_naam	Wemeldinge	Core_name	Goes / Kloetinge	
PV29	Prov_code	PV29	Prov_code	PV29	Prov_code	PV29	Prov_code	PV29	
BKGR04	Bkgr_code	BKGR03	Bkgr_code	BKGR03	Bkgr_code	BKGR04	Bkgr_code	BKGR07	
59085	X_gba	61536	X_gba	59771	X_gba	58477	X_gba	51298	
407643	Y_gba	407721	Y_gba	400549	Y_gba	392957	Y_gba	391616	
1	Numbers01	1	Numbers01	1	Aantkern01	1	Numbers01	1	
2360	Bev11tot	1930	Bev11tot	1250	Bev11tot	2710	Bev11tot	29795	50545
39	Gemlft	39	Gemlft	39	Gemlft	41	Gemlft	43	
495	Bev_t0_14	380	Bev_t0_14	265	Bev_t0_14	480	Bev_t0_14	4590	8105
260	Bev_t15_24	270	Bev_t15_24	185	Bev_t15_24	240	Bev_t15_24	3285	
595	Bev_t25_44	465	Bev_t25_44	255	Bev_t25_44	715	Bev_t25_44	7350	
1350		1115		705		1435		15225	
	41%		41%		39%		34%		41%
605	Bev_t45_64	475	Bev_t45_64	325	Bev_t45_64	785	Bev_t45_64	8560	
405	Bev_t65pl	340	Bev_t65pl	220	Bev_t65pl	490	Bev_t65pl	6005	
1185	Bev_man	995	Bev_man	610	Bev_man	1350	Bev_man	14445	
1175	Bev_vrw	935	Bev_vrw	640	Bev_vrw	1360	Bev_vrw	15350	
2360	Ppart_tot	1930	Ppart_tot	1250	Ppart_tot	2690	Ppart_tot	28955	
495	Ppart0_14	380	Ppart0_14	265	Ppart0_14	480	Ppart0_14	4585	
260	Ppart15_24	270	Ppart15_24	185	Ppart15_24	230	Ppart15_24	3265	
595	Ppart25_44	465	Ppart25_44	255	Ppart25_44	705	Ppart25_44	7255	
605	Ppart45_64	475	Ppart45_64	325	Ppart45_64	780	Ppart45_64	8385	
405	Ppart65pl	340	Ppart65pl	220	Ppart65pl	490	Ppart65pl	5465	
260	Up to_a	200	Up to_a	135	Tot_eenp	340	Up to_a	5265	
10	Eenp15_24	5	Eenp15_24	5	Eenp15_24	10	Eenp15_24	365	
60	Eenp25_44	55	Eenp25_44	25	Eenp25_44	95	Eenp25_44	1550	
60	Eenp45_64	40	Eenp45_64	40	Eenp45_64	80	Eenp45_64	1400	
135	Eenp65pl	100	Eenp65pl	65	Eenp65pl	150	Eenp65pl	1950	
1450	Tot_mp_mk	1225	Tot_mp_mk	770	Tot_mp_mk	1470	Tot_mp_mk	15020	
490	Mp_mk0_14	370	Mp_mk0_14	265	Mp_mk0_14	480	Mp_mk0_14	4565	
230	Mp_mk15_24	235	Mp_mk15_24	160	Mp_mk15_24	195	Mp_mk15_24	2565	
435	Mp_mk25_44	340	Mp_mk25_44	195	Mp_mk25_44	460	Mp_mk25_44	4270	
280	Mp_mk45_64	240	Mp_mk45_64	135	Mp_mk45_64	310	Mp_mk45_64	3405	
15	Mp_mk65pl	35	Mp_mk65pl	15	Mp_mk65pl	25	Mp_mk65pl	215	
645	Tot_mp_zk	505	Tot_mp_zk	345	Tot_mp_zk	875	Tot_mp_zk	8675	
5	Mp_zk0_14	5	Mp_zk0_14	0	Mp_zk0_14	0	Mp_zk0_14	20	
20	Mp_zk15_24	25	Mp_zk15_24	20	Mp_zk15_24	25	Mp_zk15_24	335	
100	Mp_zk25_44	75	Mp_zk25_44	35	Mp_zk25_44	150	Mp_zk25_44	1435	
