2015
연안 및 하구 생태복원 국제포럼
International Forum on Coastal and Estuarine Ecosystem Restoration

연안 및 하구 생태복원 국제포럼

2015·8·20~21

충청남도 충남연구원

International Forum on Coastal and Estuarine Ecosystem Restoration

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일시 : 2015. 8. 20.(목) ~ 21.(금)

장소 : 보령 웨스토피아 동백홀

주최 : 충청남도

주관 : 충남연구원

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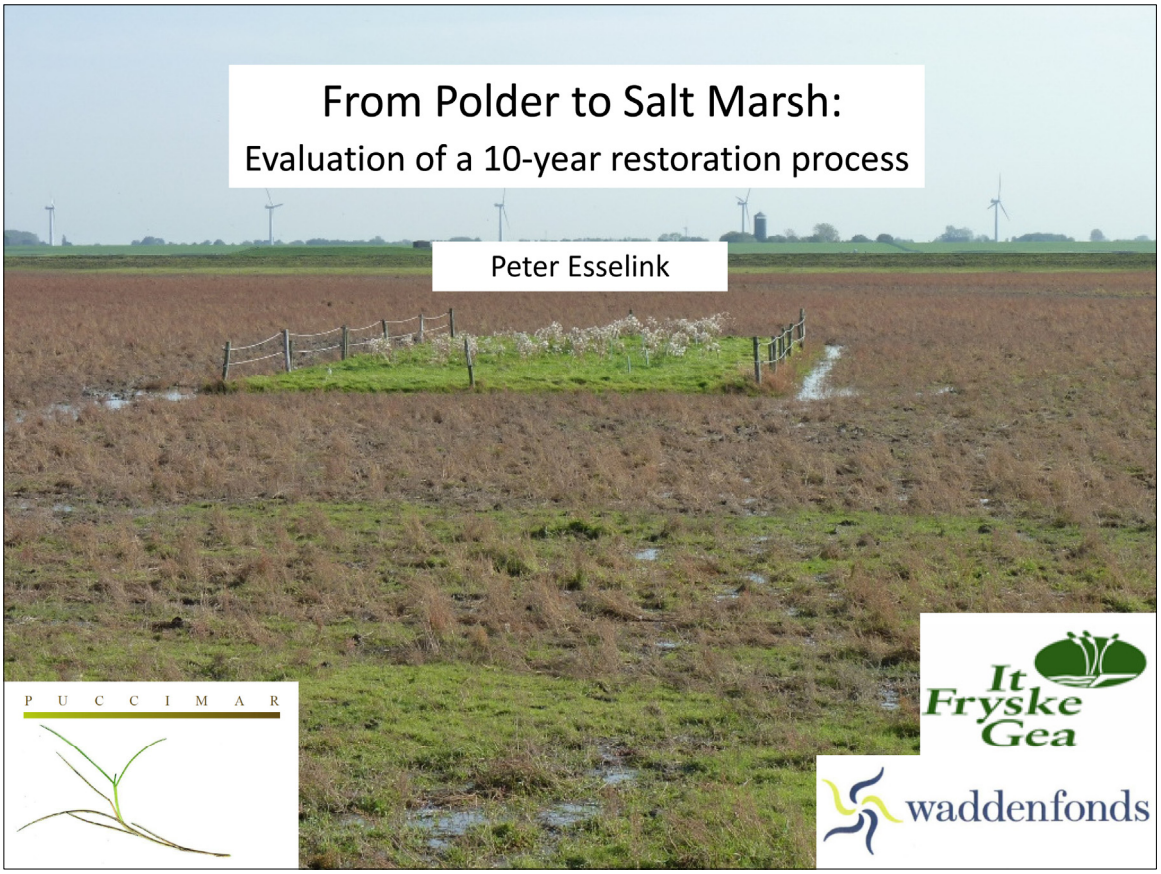
국제포럼 행사일정

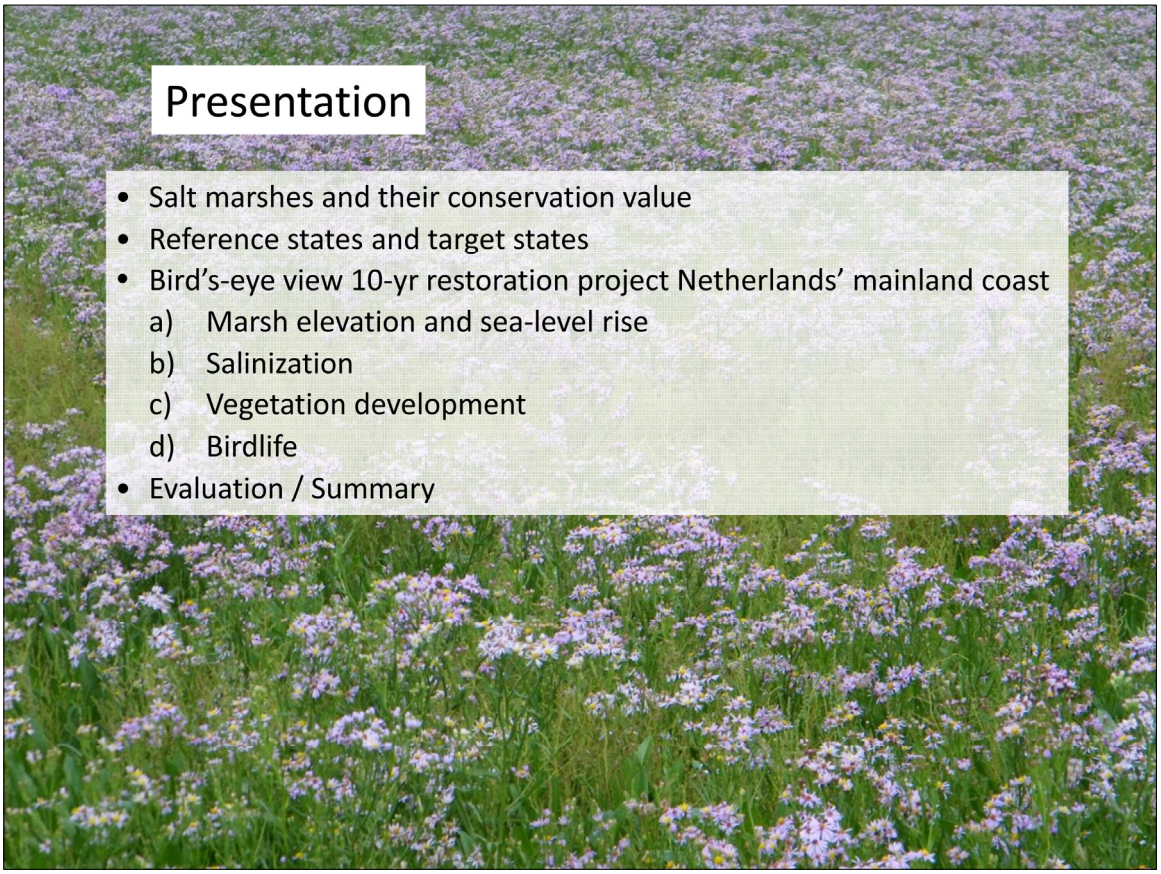
일 시		행사 내용	비고
8월 20일 (목)	13:00~14:00	참석자 등록 및 접수	1층 로비
	14:00~14:04	국민의례 및 주요내빈 소개	사회자
	14:04~14:08	개회사 : 충남연구원장 강현수	
	14:08~14:12	환영사 : 충청남도지사 안희정	
	14:12~14:16	축 사 : 보령시장 김동일	
	14:16~14:20	축 사 : 국회의원 김태흠	
	14:20~14:50	간척지에서 염습지로: 10년 복원과정의 평가 (그로닝겐 대학, Peter Esselink 박사)	
	14:50~15:20	중국의 연안 및 하구복원 (중국해양대학, 이동영 교수)	
	15:20~15:50	중국 산동지역의 연안관리사업 (중국해양대학, Hongda Shi 교수)	
	15:50~16:00	휴식	
	16:00~16:30	충청남도 연안 및 하구 생태복원방안 (충남연구원 이상진 연구실장)	
	16:30~17:00	영산강 하구역 종합관리시스템 개발사례 (인하대학교 우승범 교수)	
	17:00~17:10	휴식	
	17:10~18:30	종합토론 허재영 교수(대전대학교 토목공학과, 좌장) 이창희 교수(명지대학교 환경에너지공학과) 노영재 교수(충남대학교 해양환경과학과) 손규희 박사(해양환경관리공단) 김경철 국장(습지와 새들의 친구) 전호성 기자(내일신문)	
8월 21일 (금)	09:00~13:00	현장투어(홍보지구, 간월호 및 부남호)	
	13:00~14:00	오찬	
	14:00~	폐회	

From Polder to Salt Marsh:
Evaluation of a 10-year restoration process

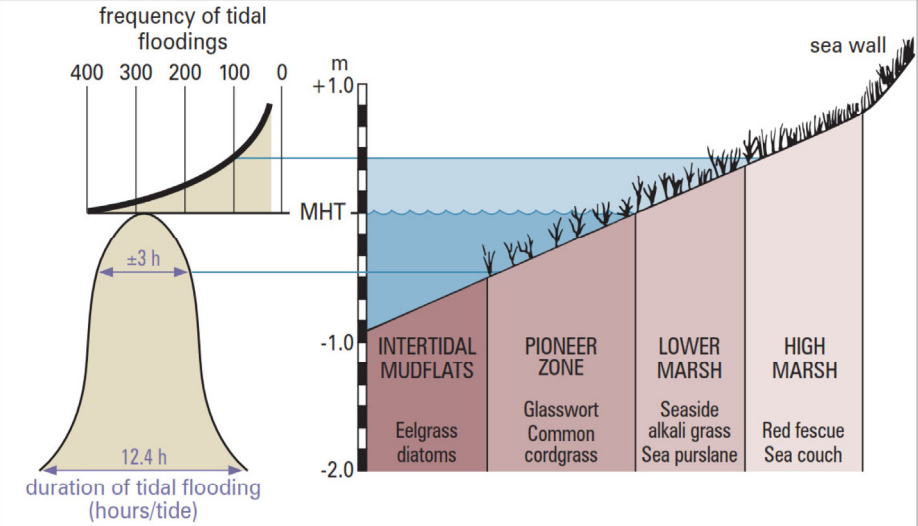
간척지에서 염습지로: 10년 복원과정의 평가

그로닝겐대학 Peter Esselink 박사


From Polder to Salt Marsh:
Evaluation of a 10-year restoration process
Peter Esselink
P U C C I M A R
It Fryske Gea
waddenfonds


Presentation
• Salt marshes and their conservation value
• Reference states and target states
• Bird's-eye view 10-yr restoration project Netherlands' mainland coast
a) Marsh elevation and sea-level rise
b) Salinization
c) Vegetation development
d) Birdlife
• Evaluation / Summary

Coastal salt marsh

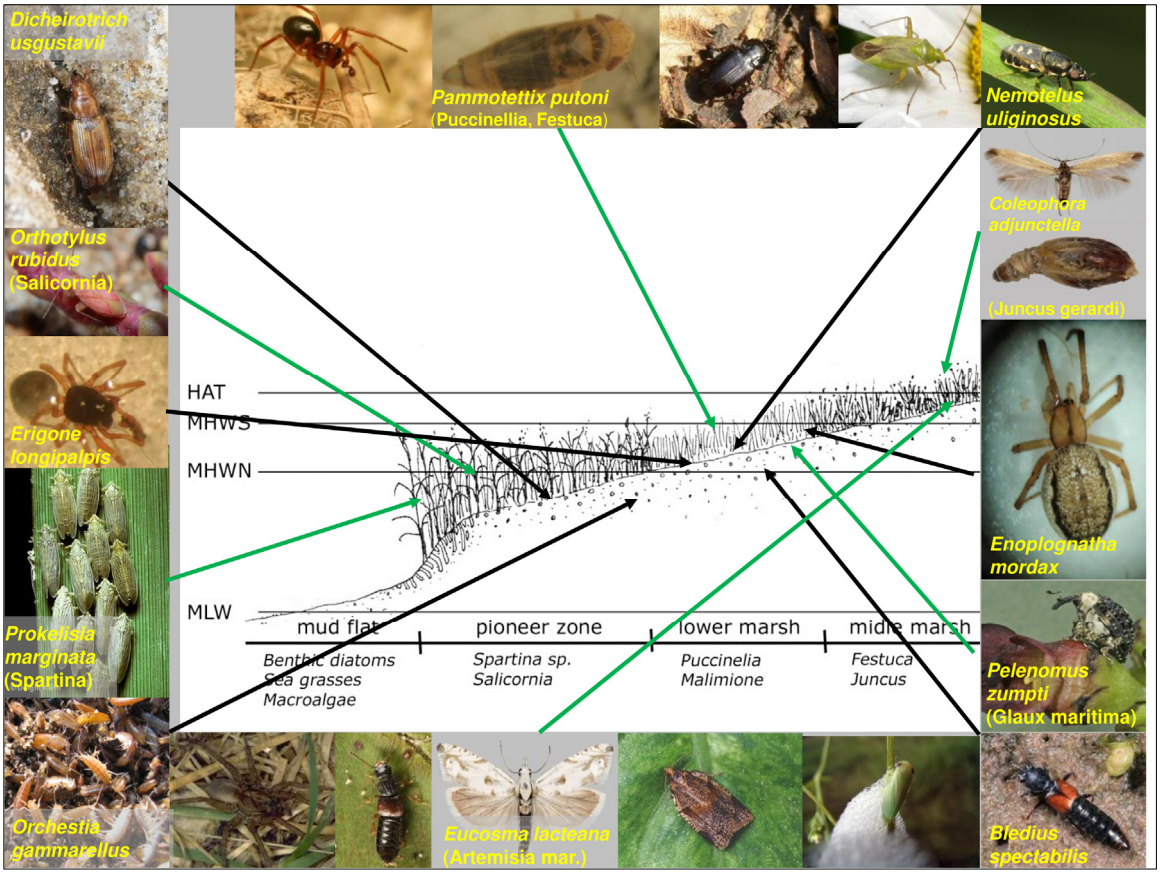


- Area vegetated by higher plants (herbs, grasses or low shrubs)
- subject to periodic flooding with saline water

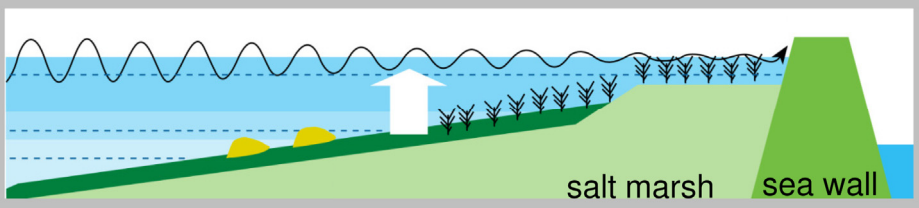
➔ Extreme environment for plants and animals

Conservation value of salt marshes

- Plant species (NW Europe): *ca*. 30 species restricted to salt marshes; outcompeted in other environments
- Invertebrates (Insects, spiders, *etc*.): a few hundred species restricted to salt marshes, because, e.g. their dependence to a single host plant
- Plants and invertebrates: often specialized to survive in saline environment and submergence with salt water
- Also a few bird species dependent on salt marshes, *e.g.* : Barnacle goose and Brent goose

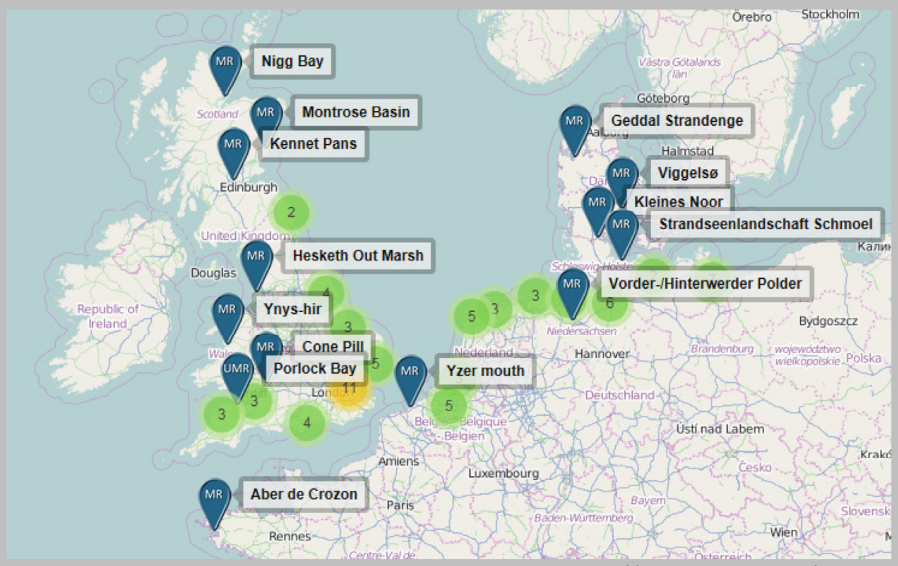


Ecosystem services of salt marshes



- Wave attenuation (cost reduction in coastal defence)
- Nursery ground of several fish species
- Cultural values (including recreation)
- Carbon sequestration (global change)