265	Mp_zk45_64	195	Mp_zk45_64	150	Mp_zk45_64	390	Mp_zk45_64	3585	
255	Mp_zk65pl	205	Mp_zk65pl	140	Mp_zk65pl	310	Mp_zk65pl	3300	
180	Tot_ongeh	135	Tot_ongeh	65	Tot_ongeh	340	Tot_ongeh	3730	
90	Tot_ong_mk	65	Tot_ong_mk	35	Tot_ong_mk	180	Tot_ong_mk	1995	
90	Tot_ong_zk	70	Tot_ong_zk	35	Tot_ong_zk	160	Tot_ong_zk	1735	
1805	Until married	1485	Until married	1000	Tot_gehuwd	1875	Until married	17775	
1255	Tot_geh_mk	1060	Tot_geh_mk	690	Tot_geh_mk	1170	Tot_geh_mk	10935	
550	Tot_geh_zk	425	Tot_geh_zk	310	Tot_geh_zk	705	Tot_geh_zk	6840	
105	Up to one	95	Up to one	45	Tot_eenoud	120	Up to one	2090	
5	Tot_samenw	15	Tot_samenw	0	Tot_samenw	10	Tot_samenw	95	
0	Tot_instit	0	Tot_instit	0	Tot_instit	20	Tot_instit	835	
2215	Kn_autoch	1800	Kn_autoch	1205	Kn_autoch	2445	Kn_autoch	25250	
105	Kn_allo_w	100	Kn_allo_w	35	Kn_allo_w	195	Kn_allo_w	2390	
40	Kn_allo_nw	25	Kn_allo_nw	10	Kn_allo_nw	70	Kn_allo_nw	2155	
40	P_lagopl15	-99999	P_lagopl15	-99999	P_lagopl15	40	P_lagopl15	38	
50	P_midopl15	-99999	P_midopl15	-99999	P_midopl15	40	P_midopl15	42	
10	P_hogopl15	-99999	P_hogopl15	-99999	P_hogopl15	20	P_hogopl15	20	
14	P_wbv_1524	21	P_wbv_1524	24	P_wbv_1524	9	P_wbv_1524	12	
33	P_wbv_2544	29	P_wbv_2544	30	P_wbv_2544	33	P_wbv_2544	32	
38	P_wbv_4554	34	P_wbv_4554	33	P_wbv_4554	42	P_wbv_4554	39	
14	P_wbv_5564	15	P_wbv_5564	12	P_wbv_5564	15	P_wbv_5564	17	
1	P_wbv_6574	2	P_wbv_6574	1	P_wbv_6574	1	P_wbv_6574	1	
3	P_wrk_lndb	6	P_wrk_lndb	2	P_wrk_lndb	2	P_wrk_lndb	1	
23	P_wrk_nijv	25	P_wrk_nijv	31	P_wrk_nijv	21	P_wrk_nijv	18	
34	P_wrk_cmd	34	P_wrk_cmd	32	P_wrk_cmd	34	P_wrk_cmd	31	
29	P_wrk_ncmd	26	P_wrk_ncmd	25	P_wrk_ncmd	30	P_wrk_ncmd	38	
9	P_wrk_ov	8	P_wrk_ov	7	P_wrk_ov	11	P_wrk_ov	11	
2	P_wrk_onb	2	P_wrk_onb	2	P_wrk_onb	2	P_wrk_onb	2	
2300	Bev01tot	2060	Bev01tot	1195	Bev01tot	2530	Bev01tot	29190	
-85	Balance_bin	-285	Balance_bin	-50	Saldo_bin	30	Balance_bin	1325	
-10	Balance_bout	10	Balance_bout	10	Saldo_buit	-5	Balance_bout	-85	
260	Tothh_eenp	200	Tothh_eenp	135	Tothh_eenp	340	Tothh_eenp	5245	
370	Tothh_mpmk	300	Tothh_mpmk	180	Tothh_mpmk	405	Tothh_mpmk	4145	
320	Tothh_mpzk	255	Tothh_mpzk	175	Tothh_mpzk	435	Tothh_mpzk	4310	
950	Tothh_t	755	Tothh_t	490	Tothh_t	1180	Tothh_t	13705	
260	Tothh_1	200	Tothh_1	140	Tothh_1	340	Tothh_1	5260	
335	Tothh_2	260	Tothh_2	185	Tothh_2	465	Tothh_2	4750	
125	Tothh_3	110	Tothh_3	60	Tothh_3	155	Tothh_3	1505	
135	Tothh_4	90	Tothh_4	55	Tothh_4	160	Tothh_4	1525	
55	Tothh_5	55	Tothh_5	20	Tothh_5	45	Tothh_5	480	
30	Tothh_6pl	35	Tothh_6pl	30	Tothh_6pl	15	Tothh_6pl	180	
960	House11	775	House11	490	Woning11	1205	House11	13855	
890	Housing01	760	Housing01	475	Woning01	1105	Housing01	12760	
71	Won_prc_e	60	Won_prc_e	71	Won_prc_e	71	Won_prc_e	50	
28	Won_prc_h	40	Won_prc_h	28	Won_prc_h	28	Won_prc_h	45	
1	Won_prc_o	1	Won_prc_o	1	Won_prc_o	1	Won_prc_o	5	
2.5	Won_bez_t	2.6	Won_bez_t	2.6	Won_bez_t	2.3	Won_bez_t	2.1	
2.7	Won_bez_e	3	Won_bez_e	3	Won_bez_e	2.5	Won_bez_e	2.5	
1.8	Won_bez_h	2	Won_bez_h	1.7	Won_bez_h	1.8	Won_bez_h	1.7	
217000	Won_woz_t	195000	Won_woz_t	160000	Won_woz_t	226000	Won_woz_t	217000	
244000	Won_woz_e	228000	Won_woz_e	175000	Won_woz_e	250000	Won_woz_e	270000	
147000	Won_woz_h	146000	Won_woz_h	122000	Won_woz_h	165000	Won_woz_h	158000	
0	Living unit	0	Living unit	0	Wooneenh	0	Living unit	115	
0	Recrwon	0	Recrwon	0	Recrwon	25	Recrwon	0	
0.5	Afs_haprak	0.6	Afs_haprak	0.3	Afs_haprak	0.5	Afs_haprak	0.8	
2	Av5_haprak	2.8	Av5_haprak	1	Av5_haprak	1.3	Av5_haprak	7.4	
6.4	Afs_hapost	9.1	Afs_hapost	28.3	Afs_hapost	9.4	Afs_hapost	2.9	
6.4	Afs_ziekhs	9.1	Afs_ziekhs	28.1	Afs_ziekhs	9.4	Afs_ziekhs	2.9	
0.5	Afs_apoth	0.6	Afs_apoth	0.3	Afs_apoth	0.5	Afs_apoth	1.1	
0.4	Afs_bsop	0.4	Afs_bsop	7.1	Afs_bsop	0.5	Afs_bsop	0.7	
0.4	Afs_kdvblf	0.4	Afs_kdvblf	7.1	Afs_kdvblf	0.5	Afs_kdvblf	0.7	
0.4	Afs_basond	0.4	Afs_basond	0.3	Afs_basond	0.4	Afs_basond	0.6	
7.5	Afs_vmbo	10.1	Afs_vmbo	17.8	Afs_vmbo	8.9	Afs_vmbo	1.1	
7.5	Afs_havwo	10.1	Afs_havwo	25.1	Afs_havwo	8.9	Afs_havwo	1.2	
0.5	Afs_super	0.4	Afs_super	0.3	Afs_super	0.5	Afs_super	0.9	
0.4	Afs_ovlevm	0.3	Afs_ovlevm	0.2	Afs_ovlevm	0.4	Afs_ovlevm	0.8	
8.4	Av5_ovlevm	9.8	Av5_ovlevm	2	Av5_ovlevm	6.5	Av5_ovlevm	43.1	
0.5	Afs_oprit	0.8	Afs_oprit	0.5	Afs_oprit	1.1	Afs_oprit	1.4	
82	Opptot	55	Opptot	32	Opptot	77	Opptot	1169	
82	Landn	55	Landn	32	Landn	76	Landn	1120	
0	Watern	0	Watern	0	Watern	0	Watern	49	
324	Oad	282	Oad	247	Oad	409	Oad	1448	
non urban, less th	Sted	non urban, less th	Sted	non urban, less th	Sted	non urban, less th	Sted	Moderately urban 1000-1500 addresses	
TRUE	Geom_valid	TRUE	Geom_valid	TRUE	Geom_valid	TRUE	Geom_valid	TRUE	