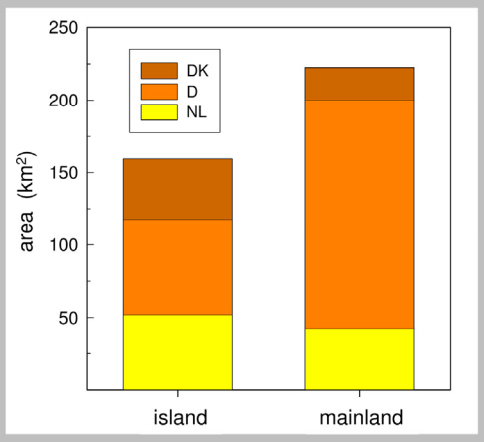
Managed realignment in NW Europe



Source: http://www.omreg.net/view-maps/

- approx. 100 sites (50% in UK)

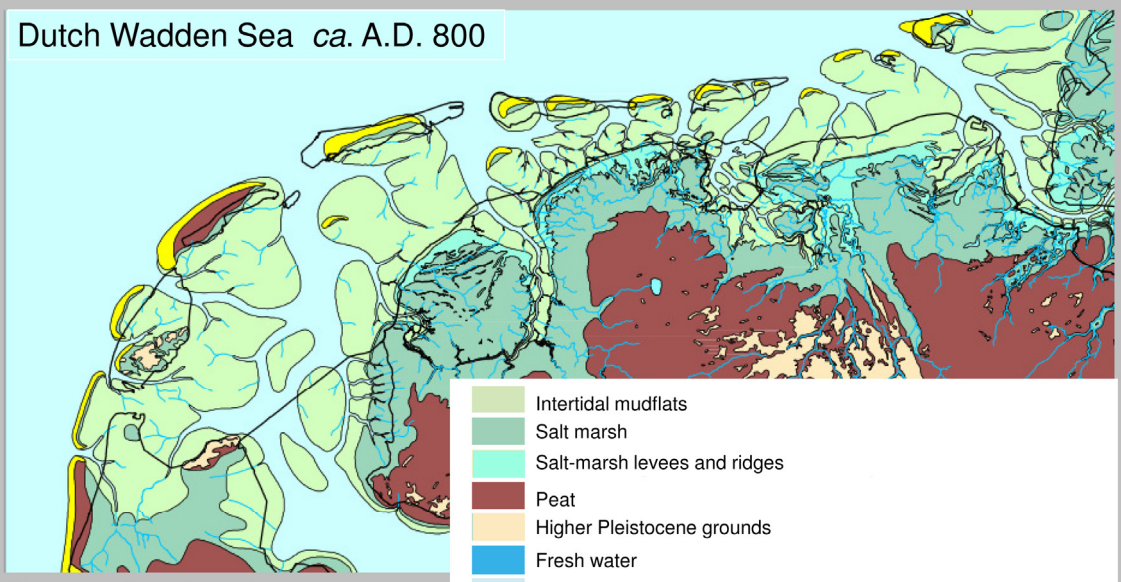
Salt marshes of the Wadden Sea



- 400 km² or
  ≈ 20 % total area in Europe
- of great value for nature conservation !

Historic reference

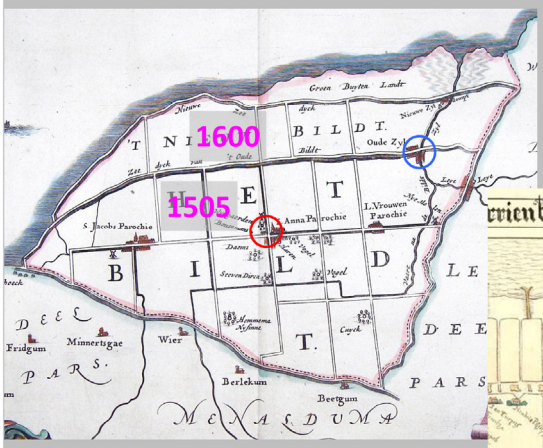
Dutch Wadden Sea *ca.* A.D. 800



(from: Vos & Knol 2014)

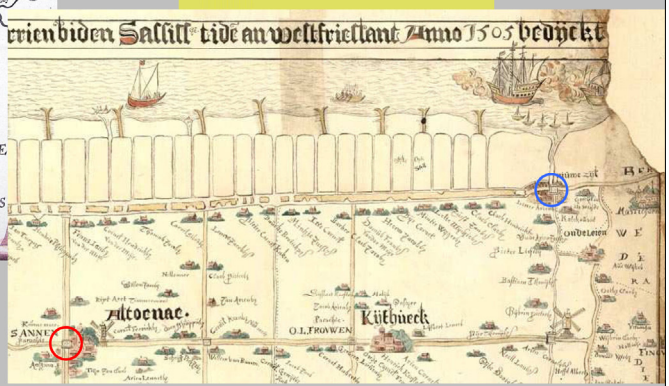
- Vanished landscape; not restorable

Historic reference



(Schotanus 1664)

Salt-marsh works 1570

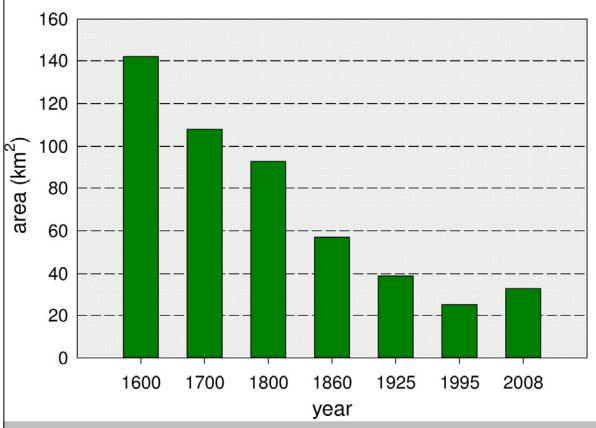


(from: De Rijcke 2001)

Rate of embankments faster than development of new (artificial) salt marshes

Historic development

Decrease NL mainland salt marshes Wadden Sea

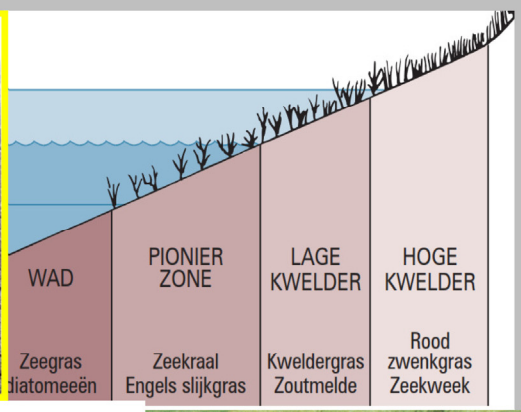


(After Dijkema 1987; Dijkema *et al*. 2011)

- Present state: Size << historic references

→ Recommendation Int. Wadden Sea Symposium (1993): Salt-marsh restoration by experiments with realignment of summer-polder banks

Present state mainland salt marshes

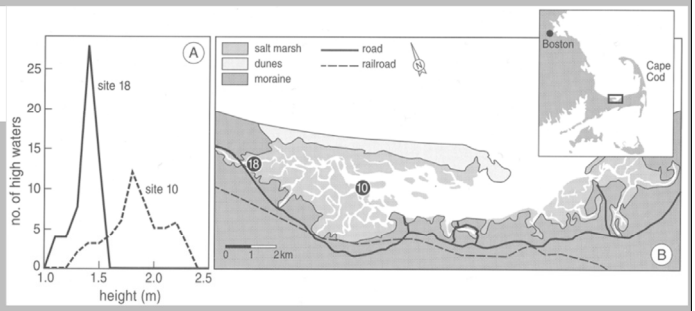


- Semi-natural
- a <u>shadow</u> of the past
- **<u>narrow zone</u>** (without natural hinterland)
  - ☛ high sedimentation rates
  - ☛ high succession rates

  (from pioneer marsh to climax of *Elytrigia* **< 40 year**)
- Wadden Sea "amputated landscape" without a natural hinterland

Geographic reference state (1/1)

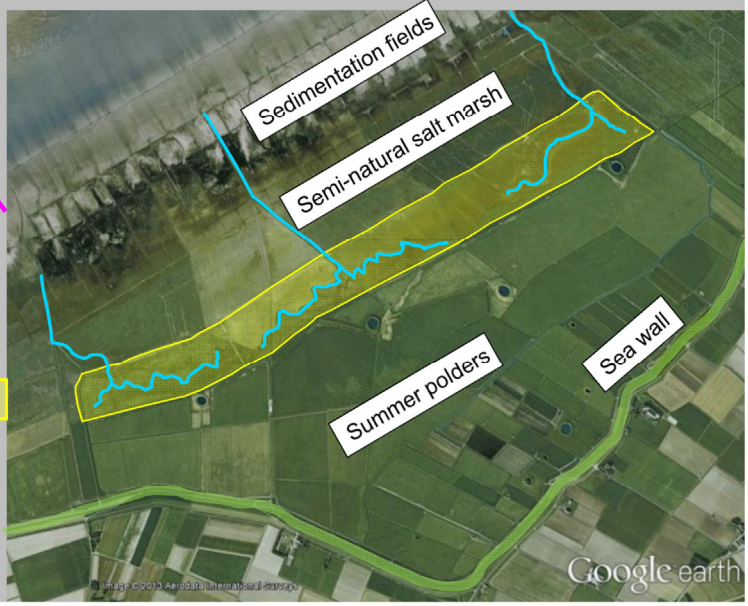
Hydrodynamic gradient:
4 km ➔ 0.5 m reduction local MHT
(van der Molen 1997)



"The current shape of the mainland salt marshes in the Wadden Sea has strongly been determined by a history of successive land claims and sedimentation works. Consequently, the grand majority of the mainland marshes are not more than a narrow fringe along the seawalls. It follows that in very few situations these marshes feature a complete hydrodynamic gradient of natural wide salt marshes. Nature conservancy should give priority to conserve and restore wide salt marshes wherever this is attainable."

(QSR 2009)

Restoration site Noard-Fryslân Bûtendyks



Restoration site (117 ha)

Target:
"grazed salt marsh"

Main measures: - three breaches in the seaward summer bank
2001 - digging artificial creeks; rewetting by filling of ditches
- continuation of livestock grazing

Monitoring research 2000 – 2011/12

Aim:

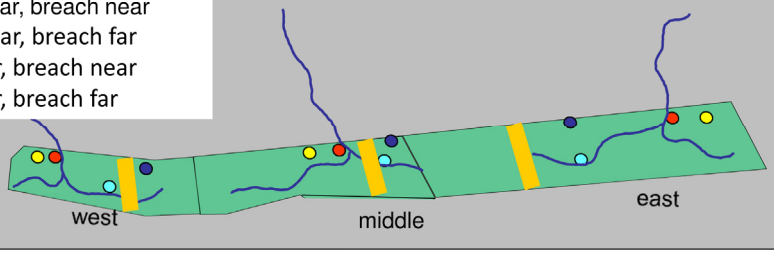
- Study abiotic and biotic changes after de-embankment (2000 – 2011/12)
- Evaluation of ecological success (2006, 2012/13)

Approach:

Combination of

1) Descriptive fieldwork (monitoring)
2) Field experiments (2001-2011/12), full-factorial design
   Factors: - distance to breaches
   distance to creeks
   surface elevation
   livestock grazing (exclosure)

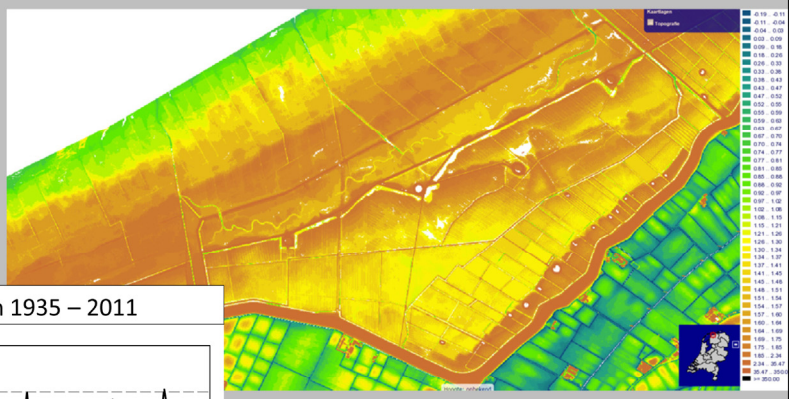
Creek near, breach near
Creek near, breach far
Creek far, breach near
Creek far, breach far



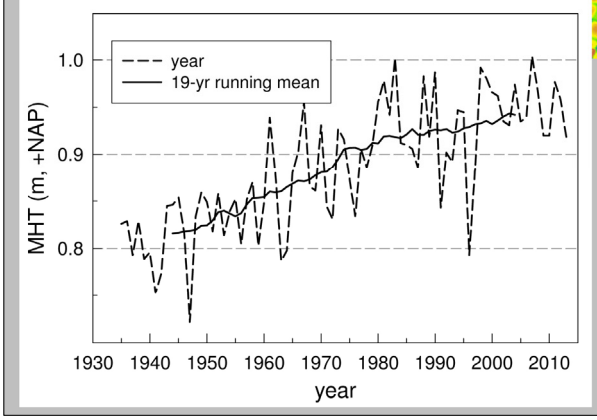
High elevation, creek far, breach far

Low elevation, creek far, breach far

Sea-level rise and surface elevation



Mean high tide Harlingen 1935 – 2011

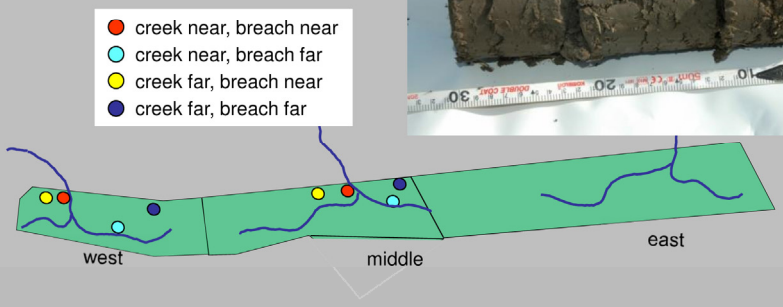


Sea-level rise 2.2 mm/year
Restoration of tidal influence:
☛ can the area keep pace with SLR ?
Summer polders: any elevation change ?