cost benefit analysis of ecological infrastructures

COST BENEFIT ANALYSIS - ANNUAL BASIS

100km squared scenario	Macroalgae (1)	Mussel poles (4)	Oyster fields	Salt marshes	Pine plantations	Total area	Local schools popn	
Area (hectares)	2200	1120	2780	3750	3360	9850	8105	
Costs								
Full time workers	50	150	21	30				
Labour costs p.a. (€45k pp pa)	€ 2,247,300	€ 6,753,600		€ 1,350,000				
Seasonal workers				300				
Labour costs seasonal (€20k pp pa)				€ 6,000,000				
Material costs	€ 17,600,000	€ 7,392,000						
Aggregated costs			€ 16,054,500		€ 6,720,000			
Number of CHP plants reqd	13							
CHP plant running costs(2)	€ 1,508,117							
Loss of agricultural productivity				€ 1,593,750	€ 1,428,000			
Total costs	€ 21,355,417	€ 14,145,600	€ 16,054,500	€ 8,943,750	€ 8,148,000			€ 68,647,267
Benefits, crop								
Productive yield (tonnes)	145200	47040		5625				
Productive yield		€ 47,040,000		€ 31,500,000				€ 39,270,000
Energy via CHP, 80% of crop (MWh)	178464							
Energy savings at std 20c tarif	€ 35,692,800							
Heat via CHP (Gj)	722700							
Heat energy savings(3)	€ 40,150							
N fertiliser savings via CHP	€ 1,097,712							
8% crop for animal feed(@€420/t)	€ 487,872							
10% crop for fertiliser (@€4200/t)	€ 6,098,400							
2% crop for food products (@€2000/t)	€ 5,808,000							
Sum of benefits, crop	€ 49,224,934	€ 47,040,000	€ -	€ 31,500,000	€ -			€ 127,764,934
								€ 59,117,667
Benefits, ecosystem services								
Carbon uptake (tonnes)	43560			5625	29904			
Carbon uptake	€ 581,526			€ 75,094	€ 399,218			€ 1,055,838
NO2 uptake					€ 48,354			
SO2 uptake					€ 69,923			
Particulate matter uptake					€ 5,397,840			
Dike reinforcement cost savings (5)						€ 1,970,000		
BEST, biodiversity improvements			€ 4,420,200	€ 5,962,500				€ 10,382,700
BEST, educational visits (1 per pupil/year x 75%)							€ 139,811	
BEST, recreation benefits			€ 1,331,620	€ 1,796,250				€ 3,127,870
Sum of benefits, ecosystem services	€ 581,526	€ -	€ 5,751,820	€ 7,833,844	€ 5,915,335	€ 1,970,000	€ 139,811	€ 22,192,336
Total benefits	€ 49,806,460	€ 47,040,000	€ 5,751,820	€ 39,333,844	€ 5,915,335	€ 1,970,000	€ 139,811	€ 149,957,270
Balance								**€ 81,310,003**

Notes: Installation costs of reef spread over expected roll out time of system...10yrs
1. Macroalgae materials, perimeter rope nom. €1 / m, fabric nom. €10 / m, floatation bouys nom. €20 ea. Materials last 3 years?
2. With 1/30th of €1.75m installation costs incorporated
3. At 1MWh = 3.6Gj
4. Pole netting materials, 3m of netting per pole (@ €5 / m), 880 poles per ha. Nets last 2 years?
5. Assuming each 10,000ha of mechanisms saves €2 million

COST BENEFIT ANALYSIS

Per hectare	Macroalgae (1)	Mussel poles (4)	Oyster fields	Salt marshes	Pine plantations	Total area	
Area (hectares)	1	1	1	1	1	4	
Costs							
Full time workers	4	6	6	6			
Labour costs p.a. (€45k pp pa)	€ 180,000	€ 270,000		€ 270,000			
Seasonal workers				1			
Labour costs seasonal (€20k pp pa)				€ 20,000			
Material costs	€ 3,633	€ 1,320					
Aggregated costs			€ 57,750		€ 2,000		
Number of CHP plants reqd	0						
CHP plant running costs(2)	€ 686						
Loss of agricultural productivity				€ 425	€ 425		
Total costs	€ 184,319	€ 271,320	€ 57,750	€ 290,425	€ 2,425		€ 806,239
Benefits, crop							
Productive yield (tonnes)	66	42		1.5			
Productive yield		€ 42,000		€ 8,400			
Energy via CHP, 80% of crop (MWh)	81						
Energy savings at std 20c tarif	€ 16						
Heat via CHP (Gj)	329						
Heat energy savings(3)	€ 18						
N fertiliser savings via CHP	€ 499						
8% crop for animal feed(@€420/t)	€ 222						
10% crop for fertiliser (@€4200/t)	€ 2,772						
2% crop for food products (@€2000/t)	€ 2,640						
Sum of benefits, crop	€ 6,167	€ 42,000	€ -	€ 8,400	€ -		€ 56,567
Benefits, ecosystem services							
Carbon uptake (tonnes)	19.8			2	8.9		
Carbon uptake	€ 264			€ 20	€ 119		
NO2 uptake					€ 14		
SO2 uptake					€ 21		
Particulate matter uptake					€ 1,607		
Dike reinforcement cost savings (5)						€ 800	
BEST, biodiversity improvements			€ 1,590	€ 1,590			
BEST, educational visits (1 per pupil/year x 75%)							
BEST, recreation benefits			€ 479	€ 479			
Sum of benefits, ecosystem services	€ 264	€ -	€ 2,069	€ 2,089	€ 1,761	€ 800	
Total benefits	€ 6,432	€ 42,000	€ 2,069	€ 10,489	€ 1,761	€ 800	€ 63,550
Balance							**€ (742,689)**
						with eco services	**€ (686,122)**

Notes:
1. Macroalgae materials, perimeter rope nom. €0.25 / m, fabric nom. €5 / m, floatation bouys nom. €10 ea. Materials last 3 years?
2. With 1/30th of €1.75m installation costs incorporated
3. At 1MWh = 3.6Gj
4. Pole netting materials, 3m of netting per pole (@ €1 / m), 880 poles per ha. Nets last 2 years?
5. Assuming each 10,000ha of mechanisms saves €2 million