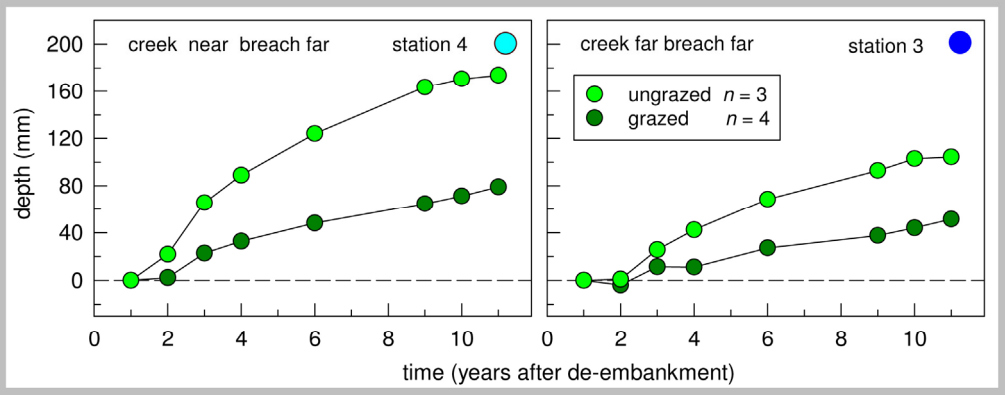
Surface elevation restoration site (methods)

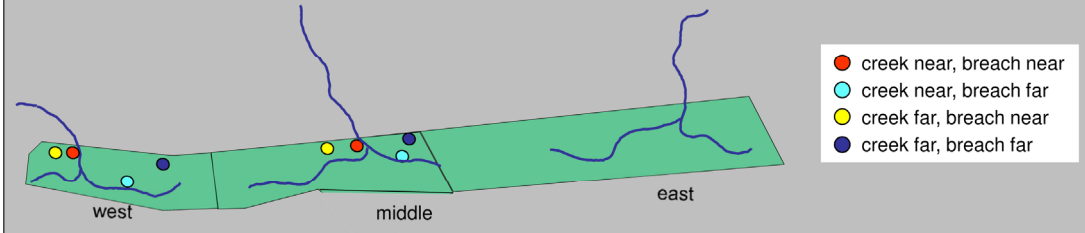
- Accretion (mm/yr):
  - Sedimentation plates buried 10 cm deep
  - 8 stations inside and outside exclosures
  - depth monitored during 10-yr period

- Sedimentation (kg/m^2/yr):
  - Sediment accumulation above the plates
  - 10-yr period
  - soil cores Ø 8 cm, drying & weighing



Accretion restoration site

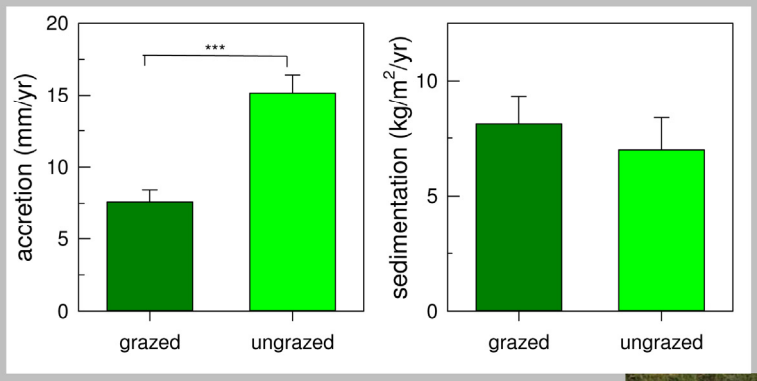




creek near, breach near
creek near, breach far
creek far, breach near
creek far, breach far

- Effect of creeks and livestock grazing

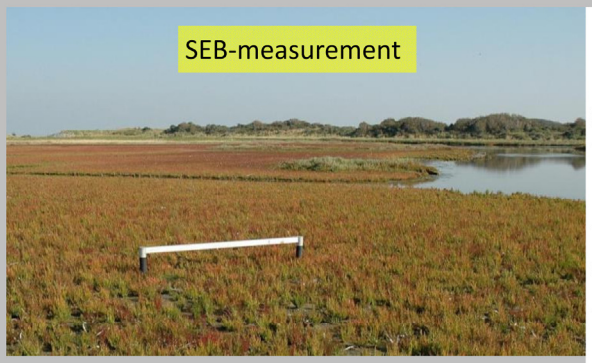
Surface elevation restoration site

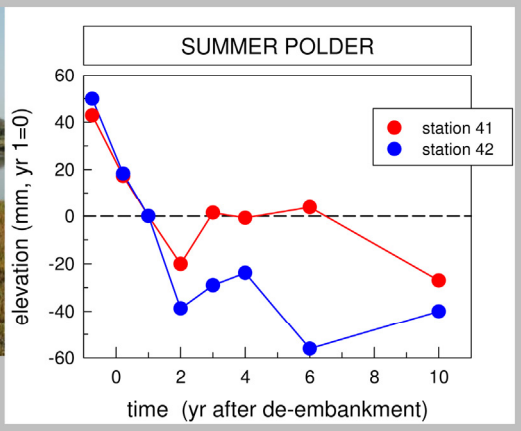


Restoration site:

- Elevation increase: 7.6 mm/ year
- Grazing retards accretion (compaction)
- No effect of grazing on sedimentation
- Site is catching up with sea-level rise

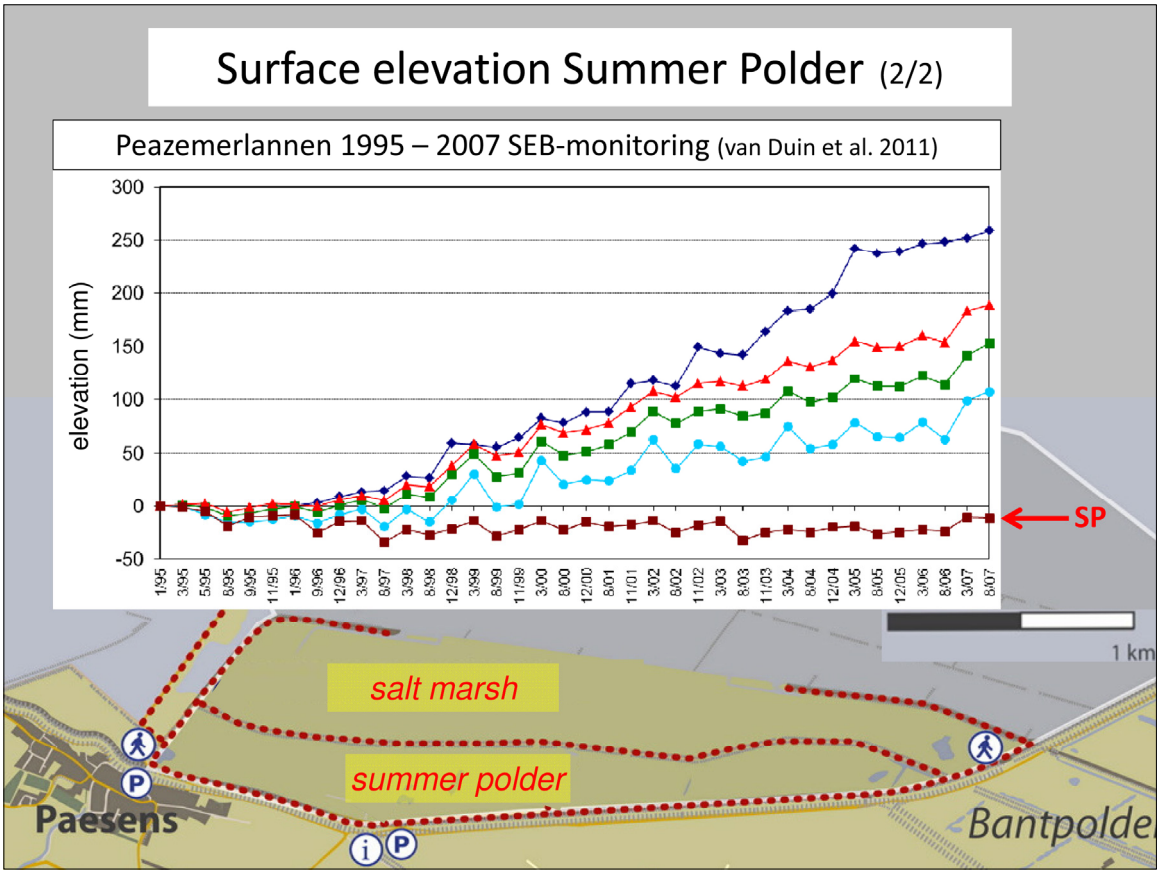
Surface elevation summer polder (1/2)

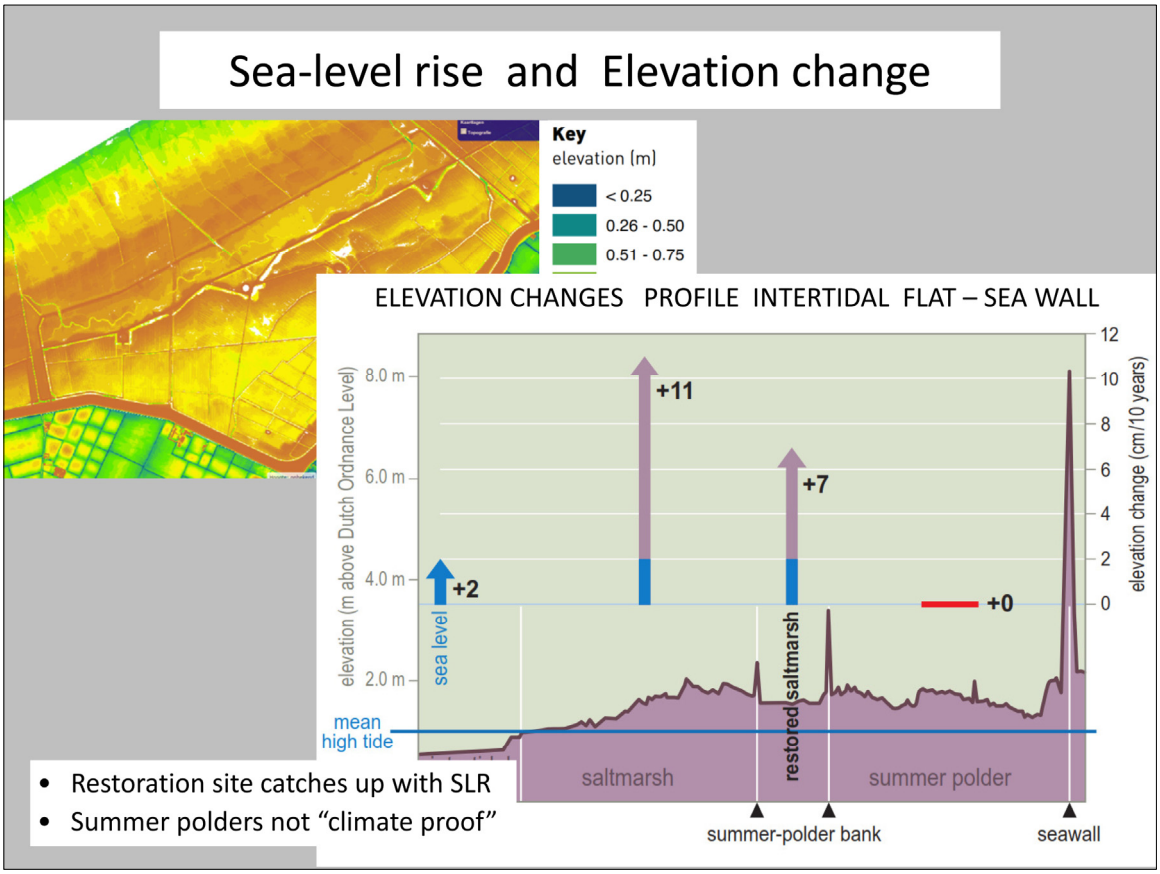




- No indication of any significant accretion.
  This holds also for years with a high storm activity (years 6 and 7).

☛ Elevation deficit; not resilient to climate change


Surface elevation Summer Polder (2/2)
Peazemerlannen 1995 – 2007 SEB-monitoring (van Duin et al. 2011)
elevation (mm)
300
250
200
150
100
50
0
-50
SP
1 km
salt marsh
summer polder
Paesens
Bantpolder

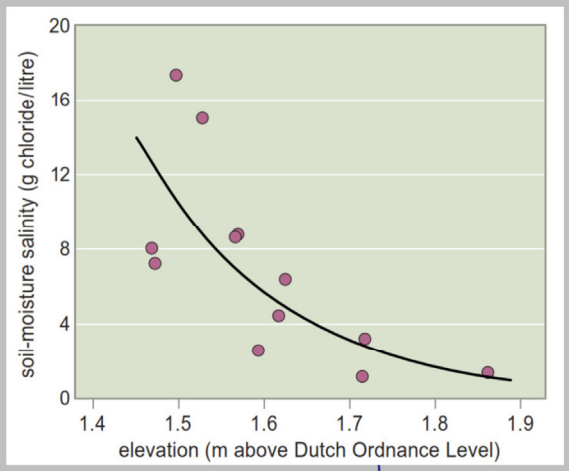

Sea-level rise and Elevation change
Key
elevation (m)
< 0.25
0.26 - 0.50
0.51 - 0.75
ELEVATION CHANGES PROFILE INTERTIDAL FLAT – SEA WALL
elevation (m above Dutch Ordnance Level)
8.0 m
6.0 m
4.0 m
2.0 m
elevation change (cm/10 years)
12
10
8
6
4
2
0
+11
+7
+2
+0
sea level
mean high tide
restored saltmarsh
saltmarsh
summer polder
summer-polder bank
seawall
• Restoration site catches up with SLR
• Summer polders not "climate proof"

Salinization

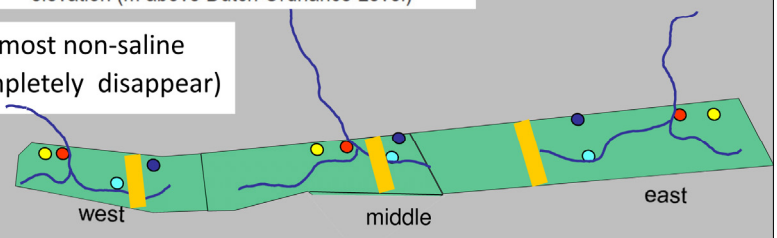
- Dependent on frequency of tidal inundations (and thus position in tidal frame)
- Restoration site: lower area 100× per year
  higher area 12× per year

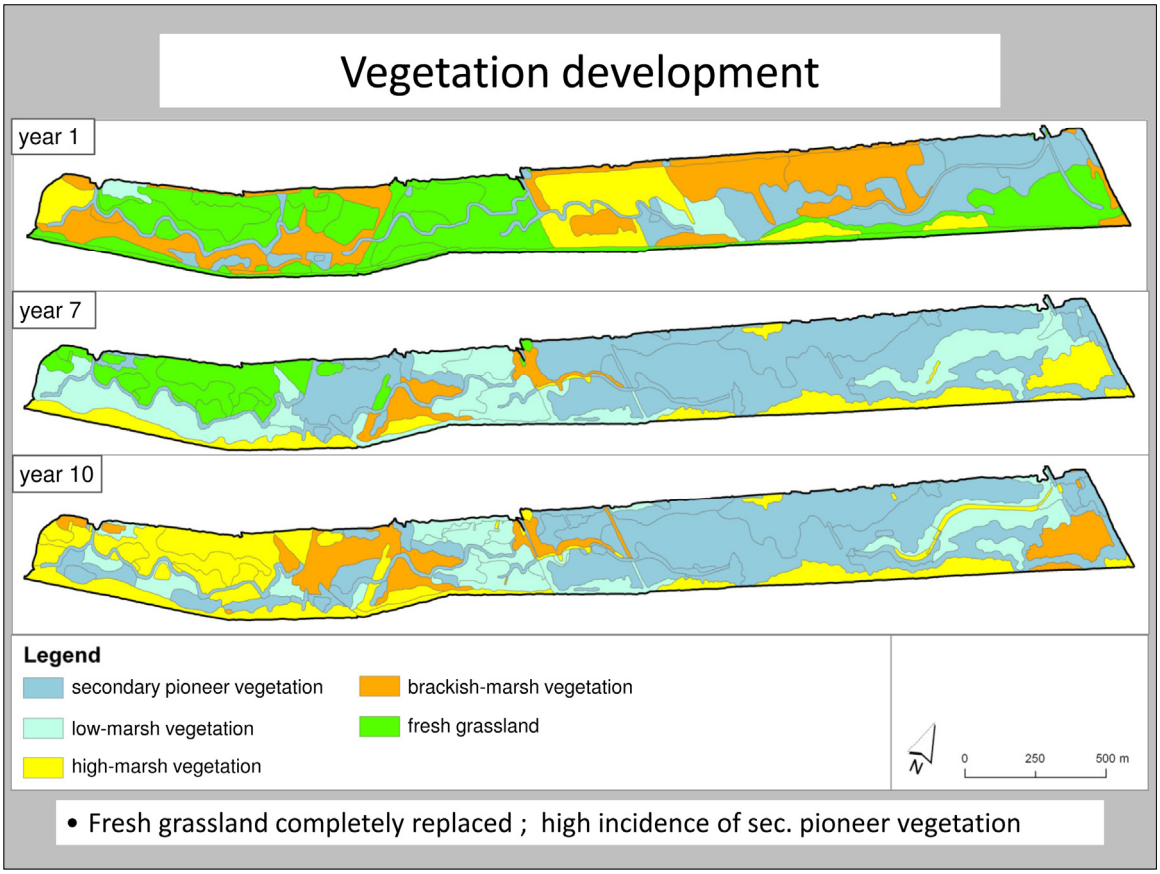
- Salinity measured in: upper 5 cm of marsh bed
  groundwater

Salinization marsh soil (0 – 5 cm)



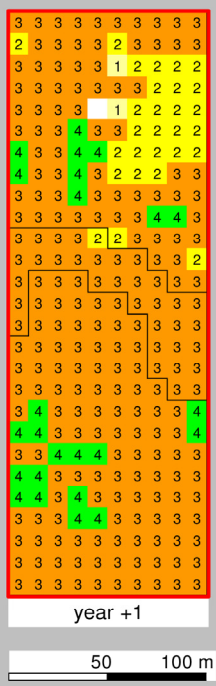
- Gradient from saline to almost non-saline (earth worms did not completely disappear)




Vegetation development
year 1
year 7
year 10
Legend
secondary pioneer vegetation
low-marsh vegetation
high-marsh vegetation
brackish-marsh vegetation
fresh grassland
0
250
500 m
• Fresh grassland completely replaced ; high incidence of sec. pioneer vegetation