COST BENEFIT ANALYSIS - ANNUAL BASIS

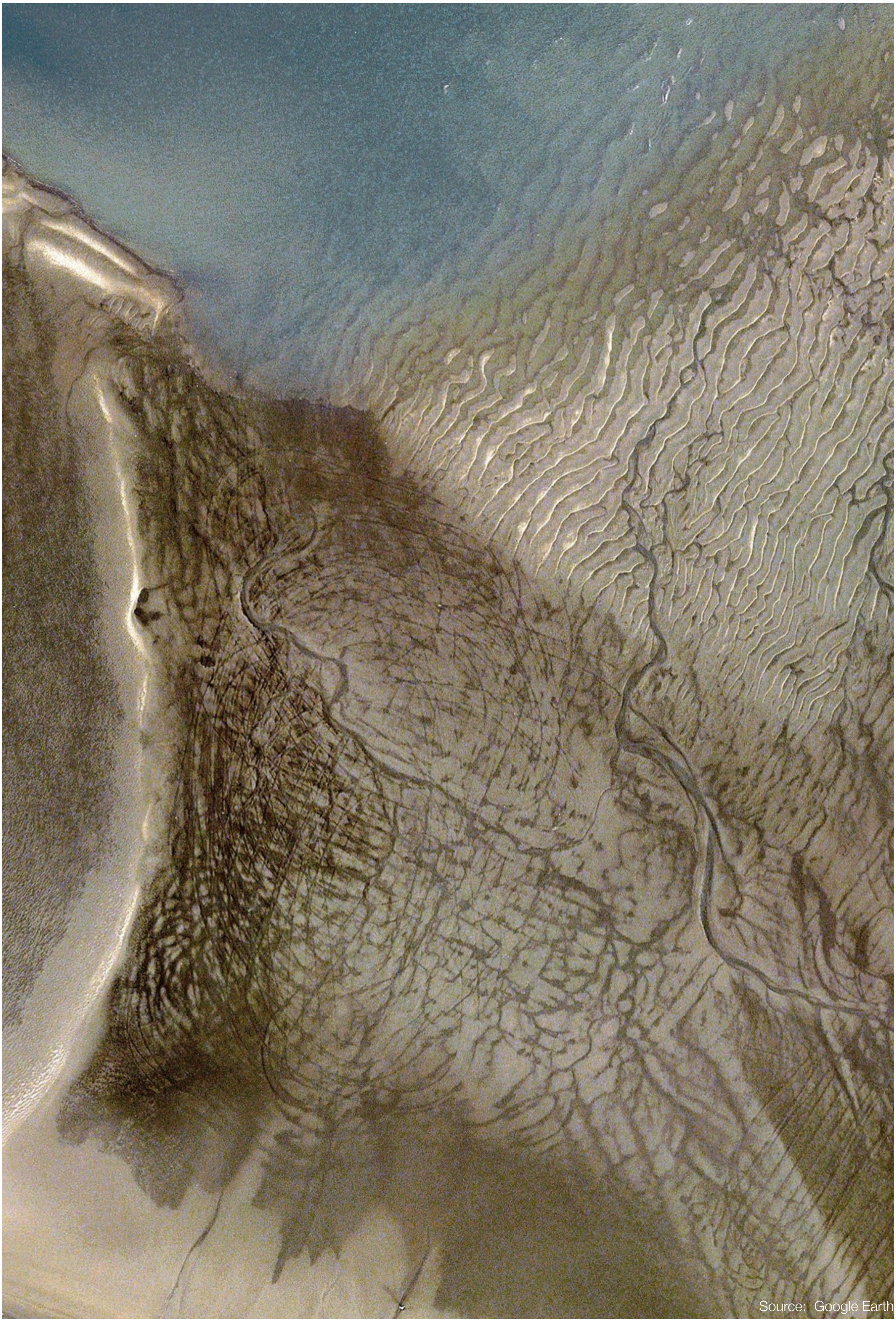
Revised scenario	Macroalgae (1)	Mussel poles (4)	Oyster fields	Salt marshes	Pine plantations	Total area	Local schools popn		
Area (hectares)	1320	720	1750	3100	540	6890	8105		
Costs									
Full time workers	30	96	21	30					
Labour costs p.a. (€45k pp pa)	€ 1,348,380	€ 4,341,600		€ 1,350,000					
Seasonal workers				300					
Labour costs seasonal (€20k pp pa)				€ 6,000,000					
Material costs	€ 10,560,000	€ 4,752,000							
Aggregated costs			€ 10,106,250		€ 1,080,000				
Number of CHP plants reqd	8								
CHP plant running costs(2)	€ 904,870								
Loss of agricultural productivity				€ 1,317,500	€ 229,500				
Total costs	€ 12,813,250	€ 9,093,600	€ 10,106,250	€ 8,667,500	€ 1,309,500			€ 41,990,100	
Benefits, crop									
Productive yield (tonnes)	87120	30240		4650				122010	
Productive yield		€ 30,240,000		€ 26,040,000				€ 28,140,000	
Energy via CHP, 80% of crop (MWh)	107078							15951	per capita
Energy savings at std 20c tarif	€ 21,415,680								
Heat via CHP (Gj)	433620								
Heat energy savings(3)	€ 24,090								
N fertiliser savings via CHP	€ 731,808								
8% crop for animal feed(@€420/t)	€ 292,723							697	tonnes
10% crop for fertiliser (@€4200/t)	€ 3,659,040							871	tonnes
2% crop for food products (@€2000/t)	€ 3,484,800							1742	tonnes
Sum of benefits, crop	€ 29,608,141	€ 30,240,000	€ -	€ 26,040,000	€ -			€ 85,888,141	
								€ 43,898,041	
Benefits, ecosystem services	2635			469	484				
Carbon uptake (tonnes)	26136			4650	4806			35592	
Carbon uptake	€ 348,916			€ 62,078	€ 64,160			€ 475,153	
NO2 uptake					€ 7,771				
SO2 uptake					€ 11,238				
Particulate matter uptake					€ 867,510				
Dike reinforcement cost savings (5)						€ 1,378,000			
BEST, biodiversity improvements			€ 2,782,500	€ 4,929,000				€ 7,711,500	
BEST, educational visits (1 per pupil/year x 75%)							€ 139,811		
BEST, recreation benefits			€ 838,250	€ 1,484,900				€ 2,323,150	
Sum of benefits, ecosystem services	€ 348,916	€ -	€ 3,620,750	€ 6,475,978	€ 950,679	€ 1,378,000	€ 139,811	€ 12,914,133	
Total benefits	€ 29,957,057	€ 30,240,000	€ 3,620,750	€ 32,515,978	€ 950,679	€ 1,378,000	€ 139,811	€ 98,802,274	
Balance								**€ 56,812,174**	
				€ 6,413,900	€ 886,519				