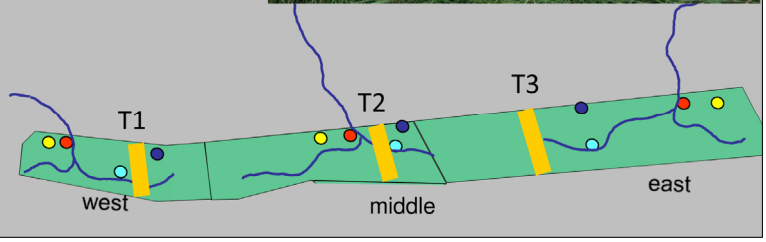

HIGH ELEVATION / BACK MARSH
LOW ELEVATION / BACK MARSH
© J. de Vlas

Vegetation development *Species mapping permanent transects*

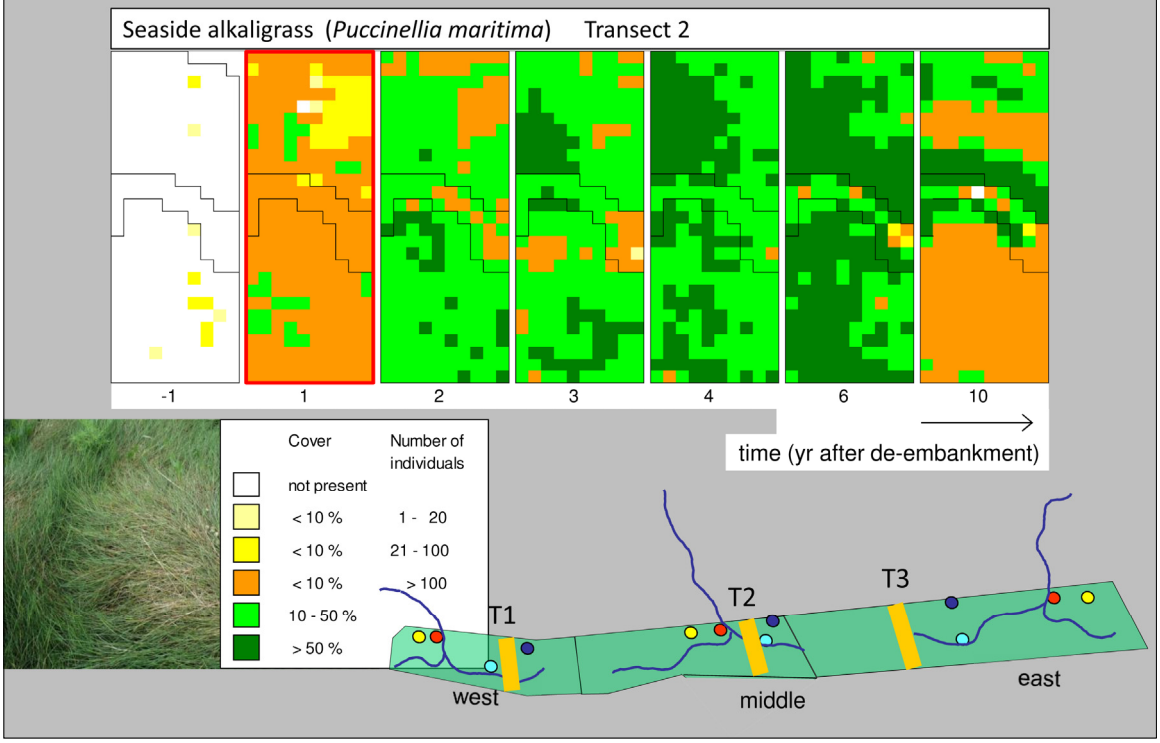


- Three 100-m wide transects; grid cells of 10 m × 10 m
- 40 plant species, simple abundance scale

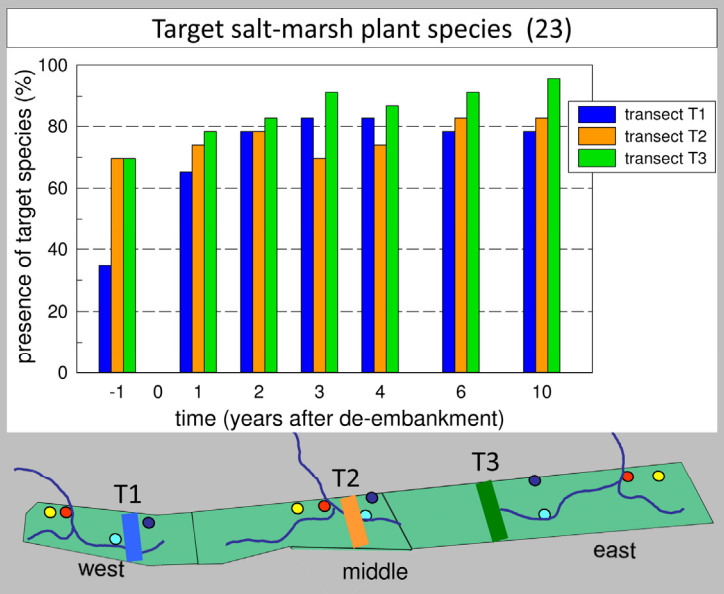
	Cover	Number of individuals
	not present	
1	< 10 %	1 - 20
2	< 10 %	21 - 100
3	< 10 %	> 100
4	10 - 50 %	
5	> 50 %	



Vegetation development *Species mapping permanent transects*

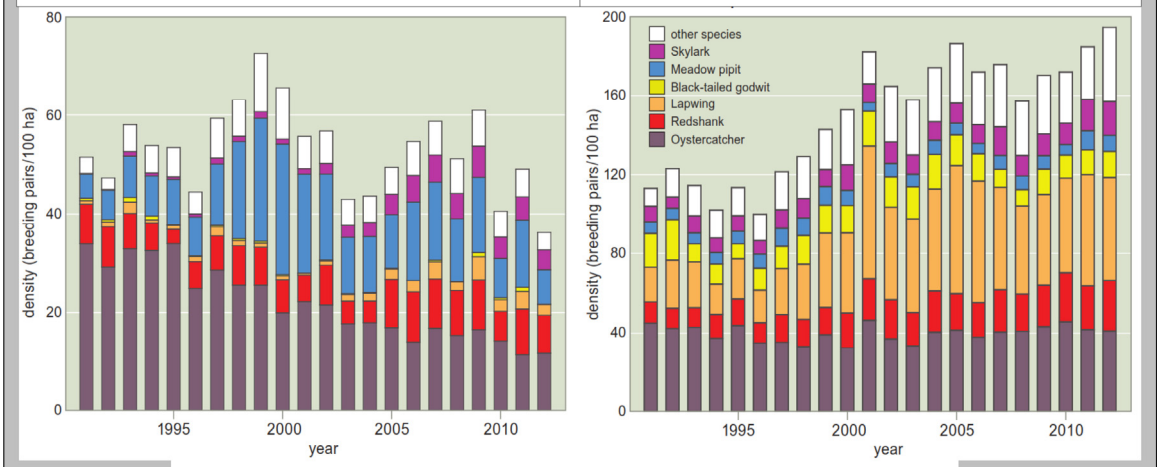


Vegetation development *Species mapping permanent transects*



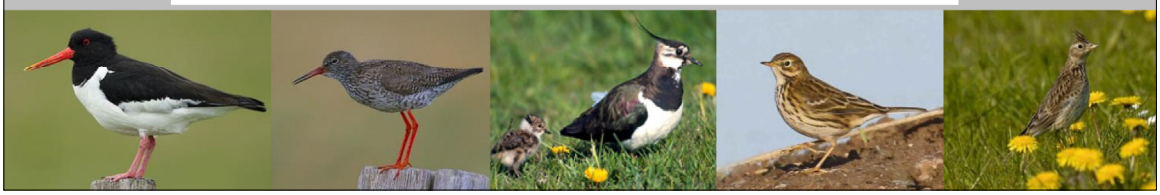
- Selection target species based on phytosociologically criteria
  Almost all species present

Breeding birds



- Lower densities on salt marshes than in summer polders

  Conservation conflict



Evaluation / Summary

Criteria	Salt marsh (target)
Vegetation	
Suitablity for livestock grazing	→
Establishment of salt-marsh vegetation	→
Development of main zonation	→
Establishment of target plant species	→
Abiotics	
Accretion	→
Soil salinity	→
Creek development / drainage	→
Gradient of local MHT level	?
Staging geese	
Food supply	→
Utilisation during autumn	→
Utilisation during spring	→
Breeding-bird population	
Grassland birds	→
Colonial birds	-

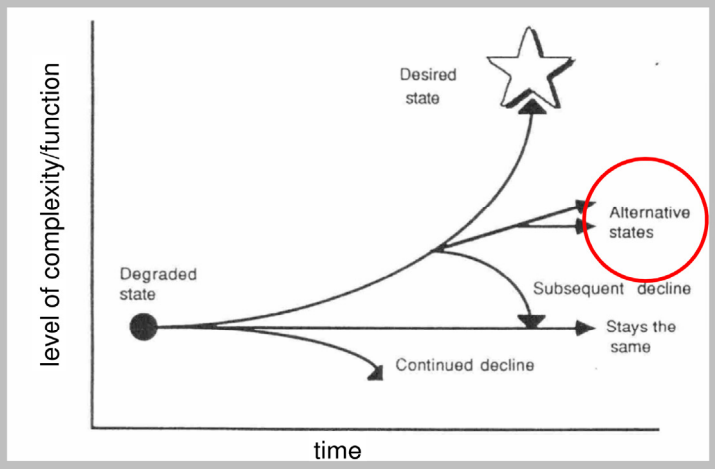
ambiguous criterium

a posteriori criteria

a posteriori criteria
restoration site < summer polders

Recommendations

- Historic reference state not attainable; consider alternative states
- Define clear restoration targets



(Hobbs & Norton 1996)

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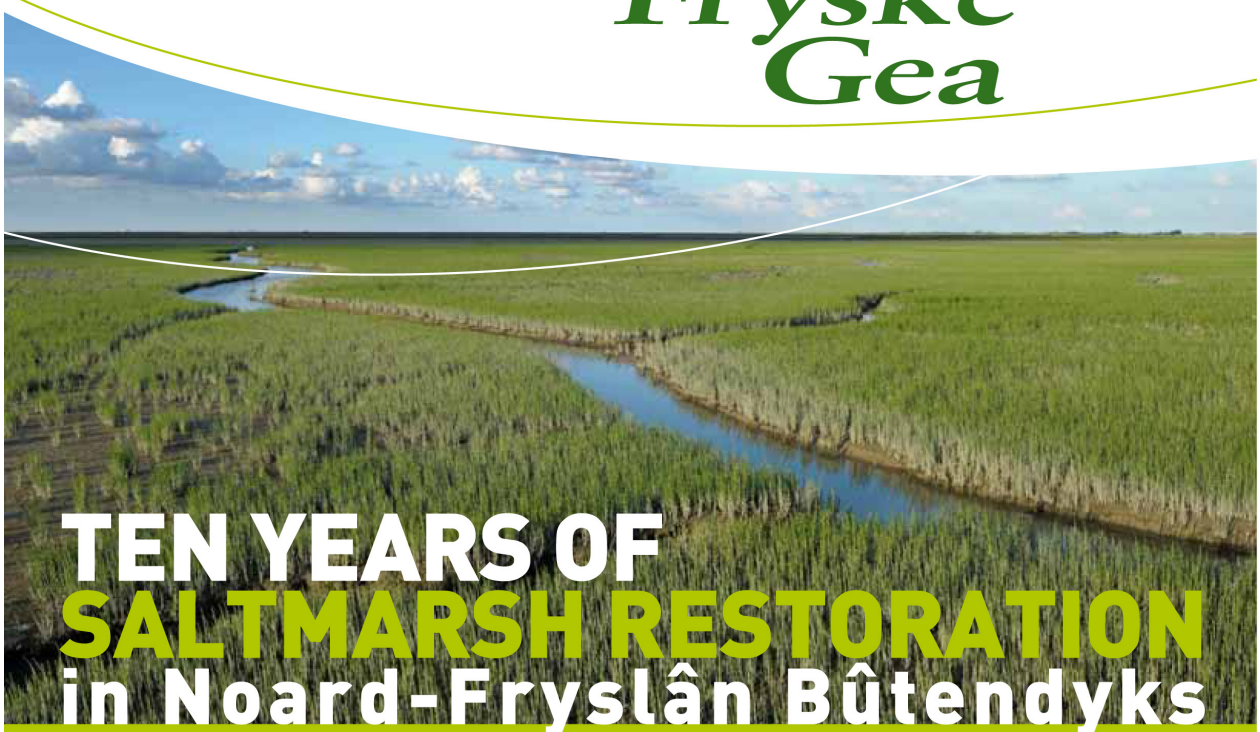


TEN YEARS OF SALTMARSH RESTORATION in Noard-Fryslân Bûtendyks

Contents

With its wide-open spaces, magnificent colours and ever-changing skies, Noard-Fryslân Bûtendyks is an area with a raw kind of beauty. Part of the Wadden Sea, a World Heritage site, it stirs our sense of primeval nature. The nature conservation organisation, *It Fryske Gea*, is committed to preserving the natural values of this area just outside the seawall and so, in 2001, initiated a trial to restore saltmarshes in the area. The bank of a 123-hectare summer polder was breached in three places to let seawater in; then, for the next ten years, researchers carefully investigated the effects on the flora and fauna, the changes in marsh-surface level, soil salinity – everything involved in the restoration of a saltmarsh. The research, financially supported by the *Waddenfonds*, produced a wealth of information and insights that will be useful for future projects. The results from this research have been recorded in various reports and in articles in scientific journals. This brochure contains the highlights of this research.

Henk de Vries:

‘Saltmarsh restoration trial a great success’

Friday, 14 September 2001 was the big day: an excavator took a large bite out of the summer-polder bank. Saltwater flowed into the experimental saltmarsh, an area of 123 hectares in Noard-Fryslân Bûtendyks. Henk de Vries, now the director of *It Fryske Gea*, was present. He looks back with satisfaction. ‘Saltmarsh restoration works. The area has successfully changed from a summer polder into a saltmarsh.’

There was a long run-up to the trial. The plan to transform summer polders into saltmarshes was devised more than ten years earlier. According to Henk de Vries, this was partly the result of the international Wadden Sea strategy which recommends restoring thousands of hectares of saltmarsh. One way to achieve this is to expose summer polders to tidal flooding again. ‘Noard-Fryslân Bûtendyks (North Friesland outside the seawall) was regarded as the area with the greatest chance of success. After all, it contained a thousand hectares of summer polder and so, plenty of potential for saltmarsh restoration.’
The trial was much in the news at the time, with detailed coverage in both local and national media. By testing saltmarsh restoration, *It Fryske Gea* was taking the first step; they were pioneers. ‘Never before had such a large tract of agricultural land been returned to the sea. Saltmarsh development was possible in theory, but we needed real-world proof. That was why we first did this pilot study. It was also to let the local community see what happens when a saltmarsh is restored.’ Actually, it was not the very first time this happened. In the 1970s, a summer polder further up the coast near Paesens was transformed into a saltmarsh. This, however, was not intentional. ‘After storms caused breaches in the bank of the summer polder, it was decided not to repair it,’ De Vries explained. In the early 1990s two summer polders near the Holwerd ferry causeway went the same way.

Official start of the trial saltmarsh in 2001

4

Method works

An intensive monitoring programme would show whether saltmarsh restoration actually worked. Over a period of ten years many things were monitored, from soil salinity, changes in surface elevation and vegetation development to the effects on bird populations. The main conclusion, according to De Vries, was that the method worked. ‘Saltmarsh restoration proved to be straightforward: you make an opening in the bank and nature fends for itself. After a while, the uniform agricultural fresh grassland was replaced by various saltmarsh plants. We had expected the vegetation to die off all at once, but the changes were gradual.’
The aim was to learn from this experiment and De Vries believes many lessons can be drawn from the project. The natural dynamics of the area, for example, were an eye opener for him, a case in point being the creeks that were dug out. ‘The excavator driver had done his utmost best to make meandering creeks. It turned out that wasn’t necessary. In fact, the seawater found its own way, while some of the creeks silted up really quickly. Controlling nature was more difficult than we’d thought.’

New insights

The remaining summer polders provide us with an excellent opportunity to increase the area of saltmarsh even further, but De Vries does not want to convert all summer polders into saltmarshes as was originally planned. New insights and bird counts have made it very clear how valuable the summer polders are. ‘Polders contribute to the value of the area for nature conservation. It’s there you find avocets, terns and meadow birds in huge numbers. Good polder management allows us to keep the geese away from the agricultural land inside the seawall.’ The summer polders are also essential for the safety of livestock. ‘Thousands of animals are grazed outside the seawall. During periods of extremely high water we need to keep the animals in the summer polders because it’s almost impossible to get them over the seawall in time - as we know from the occasion in 2006 when a herd of horses were trapped by high water and were rescued only with considerable effort. The polders also contain valuable historical features such as rows of wooden posts, pits dug to provide grazing animals with water, and patterns of linear features in the landscape. We want to conserve such elements.’

It Hallumer Ryt

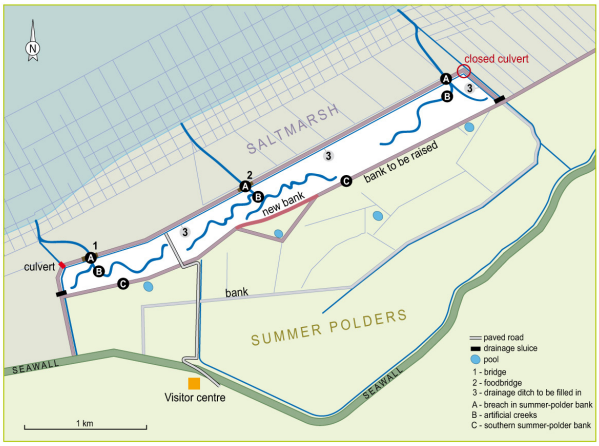
All the same, *It Fryske Gea* is looking to create more saltmarshes. The trial was followed up in 2009 by the conversion into saltmarsh of a 48-hectare summer polder in the Bildtpollen, another area in Noard-Fryslân Bûtendyks. The next project on the list is *It Hallumer Ryt*. The local water board is planning to build a new pumping station called Vijfhuizen in the seawall south of the saltmarsh restoration area. This project kills two birds with one stone. It will increase the capacity for water discharge from the polderland inside the seawall and, at the same time, restore a gradual transition from fresh to salt water outside the seawall. De Vries is enthusiastic about this project. 'We are re-introducing an element that was lost from our saltmarshes long ago, namely, river water.' He already has areas in mind for further saltmarsh restorations. 'First of all, we must prepare the area so it meets a number of specified conditions such as creating sufficient space for meadow birds,' he explained.

Collaboration

Noard-Fryslân Bûtendyks presents a challenge to the community. A vast saltmarsh area which has international appeal is not only in the interest of nature conservation but also benefits local residents, holidaymakers and business. 'Nature, recreation and climate-proof water management can profit from each other in Noard-Fryslân Bûtendyks. We are doing our best to involve the local community: there's our new visitor centre, the *Kweldercentrum Noarderleech*, our school programme, and we organise excursions and encourage discussion. By pulling together we can create new natural habitats outside the seawall that will benefit everybody. We have to work together.'

Setting up the saltmarsh trial

To let seawater into the trial restoration area, three openings (A) were made in the northern bank of the summer polder, and the ditch behind the bank was filled in. Over a total length of five kilometres, three creeks (B) were excavated in the area. These creeks were then connected outside the trial area, to existing creeks in the adjacent saltmarsh north of the trial area. To prevent the adjacent summer polders becoming brackish, the south bank (C) of the summer polder was raised and widened.



Ten years of research into saltmarsh restoration

How has the saltmarsh restoration experiment affected the natural environment? Has a salinity gradient developed from the salt-water influence? Is the marsh level rising along with the sea? A team of experts has been looking into these questions since the beginning of this century. In fact they started work even before then – they collected data to record the situation before the trial started. More than ten years later they did the final measurements. This long-term project has produced a wealth of useful information for organisations such as *It Fryske Gea*.

'Gather detailed information about the process of saltmarsh restoration.' That is what *It Fryske Gea* asked the researchers to do. The monitoring of sedimentation, increasing salt levels, plant growth, staging geese and breeding birds was integrated into the project and carried out over a long period. During the first five years this happened intensively, and then twice more – in the seventh and tenth years. Numerous organisations took part in the monitoring programme (see inset) and many researchers worked in the area collecting data. They now know the saltmarsh like the back of their hand, working there almost every day during the season for years on end – carrying around equipment, collecting data on plant growth and measuring the increasing height of the brand-new marsh. Before their eyes, they saw the area change from a summer polder with closely grazed fresh grassland into a saltmarsh with salt-tolerant plants.

Valuable information

This monitoring project was unique. The researchers involved believe few other saltmarsh restoration projects have been so thoroughly researched over such a long period. Projects involving saltmarsh regeneration have been carried out in various parts of Europe over the last few decades, but most have not been well documented so hard data is missing. This kind of research has to be long-term because certain processes like elevation change and vegetation development only become apparent after ten years have passed. Without this research we would not have known, for example, that the surface level in the trial area increased by seven centimetres. The monitoring has now finished but it would be useful to keep following developments, if not with the same intensity. It would be interesting to measure the marsh level and map vegetation development in the restored saltmarsh again around 2020.

Monitoring report

An extensive research report describing the ten-year monitoring programme, its methods and results has been published. It can be found at www.itfryskegea.nl or it can be requested from *It Fryske Gea*.

Parties involved in the monitoring

The monitoring research was commissioned by *It Fryske Gea*. During the first five years, the parties jointly implementing the programme were consultancies *Koeman en Bijkerk* and *Altenburg & Wymenga*, and the Wadden Sea Birds Working Group *(Wadvogelwerkgroep)* of the regional field-biology association *(the Fryske Feriening foar Fjildbiology – FFF)* under the supervision of Alterra-Texel (now part of IMARES-Wageningen). Financial support for the five-year research project came from the EU (LIFE-Nature programme), the then Ministry of Agriculture, Nature, and Food Quality, *Rijkswaterstaat* (the Directorate-General of Public Works and Water Management), the province of Friesland *(Provinsje Fryslân)*, the *Prins Bernhard Cultuurfond*s, the University of Groningen and *It Fryske Gea*.

During the second period of five years, the research was extended step-by-step. After a storm surge occurred on 1 November 2006, the *Prins Bernhard Cultuurfonds* provided funding to investigate the influence of storm activity on developments in the trial marsh, so in 2007 researchers were able to repeat an important part of the monitoring process. A *Waddenfonds* grant allowed a further re-run in 2011/12. The parties involved in this follow-up project were PUCCIMAR ecological consultancy, *Bosgroep Noord-Oost Nederland*, IMARES-Texel, *Altenburg & Wymenga* consultancy and the FFF Wadden Sea Birds Working Group.

6

Noarderleech receives a full salt bath

From fresh to salt water

Since September 2001 - when the polder received its first salt bath – salt water has flowed into the restoration area with every incoming tide. The water spreads further via the creeks, bringing salt into the area.

117 times in ten years: that was how often the saltmarsh trial area was completely flooded

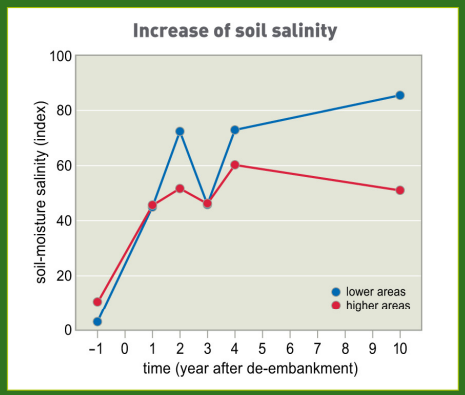
The figure below shows that salt levels rose quickly in the first year after seawater was let in. After this sudden leap, the increase levelled off. In fact the salt content of the soil in the trial area is still lower than that of the adjacent saltmarsh.

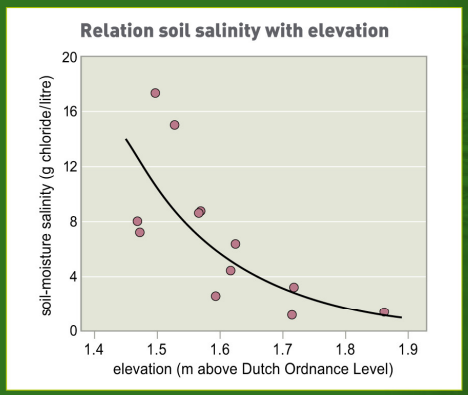
The lowest parts of the trial area are submerged fifty to a hundred times every year; in the higher areas this happens more sporadically. Because of the difference in the number of flood events, there is an inverse relationship between soil salinity and marsh elevation. Salinity is lower at higher elevations.

Now and again the whole trial area becomes submerged. During the ten years, this happened 117 times, which amounts to about twelve times a year. Before seawater was allowed in, submersion happened less than once a year.

Salt levels in the soil can vary enormously. Long and heavy rainfall causes salt levels to fall, while considerable flooding causes them to rise. In the summer, the salt content is often higher than in the winter. During dry summers, salty groundwater rises towards the surface, so the soil becomes saltier than in the winter.

The seawater has not made the adjacent summer polders any saltier. Raising the summer-polder bank proved to be adequate to prevent this from happening.





Saltmarsh workers

History: saltmarshes under pressure

Saltmarshes are scarce. Where the landscape of North Friesland once consisted largely of saltmarsh interspersed with raised inhabited mounds, now only a narrow strip running along the outside of the seawall is left. It is a strip of great value.

At first glance, there would appear to be no shortage of saltmarshes in Noard-Fryslân Bûtendyks. Walking through the area, the scale is vast and impressive. Internationally, however, saltmarshes are under great pressure. In the Netherlands no less than 80% of all the mainland saltmarshes has disappeared. Around the year 1600, saltmarshes along the northern mainland coast covered still some 14,000 hectares but only 3,300 hectares remain today, 1,500 of which in Noard-Fryslân Bûtendyks.

Terpen landscape

Saltmarshes are a natural feature of the coastal area of the Northern Netherlands. In fact, the coast used to be an immense saltmarsh area stretching some twenty kilometres towards the sea – as far as the present sea clay landscape now reaches inland. The inhabitants of the area lived on dwelling mounds called terpen (or terps) which stood just a few metres above the saltmarsh surrounding them; this is how they 'kept their feet dry' at high water. Nowadays the sea is kept out by a seawall but the former terpen landscape, which is regarded as one of the most ancient man-made landscapes in the Netherlands, can be seen wherever one looks with terp villages and winding watercourses a reminder of a time when the saltmarshes dominated the area.

Bunker

In the middle of the trial saltmarsh there is an old bunker from the Second World War when the German occupying forces used the Noarderleech area for their military training. From this bunker they watched as their airmen practiced their bombing techniques on two model ships especially placed in the area for that purpose. The bunker still serves as an excellent lookout point across the saltmarsh but, these days, not for soldiers but for nature lovers, giving the cultural heritage site a public function. A panel fixed to the bunker provides visitors with information about how the war impacted on the Noarderleech.

8

Embankments

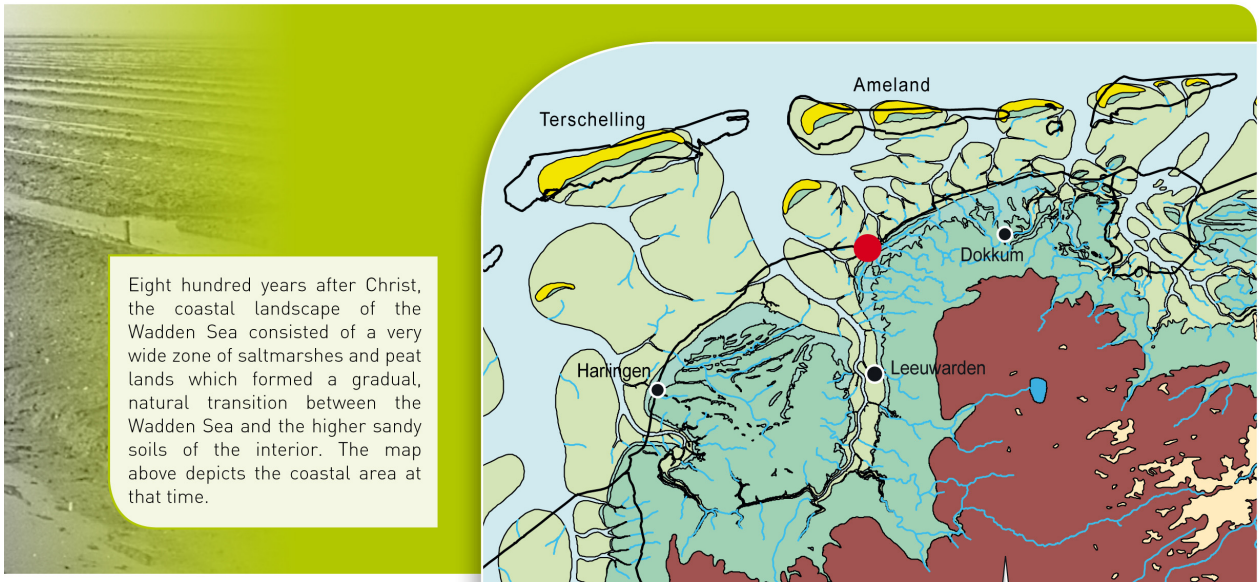
That time is past. The struggle against the sea has been gloriously won. Step by step, dike after dike man pushed back the sea. The first ring-dikes in North-West Friesland appeared in the tenth century AD and around 1200, the embankment of the Middle Sea was begun. Little remains of the wide saltmarshes of the past, the coastline has been moved towards the sea and only a narrow strip of saltmarsh still runs along the coast. Indeed, in a lot of places including the west coast of Friesland, there are no saltmarshes left at all; a decline which has occurred not just in Friesland but along the entire coast of the Dutch Wadden Sea.

Saltmarsh-works

Today's saltmarshes are man-made creations which have been claimed from the sea using ditches and brushwood groynes. In the past, ditching was applied to drain the seawater and promote vegetation development. By enclosing intertidal areas with brushwood groynes so-called sedimentation fields were created for the sediment carried in on the flood-tide to settle out. Formerly, such saltmarsh-works were applied to acquire new land for farming, but nowadays only the groynes are maintained to protect existing saltmarsh from erosion.
The summer polders in Noard-Fryslân Bûtendyks are of a relatively recent date, being claimed from the sea by private landowners between 1892 and 1956. The polder of the saltmarsh restoration trial dates from the year 1909 and for almost a century served as grazing pasture.

Heated debate

Noard-Fryslân Bûtendyks was very nearly embanked too, if this had happened it would be potatoes not saltmarsh plants growing there today. In the 1970s serious plans to embank the saltmarsh were put forward. Before this time, even more drastic plans to claim large parts of the Wadden Sea had been devised. All of this led to heated debate with agricultural interests and nature conservationists fiercely opposing each other.



Eight hundred years after Christ, the coastal landscape of the Wadden Sea consisted of a very wide zone of saltmarshes and peat lands which formed a gradual, natural transition between the Wadden Sea and the higher sandy soils of the interior. The map above depicts the coastal area at that time.

From: Vos & Knol. 2014. *Paleogeografische kaarten van het Waddengebied tussen Marsdiep en Weser 500 v. Chr. – heden.* © Deltares, Utrecht.

But, at some point, attitudes changed. The ecological value of the saltmarshes and the Wadden Sea was recognised *and* there was political room for new policies. Then, in 1986, a decision was taken not to embank Noard-Fryslân Bûtendyks. Thanks to this decision we now have a unique area of saltmarsh seaward of the seawall. After centuries of combatting the sea, people realised that the international Wadden Sea was short on saltmarshes and would benefit from the creation of new ones. Saltmarshes are important as breeding grounds for birds that forage on the mudflats. They also provide a natural habitat for dozens of plant species and are a spawning area for fish.

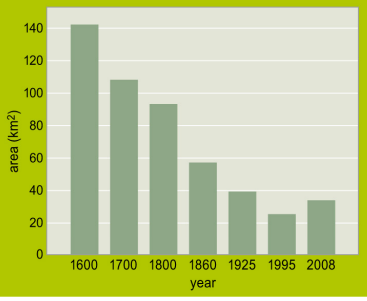
New saltmarshes

At the time, it was agreed that not only the existing saltmarshes should be preserved but that the total area of saltmarsh should be extended as well and a number of international agreements were made to this end. Because of the exceptional value of the Wadden Sea as a foraging area for migratory birds, extending seaward was not an option; instead, the dikes were to be set back inland. Noard-Fryslân Bûtendyks was chosen as the most suitable location for creating new saltmarshes because of the summer polders available in this area – a good 1000 hectares. In 1990, shortly after the planning decision had been taken, a plan to convert these summer polders into saltmarshes was developed, a plan which would make Noard-Fryslân Bûtendyks one of the largest continuous saltmarshes in Europe.
Re-establishing saltmarshes struck a sensitive chord with a number of people from the local community who, in some cases from their own experience, knew just how much time and effort it had taken to claim the polders from the sea in the first place. Restoring saltmarshes was completely at odds with their long and proud history of claiming land from the sea. Because of all the opposition to the plan, *It Fryske Gea* decided to carry out a trial restoration first.

Traces

Noard-Fryslân Bûtendyks is not only a valuable saltmarsh area but has its own unique cultural history too; a history which has left its mark on the landscape in many different ways. The banks, the land-use pattern, the ditches, the banks of the summer polders and the watering points reveal the story of centuries of sedimentation and the struggle against the sea. *It Fryske Gea* wants to preserve these cultural and historical elements so that people can see with their own eyes what Friesland looked like in the past.