Notes: Installation costs of reef spread over expected roll out time of system...10yrs
1. Macroalgae materials, perimeter rope nom. €1 / m, fabric nom. €10 / m, floatation bouys nom. €20 ea. Materials last 3 years?
2. With 1/30th of €1.75m installation costs incorporated
3. At 1MWh = 3.6Gj
4. Pole netting materials, 3m of netting per pole (@ €5 / m), 880 poles per ha. Nets last 2 years?
5. Assuming each 10,000ha of mechanisms saves €2 million

COST BENEFIT ANALYSIS

Min. economic scenario	Macroalgae (1)	Mussel poles (4)	Oyster fields	Salt marshes	Pine plantations	Total area	
Area (hectares)	185	60	40	20	180	305	
Costs							
Full time workers	4	8	12	5			
Labour costs p.a. (€45k pp pa)	€ 188,978	€ 361,800		€ 225,000			
Seasonal workers				2			
Labour costs seasonal (€20k pp pa)				€ 40,000			
Material costs	€ 672,167	€ 79,200					
Aggregated costs			€ 2,310,000		€ 360,000		
Number of CHP plants reqd	1						
CHP plant running costs(2)	€ 126,819						
Loss of agricultural productivity				€ 8,500	€ 76,500		
Total costs	€ 987,963	€ 441,000	€ 2,310,000	€ 273,500	€ 436,500		€ 4,448,963
Benefits, crop							
Productive yield (tonnes)	12210	2520		30			
Productive yield		€ 2,520,000		€ 168,000			
Energy via CHP, 80% of crop (MWh)	15007						
Energy savings at std 20c tarif	€ 3,001						
Heat via CHP (Gj)	60773						
Heat energy savings(3)	€ 3,376						
N fertiliser savings via CHP	€ 92,308						
8% crop for animal feed(@€420/t)	€ 41,026						
10% crop for fertiliser (@€4200/t)	€ 512,820						
2% crop for food products (@€2000/t)	€ 488,400						
Sum of benefits, crop	€ 1,140,931	€ 2,520,000	€ -	€ 168,000	€ -		€ 3,828,931
Benefits, ecosystem services							
Carbon uptake (tonnes)	3663			30	1602		
Carbon uptake	€ 48,901			€ 401	€ 21,387		
NO2 uptake					€ 2,590		
SO2 uptake					€ 3,746		
Particulate matter uptake					€ 289,170		
Dike reinforcement cost savings (5)						€ 61,000	
BEST, biodiversity improvements			€ 63,600	€ 31,800			
BEST, educational visits (1 per pupil/year x 75%)							
BEST, recreation benefits			€ 19,160	€ 9,580			
Sum of benefits, ecosystem services	€ 48,901	€ -	€ 82,760	€ 41,781	€ 316,893	€ 61,000	
Total benefits	€ 1,189,832	€ 2,520,000	€ 82,760	€ 209,781	€ 316,893	€ 61,000	€ 4,380,265
Balance							**€ (620,032)**
						with eco services	**€ 3,760,233**

Notes:
1. Macroalgae materials, perimeter rope nom. €0.25 / m, fabric nom. €5 / m, floatation bouys nom. €10 ea. Materials last 3 years?
2. With 1/30th of €1.75m installation costs incorporated
3. At 1MWh = 3.6Gj
4. Pole netting materials, 3m of netting per pole (@ €1 / m), 880 poles per ha. Nets last 2 years?
5. Assuming each 10,000ha of mechanisms saves €2 million


Source: Google Earth

manifesto

a nonstraightforward archipelago

Zeeland is veilig. The barriers are closed…the dikes raised…the tide held back…the waters excluded…the edges defined…the landscape fixed.