Dutch Wadden Sea decrease of mainland saltmarshes



Saltmarshes are climate-proof

Saltmarshes are climate-proof. This is because they grow with rising-sea levels. Summer polders don't: over time they become bathtubs which the water can't escape from. Aided by the tides, the trial saltmarsh is quickly catching up. In just ten years' time its level has increased by seven centimetres.

Sea level is rising; over the past century the sea level along the Dutch coastline has risen by more than twenty centimetres and continues to rise, possibly accelerated by global warming. There is no doubt that our climate is changing and that a higher sea level could seriously threaten valuable nature areas outside the seawall.
Saltmarshes can offer a measure of relief from this process. With every flood-tide a thin layer of sediment is deposited on the saltmarsh so that it grows upward as the sea level rises. Because of this function, saltmarshes are regarded as 'climate buffers', natural areas which limit the effects of climate change. Summer polders, however, are not climate-proof. Whilst the surface level of saltmarshes increases as the sea level rises, summer polders do not grow in height. When a summer polder is inundated during an extreme storm surge, the water coming into the polder is held in by the surrounding dikes and the polder acts like a bathtub without a plug to let the water drain away. 'If we do nothing, in future we will be pumping seawater from our summer polders. That is unthinkable,' said Chris Bakker, who is responsible for the Quality of the Natural Environment at *It Fryske*

Gea. He believes in keeping up with the rising sea level. 'That way we utilise natural processes. With every flood-tide the sea brings in new sediment, all for free.'

Keeping up with the sea-level rise

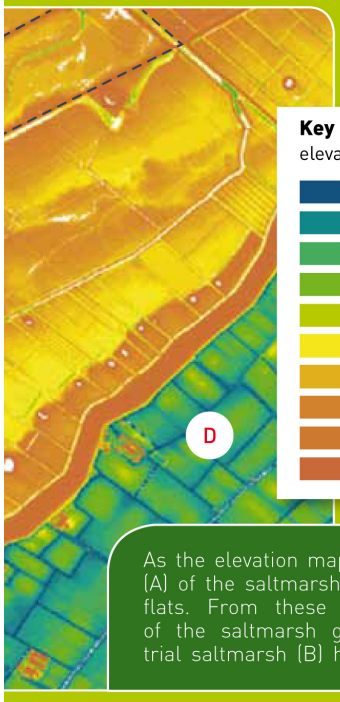
Saltmarshes keep up with the rise in sea level; this is a fact backed up by measurements. For almost a century the trial area in Noard-Fryslân Bûtendyks was only flooded occasionally. In comparison to the sea level, the polder lagged behind by about twenty centimetres, but as soon as the first floods occurred, it began to accrete sediment and grow upward again. Over a ten year period the surface of the trial saltmarsh rose by seven centimetres. The surface of the adjacent saltmarsh rose much faster during this period, by 21 centimetres on average, partly because it is located closer to the sea where more sediment is deposited. The upward growth of the trial saltmarsh was more than enough to keep up with the rising sea level; in fact, a third of the deficit has been made up. 'Keeping pace with sea level is working brilliantly,' is Bakker's conclusion. 'The trial saltmarsh will make up the deficit completely within a few decades.' The surface of the trial saltmarsh is not rising at the same rate everywhere. Sediment has been building up a lot quicker in the lower part than the higher part; three times as quick, in fact. This is because the lower part is flooded more frequently and for longer periods of time so that more sediment is left behind. The same applies to the creeks in the area; on average, the areas next to creeks increased in height faster than the areas further away.

Coastal defence

Keeping up with sea-level rise doesn't only benefit the saltmarshes but makes us safer too. Acting as a buffer, a saltmarsh reduces the force of the waves rolling in towards the dike. Without this damping effect the waves would roll on and pound the dike, potentially causing a lot of damage. Bakker: 'Awareness is growing that the areas outside the seawall, like Noard-Fryslân Bûtendyks, are strategically important for coastal defence. They increase the safety afforded by the seawalls. Converting more summer polders into saltmarshes can contribute to the creation of a climate-proof dike zone. If we don't do this, thirty or so years from now there will be a permanent lake of water standing in the low-lying summer polders next to the seawall.'

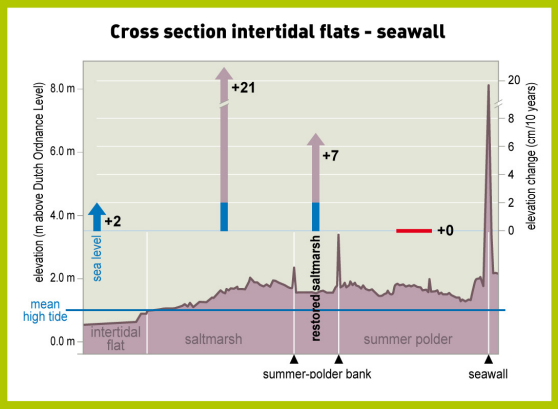
Chris Bakker:

"Areas seaward of the seawall such as Noard-Fryslân Bûtendyks are important for coastal defence."



Key
elevation (m)

- < 0.25
- 0.26 - 0.50
- 0.51 - 0.75
- 0.76 - 1.00
- 1.01 - 1.25
- 1.26 - 1.50
- 1.51 - 1.75
- 1.76 - 2.00
- 2.01 - 2.25
- > 2.25

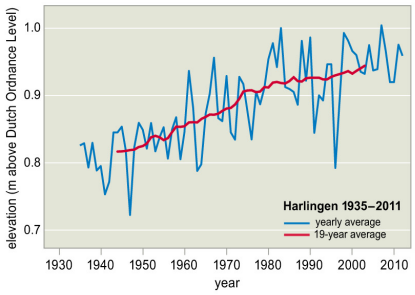


As the elevation map shows, the lower parts (A) of the saltmarsh border on the intertidal flats. From these flats the surface level of the saltmarsh gradually increases. The trial saltmarsh (B) has grown upward but is still lower that the adjacent saltmarsh. The summer polders (C) are a lot lower again. The land inside the seawall (D) has not been accreting since the seawall was built and is, therefore, lower.

How is sediment accretion of a salt-marsh measured?

Sediment accretion in the trial saltmarsh was measured in several ways. Out in the field, researcher Peter Esselink points at two posts standing two metres apart. 'I would rest a bar on the top of these posts and then use a measuring rod to measure the distance from this bar to the surface.' Posts like these were sited at over a hundred different places in the project area. Nine months before the saltmarsh trial began a number of initial measurements were taken. Then in the years up to 2005 the researchers visited three times a year. In 2007 and 2011 a single set of measurements were taken in late summer. The researchers also buried 56 stainless steel plates in the ground which they later located using a metal detector: By pushing a measuring rod vertically into the sediment until it hit the plate, they were able to monitor each year's sediment accretion.

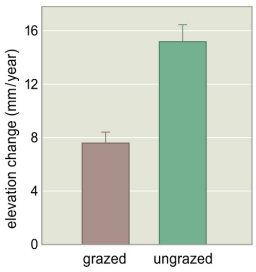
Sea-level rise



Grazing retards sediment accretion

Grazing inhibits the accretion of sediment because the animals trample the soil and compact it. In grazed areas, vertical accretion was sixty per cent lower than in ungrazed areas.

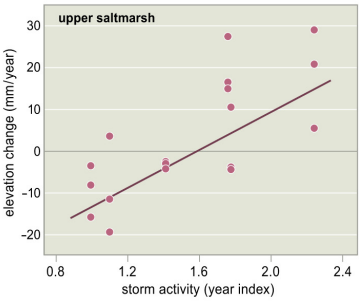
Livestock grazing and elevation change



Storms speed up sediment accretion

Storms accelerate the accretion of sediment. The more violent the storm, the more sediment is deposited on the saltmarsh. Why is this? For one thing, during a storm seawater carries a larger number of particles than usual, then there is the additional impact of a deeper layer of water above the saltmarsh during a flood. In years with many storms the surface level of the trial saltmarsh increased more rapidly than in other years. The accretion rate also differs throughout the year. Vertical accretion of the saltmarsh is more rapid in autumn and winter when most of the storms occur. In years with few floods, surface elevation of the saltmarsh may even decrease as a result of soil shrinkage, induced by dryness in summer, and trampling by livestock.

Effect of storms on elevation change



Johannes Kramer:

‘Saltmarsh restoration stirs up strong feelings’

Restoring a saltmarsh raises the ecological value of the natural environment. This is what Johannes Kramer, a member of the Friesland Provincial Executive, believes. He passionately supports saltmarsh restoration, but also understands how sensitive various issues can be.

Kramer regularly visits Noard-Fryslân Bûtendyks. If he happens to be in the neighbourhood, he drives to the seawall to see how the land beyond it is faring. ‘The wide-open spaces, the changing skies, the water. It looks different every time, but it’s always beautiful,’ he said. The land beyond the dike fascinates him. For him, it is an area of contradictions. ‘You can look at it in many different ways. You could call it a wild landscape where nature is in control. Yet it is totally created by human intervention, an important piece of Friesland’s cultural history.’

Commitment

Kramer believes that increasing the total area of saltmarsh by exposing summer polders to salt water from the Wadden Sea is a task facing the province and associated parties. There is an international commitment to saltmarshes, agreed on as part of European and national policy, according to Kramer. ‘The Natura 2000 and the Water Framework Directive both deal with matters outside the seawall.’

A member of the provincial government, he is very committed to this particular cause. He believes the saltmarsh restoration trial begun in 2001 is enhancing the natural environment. ‘Although I’m not a biologist, I can see that the project is having a positive effect on the ecological value of the area.’ The role of a saltmarsh as a roosting place for migrating birds during high tide is an especially important one, Kramer feels. Furthermore, a saltmarsh grows at the same speed as the sea level rises. ‘In this way, saltmarshes help to defend our coastline. Summer polders do not increase in height; they are simply a low-lying basin next to the seawall.’

Communication

All the same, as an administrator Kramer has to take other aims into account as well, such as the Province’s ambitions for meadow birds and the support from local residents. ‘The plans cause friction, especially within the local community. The debate about the land outside the seawall has gone on for decades. It stirs up strong feelings. The forefathers of some of the local people created the land with their bare hands. Saltmarsh restoration – something they see as giving the land back to the sea – causes them pain. It’s in their genes. As far as they’re concerned it’s first-rate farmland.’

Kramer always keeps the dialogue open. He receives all sorts of queries from worried residents, farmers and politicians. Communication is crucial, he believes. He is paving the way with enthusiasm. ‘I’ve done my very best to convince the local council. People are beginning to understand what it’s all about, although it’s still a sensitive issue. We have to adequately explain what we’re doing and ensure the benefits for the area are visible. *It Fryske Gea* does this really well, for example, with their visitor centre and publications such as this brochure.’ Kramer emphasises that the region benefits from the natural saltmarsh environment outside the seawall. ‘The spectacle of nature draws more visitors and the whole community profits from small-scale, high-quality tourism.’ He regards the experiment with saltmarsh restoration as a touchstone for the future. ‘We can learn from this and improve our methods for future restoration projects.’

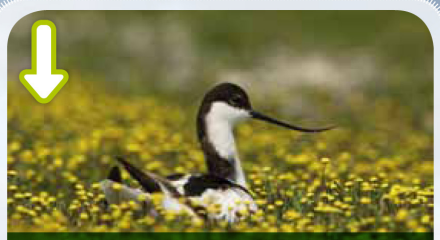
Winners
and losers

There are winners and losers in saltmarsh restoration. Salt-tolerant plants benefit from seawater whereas meadow birds prefer to seek refuge in a summer polder. Here we show seven plants and animals characteristic for the area. How are they doing?

Redshank

Length: 27-29 centimetres, span 45-52 centimetres
Colour: grey-brown with bright orange legs and bill
Trend: increasing in the whole of Noard-Fryslân Bûtendyks, including the trial area

The redshank is doing well in Noard-Fryslân Bûtendyks. In 2011, there were 392 territories; 59 more than round 2000. Redshanks like saltmarshes. They breed in the rougher areas. Redshank numbers are increasing in the trial area.



Avocet

Length: 42-46 centimetres, span 77-80 centimetres
Colour: white body, black crown and black markings on back and wings
Trend: decreasing in the Netherlands and Noard-Fryslân Bûtendyks, including the trial area

The thousands of avocets in Noard-Fryslân Bûtendyks are an amazing sight with their black-and-white markings, slender legs and upturned bills. The numbers of avocets are decreasing probably due to predation, certainly in Noard-Fryslân Bûtendyks. Outside the seawall, the number of breeding avocets has fallen by 25% over the last twenty years. When the saltmarsh restoration trial began, the numbers increased initially, but after 2006 there was a sudden drop. In 2002, a year after seawater was let in, there were 79 breeding pairs. In 2011, only nine.

Oystercatcher

Length: 40-45 centimetres, span 80-86 centimetres
Colour: black back and crown, white belly; distinctive long orange-red bill and legs
Trend: decreasing in the Netherlands, in saltmarshes as well

The numbers of oystercatchers are decreasing dramatically in the Netherlands, partly because of disappearing mussel beds. The population of oystercatchers has more than halved since 1990. This long-term trend also applies to Noard-Fryslân Bûtendyks, with decreasing numbers in both the saltmarsh and trial area. The population is stable only in the summer polders.

Seaside alkali grass

Length: 30 to 70 centimetres
Colour: grey-green
Flowering season: June to September
Trend: increasing substantially in the trial area

Seaside alkali grass (*Puccinellia maritima*) copes well with salt. The plant grows on low saltmarshes that are regularly flooded by seawater. On the grazed saltmarsh, it can form a dense mat. Seaside alkali grass is nourishing, being rich in protein. It appeared from nowhere during the first year after the polder was flooded. In the years following, the grass spread rapidly, especially in the low-lying areas. Subsequently its development has varied from place to place. At some spots, the grass has become less common due to inadequate drainage, being trampled by grazing animals, etc. At other places it has increased.

Glasswort

Length: 2 to 30 centimetres
Colour: flowers are green, rest of plant dull green
Flowering season: July to October
Trend: increasing substantially in the low parts of the trial area

Glasswort (*Salicornia europaea*) grows in the wettest and saltiest parts of a saltmarsh. Where the saltmarsh merges into intertidal flats, glasswort turns the marsh dark red in late summer. This annual plant has spread very rapidly in the trial area. In the low-lying eastern area, glasswort has been doing especially well in recent years and now dominates half the area.

Great white egret

Length: 85 - 100 centimetres, span 1.45 to 1.70 metres
Colour: white body and wings, black legs, yellow bill
Trend: increasing all over the Netherlands, including Noard-Fryslân Bûtendyks

The great white egrets – brilliant white in colour – are an imposing sight in the saltmarshes. The species is increasing explosively in the whole of the Netherlands. Just ten years ago, this egret was rare and now it is part of our winter landscape. It is remarkable that the birds have recently started visiting saltmarshes.

Barnacle goose

Length: 58 - 70 centimetres, span 1.20 to 1.42 meter
Colour: yellowish white face, black nape and breast, grey-white belly, black legs and bill
Trend: decreasing in spring, increasing in autumn

Noard-Fryslân Bûtendyks has been an important staging post for geese for some time. Geese use the trial area mainly in autumn. In spring, few geese are seen in the restoration saltmarsh because the vegetation – glasswort and common seablite (*Suaeda maritima*) – is not a suitable feeding habitat for geese in this season. In the autumn these two plants become edible so that, when the geese arrive from their breeding grounds, they find sufficient food in the trial saltmarsh.

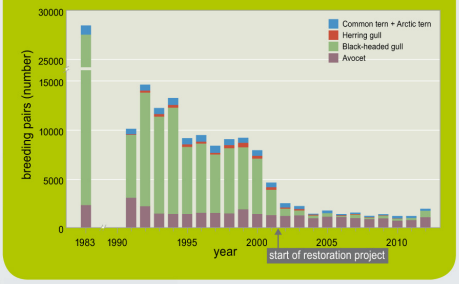
Noard-Fryslân Bûtendyks as bird paradise

Noard-Fryslân Bûtendyks is one of best bird areas in the Netherlands. In the winter, as many as 100,000 geese alight there, with 40,000 of them making for the *Noarderleech*. It was to be expected that converting a summer polder to a saltmarsh would have an effect on the bird populations. After all, each landscape has its own distinct birdlife. The birds on agricultural land are different from the ones on natural saltmarshes. Daan Bos, a biologist and researcher at *Altenburg & Wymenga* provides some answers to the key question: what is the effect of saltmarsh regeneration on bird populations?

BIRD COLONIES:
big reduction before saltmarsh trial

Noard-Fryslân Bûtendyks has always been known for its imposing flocks of birds, with huge numbers of black-headed gulls, common terns, Arctic terns and avocets breeding there. Until the end of the last century. Since then, the number of colonial birds has been decreasing. 'This is most probably because predators such as foxes are on the rise,' Daan Bos explained. He also mentioned other causes, such as the way the area is managed and the availability of food in the Wadden Sea. Bos emphasised that the decrease was not simultaneous with saltmarsh restoration. What's more, the large colonies which have disappeared did not live in the restoration area. 'That's why I don't believe there's a direct relationship between the saltmarsh trial or any other saltmarsh restoration in the past and the decrease in colonial nesting birds,' he said.

Decrease of colonial birds in Noard-Fryslân Bûtendyks



Daan Bos:

'A significant percentage of the geese can be found on the grazed saltmarshes.'

GEESE: total numbers remain stable

Brent geese, in particular, have a strong preference for saltmarshes, but barnacle geese are also found there in large numbers. 'In Noard-Fryslân Bûtendyks, a significant percentage of the geese are present on the grazed saltmarshes,' Bos related. Yet hardly any geese visited the saltmarsh restoration area in the first spring of the trial. Since then, the geese have been re-establishing themselves and now, just as many geese graze there as before the trial started. But only in the autumn period; in spring the numbers are still low. Bos blames this spring decrease on inadequate drainage and overgrazing. 'These two factors make the lower parts of the saltmarsh trial area less suitable for geese. Hardly any vegetation suitable for geese, like seaside alkali grass and sea plantain *(Plantago maritima)*, grows on the bare soil in spring.' Nevertheless he believes the results are positive. 'Eventually, plants that geese can eat will establish themselves there. Areas with suitable food sources will increase – partly because of natural sedimentation and partly because of better grazing and drainage.'

Since the trial area was de-embanked the total geese population in Noard-Fryslân Bûtendyks has remained stable, this applies to both barnacle and brent geese. Bos believes the saltmarsh restoration has not had any effect on the numbers of geese staging in the total area outside the seawall, partly because of the limited scale of the trial. 'Noard-Fryslân Bûtendyks has always been an important staging post for geese and still is. There was concern that the geese would look for alternative places inland but that hasn't happened.'

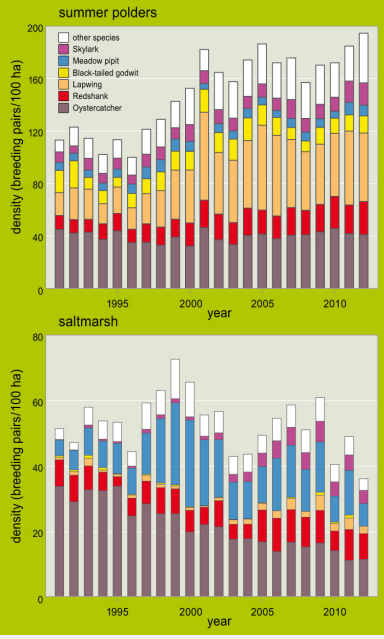
Goose numbers in Noard-Fryslân Bûtendyks

MEADOW BIRDS: more in summer polders than on saltmarshes

Black-tailed godwits, redshanks, meadow pipits and skylarks are present in the whole of Noard-Fryslân Bûtendyks in large numbers, but the populations differ somewhat: in the summer polders, the density of meadow birds has increased whereas on the saltmarshes there has been a slight fall. 'In the trial area the number of meadow birds has fallen to the levels usual in an average saltmarsh. This decrease was to be expected. Black-tailed godwits and lapwings are typical farmland birds. If you convert a summer polder into saltmarsh, the density of meadow birds will obviously decrease,' Bos said, at the same time emphasising that saltmarshes are just as valuable for meadow birds as they are for geese. 'Fewer meadow birds per hectare nest on saltmarshes, but in absolute numbers the saltmarshes are incredibly important. And this will certainly be the case once saltmarsh management has been optimised. Then you can expect more of these birds.' Not all species have declined, according to Bos. You now hear the characteristic *teuk-teuk-teuk* call of the redshank more and more on the saltmarsh of Noard-Fryslân Bûtendyks, while it is becoming less common elsewhere in the Wadden Sea. The skylark is doing well too, whereas inland it is decreasing. Bos is glad to see that the number of species is increasing both in the summer polders and in the saltmarshes.

Even though summer polders probably score higher on the whole, there are specific differences between individual polders. Meadow birds generally benefit from marshy areas with pools, fairly low vegetation at the start of the breeding season, extensive management with hardly any use of fertiliser, carefully planned grazing and little disturbance. That is the case in some summer polders and the results are convincing. Bos: 'The summer polders managed by *It Fryske Gea* are probably among the best areas for meadow birds in Friesland.'

Breeding birds in summer polders and saltmarsh



Goose droppings and grazing

Goose droppings reveal how many geese have been grazing in an area. To measure the extent to which birds use an area, researchers counted the number of droppings per square metre in May. They did measurements at eight spots in both the livestock grazed and ungrazed areas. In grassy vegetation – in the high-lying western section and inside the fenced-off areas – more geese droppings were found. In the low areas where drainage was inadequate, grazing by livestock had a strongly negative effect on goose activity.

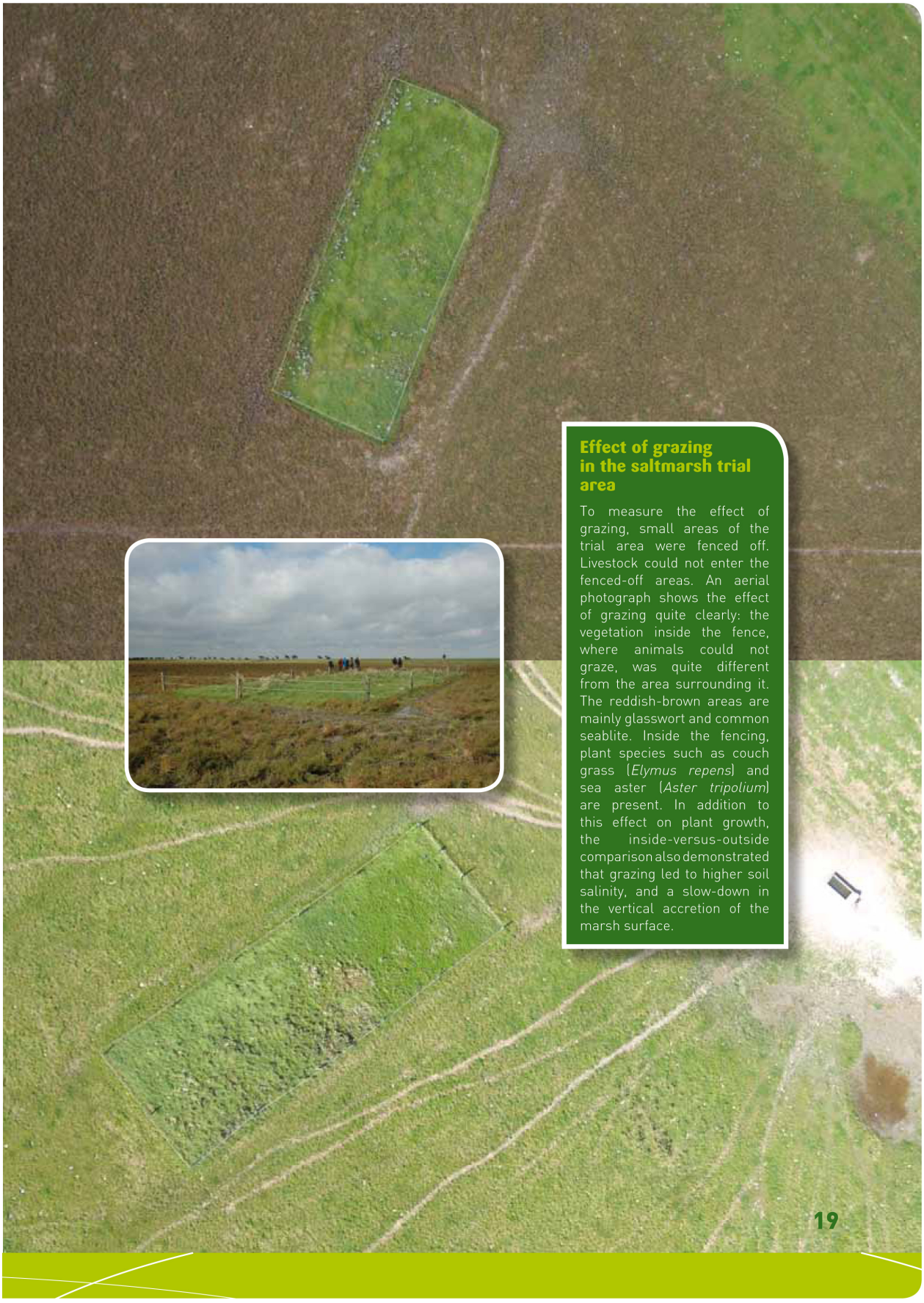
Debate: saltmarsh or summer polder?

Plans to create more saltmarshes in Noard-Fryslân Bûtendyks have not been enthusiastically received by the FFF Wadden Sea Birds Working Group in Friesland. Volunteers in this working group have been counting the breeding and migrant birds outside the seawall for decades. They are very concerned about the reduction in numbers of breeding birds that accompanies saltmarsh restoration. They are afraid there will be less room for black-tailed godwits, avocets and other breeding birds. 'Our working group does not agree with this saltmarsh restoration. It is quite clearly detrimental to the breeding bird population. These summer polders are the most heavily populated breeding areas in Noard-Fryslân Bûtendyks,' explained Sieds Boersma, a member of the FFF and an excursion leader for *It Fryske Gea*. He is less worried about the geese. 'They'll find another place outside the seawall.'

Breeding bird trends

In Noard-Fryslân Bûtendyks, 99% of the breeding birds belong to just sixteen species. The list below shows breeding trends for these species between 1991 and 2012. A green arrow pointing upwards means an increase, a red arrow pointing down is a decrease, and a double arrow means a big decrease. A dash means the population has remained stable.

	Noard-Fryslân Bûtendyks	The Netherlands
Skylark	↑	↓
Lapwing	↑	↓
Redshank	↑	-
Coot	↑	-
Reed bunting	↑	↑
Shelduck	-	↓
Black-tailed godwit	-	↓
Arctic tern	-	↓
Meadow pipit	-	↓
Mallard	-	↓
Yellow wagtail	↓	-
Oystercatcher	↓	↓
Avocet	⇊	↓
Black-headed gull	⇊	↓
Herring gull	⇊	↓
Common tern	⇊	↓



Effect of grazing in the saltmarsh trial area

To measure the effect of grazing, small areas of the trial area were fenced off. Livestock could not enter the fenced-off areas. An aerial photograph shows the effect of grazing quite clearly: the vegetation inside the fence, where animals could not graze, was quite different from the area surrounding it. The reddish-brown areas are mainly glasswort and common seablite. Inside the fencing, plant species such as couch grass (*Elymus repens*) and sea aster (*Aster tripolium*) are present. In addition to this effect on plant growth, the inside-versus-outside comparison also demonstrated that grazing led to higher soil salinity, and a slow-down in the vertical accretion of the marsh surface.

Saltmarsh plants are advancing

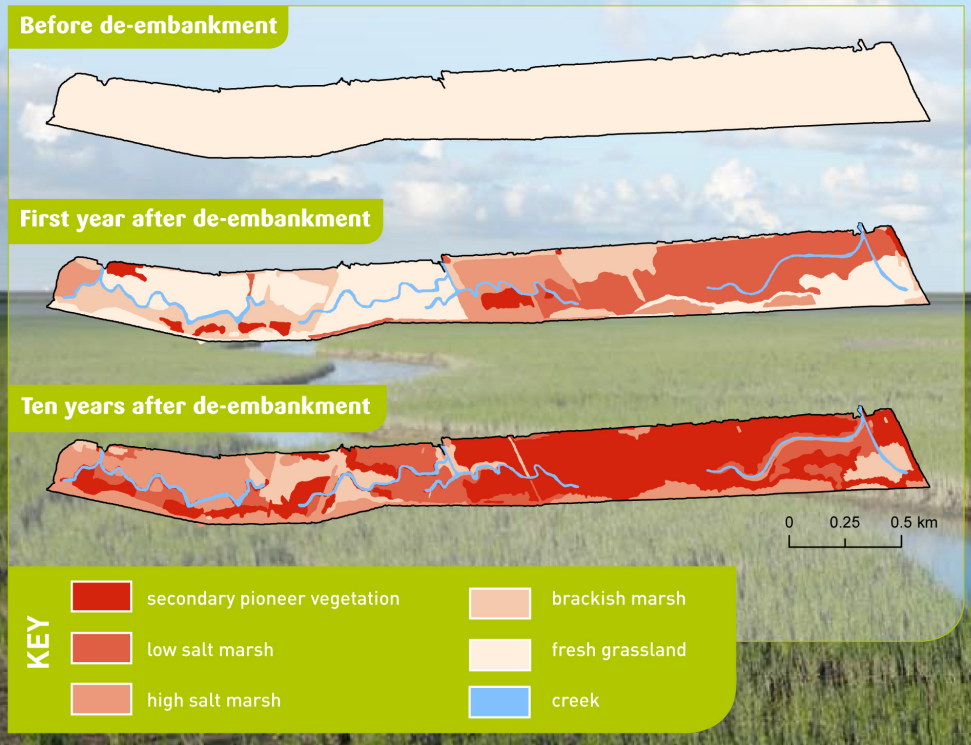
An ordinary grassland with salt-intolerant plants: that is what the polder was in 2001 before it was exposed to the tides. Then the vegetation began to change. After just one year, salt-tolerant plants had appeared everywhere and even dominated some parts of the marsh. This transformation continued steadily in the following the years.

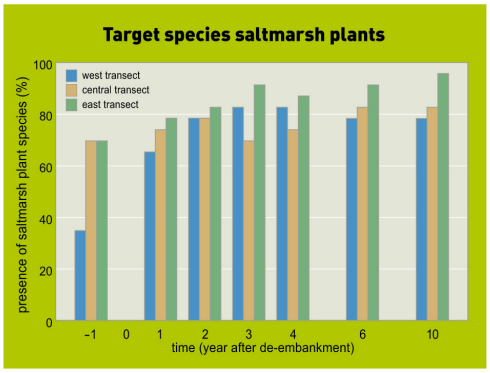
100 of the targeted species are already growing in the trial saltmarsh

Salt-tolerant plants can be found everywhere on the marsh. Glasswort, common seablite, sea aster, lesser sea-spurrey (*Spergularia marina*) ... the mere sound of the names conjures up the sea. The transition from plants that cannot tolerate salt to salt-tolerant ones has been a great success. Before saltmarsh formation began, researchers had drawn up a list of 23 salt-tolerant plants. If those appeared, saltmarsh formation could be regarded as successful. 'All the target species now grow there and are spreading,' according to Roos Veeneklaas who is a researcher for *Bosgroep Noord-Oost Nederland*, an association of woodland managers. Late in the summer of 2011, she collected data on the vegetation in the trial area; first with aerial photographs and then in the field, where she drew the boundaries with the aid of GPS. The vegetation map she made is shown on this page together with the two maps made earlier by the *Rijkswaterstaat*. The three maps illustrate how salt-tolerant plants are advancing. Before salt water was let in, there was fresh grassland with perennial ryegrass (*Lolium perenne*) and practically no salt plants. Now the area has a rich variety of saltmarsh plants. The seawater ensured that large numbers of these salt-tolerant plants could establish themselves in this area even in the very first year. Ten years later, the fresh grassland had disappeared.

Gradients

A saltmarsh consists of zones. If you walk from the seawall towards the sea, you will notice how the vegetation changes in a natural saltmarsh. In the higher and dryer areas, you will find plants such as red fescue (*Festuca rubra*) and sea couch (*Elymus athericus*). Near the sea – where the saltmarsh is





lower and the tides have a greater influence – you will find plants like seaside alkali grass and sea aster. There the soil is wet and salty. In the transition zone to the bare mudflats these factors play an even bigger role; glasswort and common seablite stick out of the mud here and there. This gradient from wet to dry and from very saline to almost fresh, can also be found in the trial area – but not at right angles to the coastline as in a natural saltmarsh. Instead it is parallel to it. The eastern part of the saltmarsh trial area is lower than the western part. Vegetation belonging to a high saltmarsh should therefore be on the left-hand side of the map with on the right-hand side, vegetation from a low saltmarsh. The high saltmarsh is clearly visible, but the low-lying saltmarsh much less so. This is because, in the eastern part, so-called 'secondary pioneer vegetation' dominates. 'This part of the saltmarsh is full of glasswort and common seablite. It is these two plants that give the saltmarsh its reddish colour early in the autumn,' Veeneklaas explained.