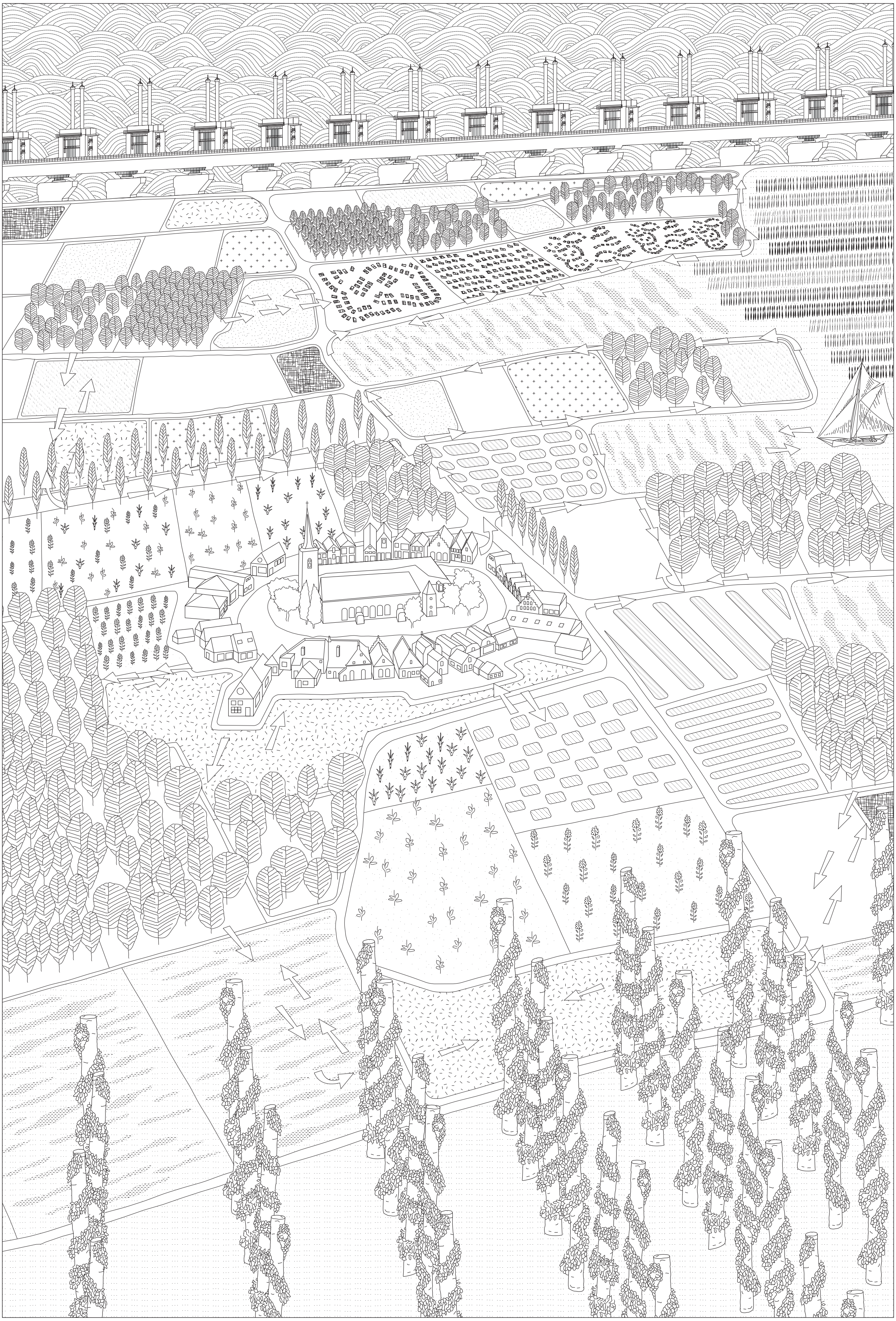
The fundamental characteristic of a deltaic landscape, constant change and flux, has been excluded. Constrained by narrow but unyielding lines of infrastructure that absolutely dictate life within as they erode life without.

Let us embrace again the promise of process…the potency of uncertainty.

Let us soften the barriers…merge the waters…expand the edges…empower the landscape.

An inward gaze is turned outward. Binary relationships become more complicated. Abrupt exchanges become fields of negotiation. Static landscapes become venues of process…economic, infrastructural, social and biotic. The certainty of refuge is consolidated but the possibilities of an experiential and cooperative landscape are exponentially expanded.

Zeeland is intriguing. A foil for the fixidity of adjacent urban assumptions. An unexpected landscape. A nonstraightforward archipelago.



a non-straightforward archipelago

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MSc Urbanism thesis
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Delft, the Netherlands