Re-wetting

At the moment, glasswort and common seablite are dominant in at least half the area. Roos Veeneklaas is surprised by this. 'At this surface level you would expect low-marsh vegetation with grasses such as seaside alkali grass. However, this is not the case.' Glasswort and common seablite normally grow in the transition zone to the bare mudflats. The eastern section is equally wet and saline. 'The reason for this is that the ditches have become blocked up, so water doesn't drain away properly. Seawater flows back very slowly. That, with the impact of grazing livestock means that grasses can't survive here.' She does not believe this trend is a problem. 'Plant growth will change again at some point. Saltmarsh vegetation keeps changing, so if the drainage improves and the area silts up then the grasses will return automatically.'

Sea couch not yet entirely dominant

If no grazing takes place, a saltmarsh eventually becomes covered by tall-growing plants. The higher levels will soon be dominated by sea couch. This grass species displaces other saltmarsh plants by growing as a thick, featureless mat on which meadow birds and colonial birds cannot live so easily. Sea couch can take over very quickly and can completely dominate a saltmarsh within five to ten years. In the restored and ungrazed Peazemerlannen saltmarsh, for instance, sea couch became dominant in the entire area. *It Fryske Gea* does not want to this happen everywhere. In the trial area sea couch has not yet taken over anywhere. During the ten years of the trial, sea couch did in fact establish itself here and there, especially in the twelve fenced-off areas from which grazing animals were excluded, but it did not come to dominate. Which demonstrates that grazing can have a favourable effect on plant diversity.

Plant survey

In order to monitor changes, information about plant growth was collected in various ways. The year before the trial began, 105 squares were pegged out, each 4 m x 4 m: in the saltmarsh trial area 72, and in the adjacent saltmarsh 27, plus 6 in the adjacent summer polder. Since then, all the squares have been checked seven times. In addition, three 100-metre-wide strips were set out at right angles to the coastline. Almost 40 different species of plants were monitored in these three transects.

Mosaic management
in Noard-Fryslân Bûtendyks

It Fryske Gea always aims for variety. A mix of short and tall vegetation in the grazed summer polders and the semi-natural saltmarshes is the best way to ensure biodiversity. Grazing is essential, but it has to be well-balanced and varied.

The saltmarsh restoration experiment was meant as a learning experience. Chris Bakker, in charge of Quality of the Natural Environment at *It Fryske Gea* emphasised this point. 'We wanted to learn by doing.' Ten years of saltmarsh research has produced a wealth of ideas for managing the area. For example, the effect of filling in ditches was enlightening for Bakker. 'We believed there shouldn't be any ditches in a natural saltmarsh so we filled them in. But what we got was a huge mud-bath full of glasswort and common seablite where water was retained for a long time. Breeding birds don't like such conditions. They would have been better off if there had been ditches.' Grazing only exacerbated the problem because the animals trampled the soil and prevented plants like seaside alkali grass becoming established. 'We've learned from this sort of thing. If we had put in less livestock – or none at all – seaside alkali grass would have established itself more quickly. These are points to take with us to the next restoration project.'

Management regime

There was never any doubt about the importance of grazing. Cattle, sheep and horses keep the vegetation under control. If the animals were to disappear, the whole area would become overgrown by tall vegetation. The question was, what animals are the most suitable and what should the population density be? Bakker adopted some ideas from a previous management experiment (see inset) which was carried out on the adjacent saltmarsh with horses and cattle in low and high densities. Each grazing regime led to different types of vegetation, insect population and birdlife. Which is precisely what *It Fryske Gea* wants: a varied landscape, because that is the best way to

Five lessons we have learned

1. Give the sea enough space. Allow water to flow in and out freely without obstacles so the saltmarsh can increase in depth along with the sea level rise.
2. There is no point in planning creeks so they meander in a particular fashion. In the end, natural processes determine where the water flows.
3. Choose a varied grazing regime to achieve a mosaic of grazed and ungrazed areas.
4. Do not allow too many animals into an area if water drainage is inadequate. This leads to muddy flats where plants normally found in low saltmarshes do not stand a chance.
5. Ensure that water flowing inshore does not form standing pools but can flow back to sea. Eventually, a mixture of areas with limited and good drainage will develop naturally.

An experiment: cattle or horses or both?

In 2010 a long-term grazing experiment began on the saltmarshes to the north of the trial area. Three PhD researchers and countless students and lecturers – all involved with animal and plant ecology – worked on this joint project set up by *It Fryske Gea* and the University of Groningen. The key question was: What effects do different forms of grazing have on a saltmarsh? The effects on plants, birds and insects were tested by means of trials. Fifteen fenced-off areas, each of about eleven hectares, were used to test grazing by horses and cattle. In some of the areas the density was one animal per hectare, in others it was less – half an animal per hectare. Rotation grazing was tested as well: one year of intensive grazing and one year completely without grazing. The differences proved to be enormous. Interestingly, a combination of management regimes appeared to be best for the natural environment. Where cattle grazed at low density, a varied mosaic of shorter grazed and rougher patches developed. High-density grazing attracted the most birds in winter. Horses galloping over the marsh not only trampled the soil but smashed nests and eggs as well. An experiment with clay pigeons which were buried just below the surface proved this. In the breeding season, horses trampled an amazing 40% of all the clay pigeons to bits.

achieve a diversity of life forms. Bakker: 'We like to see a range of grazing regimes. Our aim is variety, not just a rough saltmarsh dominated by sea couch or a grassland as smooth as a golf green, but both, or more: a level green lawn for geese and meadow birds; sea-couch-dominated marsh for the short-eared owl and meadow pipit; and a large area of low-intensity grazed saltmarsh with a variety of characteristic saltmarsh vegetation and a diversity of insects.' At the moment, the density of grazing animals appears to be too high in some areas and there are certainly too many horses. *It Fryske Gea* has adjusted the management regime. 'We're aiming for a better balance and will let fewer horses in, this year,' he revealed.

Bakker wants to vary the vegetation using what is called mosaic management. That means closely-grazed areas with salt plants, grazing geese and nesting meadow birds, plus areas with taller vegetation where young birds can find refuge. 'It is this variety that makes the area ideal for plants, insects and birds. In the rougher areas, short-eared owls breed and sea asters attract rare saltmarsh insects, while geese graze on the green lawn.'

Meadow birds

Not only saltmarshes are important for Bakker's mosaic, so are summer polders. They complement each other perfectly. Black-tailed godwits can breed on large stretches of agricultural land but the young birds can then quite happily feed on the saltmarshes. In the summer polders, Bakker has opted for a specific sort of meadow-bird management. 'Some of the polders are being grazed too intensively at the moment so that there are hardly any meadow birds. Farmers are even using slurry to manure the land.' It is not easy to get the management for meadow birds right because it demands mosaic management, rough stable manure, high groundwater levels and an efficient way of dealing with foxes. This combination does work, as research into meadow birds in the whole of Friesland has proved.

Bakker is now setting his sights even further: inland as well. At the moment the seawall is a distinct barrier between the two worlds, whereas Bakker would like to link up the areas seawards and inland of the seawall. 'I'd like to bring together certain dike-related aspects such as water management, cultural history, nature conservation and recreation. The land inwards of the dike is getting saltier and soil build-up is not going at the same pace as sea-level rise. There are opportunities here for nature, but also for recreation. To this end, we're collaborating with the *Aerden Plaats,* which provides archaeological advice as well as a culture and visitors' centre. Together with this centre, we offer activities for visitors.'

‘Size a unique feature of this saltmarsh’

The immensity of Noard-Fryslân Bûtendyks makes it unique. It has the potential to accommodate one of the largest areas of continuous saltmarsh in Europe. ‘Here it really is possible to create a wide saltmarsh, with the sea and seawall a long way off from each other’, said Jaap de Vlas, a saltmarsh expert.

Almost all the saltmarshes along the coast are narrow. An exception is Noard-Fryslân Bûtendyks opposite the Noarderleech, where at the widest point it is three kilometres from the seawall to the seaward marsh edge. This is a unique situation which harks back to the huge saltmarsh area that existed at this spot in the past. ‘We now have the chance to re-establish an ancient landscape in Noard-Fryslân Bûtendyks. Most areas of primeval nature, such as ancient forests, can no longer be regenerated on a large scale in the Netherlands. Our country has become too cultivated. In saltmarsh areas, however, there are still possibilities, but we need to use the complete width of Noard-Fryslân Bûtendyks. It is precisely the wideness of the area that makes it so interesting.’ Jaap de Vlas appreciates how valuable the summer polders outside the seawall are for meadow birds and other bird species, but pointed out that habitats that are ideal for meadow birds can be created in other places too. ‘A broad strip of saltmarsh, however, is possible here and nowhere else.’

Specialists

If you just take a quick look at a saltmarsh you see only grassland. Yet it is much more varied and dynamic than it might seem at first sight. ‘Differences in height and grazing pressure are reflected in the vegetation types. Saltmarshes contain unique plant species which flourish nowhere else. Only the real specialists can survive the conditions there: the saline soil and being flooded with seawater,’ De Vlas explained. And there are not all that many specialists. According to De Vlas, some 25 different plant species grow on mainland saltmarshes. In amongst them live 300 to 500 species of insects, spiders and other invertebrates. De Vlas: ‘These creatures, just like the plants, have to be able to cope with seawater.’ Many saltmarsh plants are home to certain insect species. On a sea aster, especially, you will find about twenty different types of insects and they are all dependent on this plant. In turn they form a food source for young birds.
In addition, large numbers of breeding birds visit saltmarshes. Some species such as avocets,

Jaap de Vlas:

‘A broad saltmarsh is possible here and nowhere else.’

Saltmarsh ridges

In Noard-Fryslân Bûtendyks there are numerous zones with saltmarsh ridges and low-lying areas in between. Upon de-embankment of a polder, these differences in surface elevation become particularly obvious in the vegetation. The southern landward area with a low surface elevation will remain relatively wet. These basin areas are ideal for vegetation now rarely seen along the coast outside the seawall. Examples are reeds and rushes in a possibly brackish environment. As the soil becomes more saline, the type of vegetation is also determined by water drainage. These basin areas sometimes give rise to new saltmarsh creeks. Such developments aid diversity – something which is not possible in narrow saltmarshes.

24

Essex skipper (*Thymelicus lineola*)

oyster-catchers and skylarks prefer short, open vegetation interspersed with grassy tussocks. Redshanks and reed buntings breed in the rougher areas. 'Some breeding birds such as short-eared owls and harriers need a large area of saltmarsh in order to breed,' De Vlas added.

Size

De Vlas also mentioned another opportunity the immensity opens up, namely, a transition zone from fresh to salt water. 'The Noarderleech is wide enough to allow this zone to move back and forth with the tides,' De Vlas explained. He applauds the project known as *'Gemaal Vijfhuizen'* which the water board hopes to implement in Noard-Fryslân Bûtendyks and which involves fish ladders. 'That will make the area even more valuable. Migrant fish such as eels and three-spined sticklebacks search out these transition zones in spring so they can swim inland. Brackish water areas are crucial to countless animals including common prawns.' De Vlas is convinced that brackish water is an essential but often missing link in saltmarshes. 'Doing away with water outlets and building causeways have more or less led to the disappearance of these links. In Noard-Fryslân Bûtendyks we now have an excellent opportunity to break through a solid boundary and allow the gradual change from fresh to salt water to be restored. There is a condition attached to this: fresh water should be able to flow from the saltmarsh to the sea during periods of drought. Otherwise the brackish zone will disappear.'

Campiglossa plantaginis

De Vlas is very enthusiastic about the saltmarsh restoration trial. 'This concept has proved itself. The new saltmarsh area looks splendid. Now they need to carry on the good work and start up other saltmarsh projects without delay. De-embanking summer polders in Noard-Fryslân Bûtendyks is one of the few ways to ensure broad saltmarshes are regenerated.'

Saltmarsh aspirations everywhere

The desire to re-establish saltmarshes is widely supported. The ecological value of saltmarshes is recognised by policymakers not just in the province of Friesland but also nationally and on a European scale. The Frisian saltmarshes are part of the Dutch Ecological Network which links up a variety of nature conservation areas, while the Wadden Sea – including Noard-Fryslân Bûtendyks – has been designated a nature protection area of European importance (Natura 2000).

Where bird migratory routes intersect

The Wadden Sea is an essential stopover site for between ten and twelve million migrant birds on the East Atlantic Flyway. The birds arrive in late summer after nesting in the North. Some of them overwinter, the rest continue on their way southwards. Early in spring, the bird migration starts up again in the reverse direction. There are 52 bird species of which more than 1% of the world population use the Wadden Sea. Of some species including oystercatchers, avocets, brent geese and wigeons, it is more than 50%. Most of these species forage for food on the mudflats at low tide. At high tide they make for the saltmarshes and take a rest there. This function of the saltmarsh as a high-tide roost is important for these birds. Geese and wigeons also look for food in the saltmarshes.

Noard-Fryslân Bûtendyks enriches the whole region

Noard-Fryslân Bûtendyks is more than just a saltmarsh. The whole area benefits from this piece of nature: local residents take walks there, tradespeople serve more customers and holiday-makers enjoy the wide open spaces and the silence. The new visitor centre, *Kweldercentrum Noarderleech*, has helped to stimulate recreation and the economy in the whole region.

Sieds Boersma:
'I let people experience the silence.'

Ramblers, nature lovers, birdwatchers, people seeking peace and quiet, artists; Noard-Fryslân Bûtendyks is attracting more and more people. 'The number of visitors is increasing, with the natural land outside the dike adding to the appeal of the region, certainly now that we have the new visitor centre,' enthused Kirsten Zwijnenburg, the secretary of the association of local recreation businesses. She is certain this nature conservation area is benefiting the region. Camping grounds, B&Bs (*Bêd & Brochjes* in Frisian), restaurants: they all profit. 'They can send their visitors here. The *Seedykster Toer*, a local business which organises trips into the area in a tractor-drawn coach, have also converted an old grain silo into a look-out tower. I think the saltmarsh centre is a wonderful leisure attraction. Visitors are given information so they can explore the saltmarshes themselves.' What local business people are really pleased about is that during the breeding season – at the same time the high season for tourists – you can still wander around the area. Although you must keep to the paths. 'Outside the breeding season you can wander all over the saltmarsh and that's an amazing experience.'

Kirsten Zwijnenburg:
'I think the saltmarsh centre is a wonderful leisure attraction.'

Jan de Boer:
'Those who come here on a visit always return.'

Special package

Kirsten Zwijnenburg visits the saltmarsh often, living just a stone's throw away. She is an artist and also the coordinator at the *Aerden Plaats*, a cultural centre for visitors in Oude Bildtzijl. '*Bildt* means 'silted-up ground'. It used to be a saltmarsh just like Noard-Fryslân Bûtendyks, but over the centuries was gradually turned into a polder. Our historical exhibition gallery provides information about the saltmarsh-engineering works and the stepwise embankment of the area.' The *Aerden Plaats* works closely with *It Fryske Gea*. They have recently put together a package including both a cultural and nature walk and a stop-over in both centres *en route*. 'We're giving each other a boost,' she explained.

The area outside the seawall is a real favourite with local residents. 'I know lots of people who visit the dike frequently. "To blow away the cobwebs," they say. It's a wonderful place for that,' said Jan de Boer, who coordinates the *Kweldercentrum Noarderleech*. The centre opened its doors last year and De Boer is a proud man. 'More and more people are discovering where we are. It looks very inviting, don't you think? Although we have several volunteer hosts and

hostesses, the centre itself is unmanned and everyone is free to walk in and out, look at the exhibition and drink a cup of coffee.' De Boer makes a big effort to network with the local people. 'We promote the region with leisure packages and the sale of local products during our open days. We also have a room upstairs which local people can use for lectures, meetings and such.'

Excursions

De Boer believes it is important lots of people see and experience the saltmarsh. 'We organise numerous excursions every year so visitors can see for themselves how remarkable this piece of nature is. Many are coming here for the first time. For them, the wide open spaces and the silence is a wonderful experience – even if the birds do make a tremendous racket during the breeding season, especially above the paths where they warn continually.' People are beginning to become more aware of the area, Jan de Boer thinks. 'Those who come here on a visit always return.'

Sieds Boersma is a volunteer for *It Fryske Gea*, taking people on excursions at least once a month. During such excursions he tells people about this landscape and the cultural history. 'I help people to read the landscape and let them experience the silence. On summer evening walks we go and sit somewhere and listen to the silence for several minutes. Some people find that threatening, others are fascinated.' Sieds Boersma was born and brought up in the area. He often goes to Noard-Fryslân Bûtendyks, mainly to collect data on the birds. He is very enthusiastic about the bird populations there. 'The area outside the dike is crucial for migrating birds because they need a staging post *en route*. On busy days in the winter, more than a hundred thousand barnacle geese can be sitting there. There is a wide variety of birds: tufted duck, dunlin, sandpipers, grey plover, avocet. Each bird species chooses its own habitat. These vary enormously and include mud fields, pioneer saltmarshes, high-lying saltmarshes, pits and summer polders.'

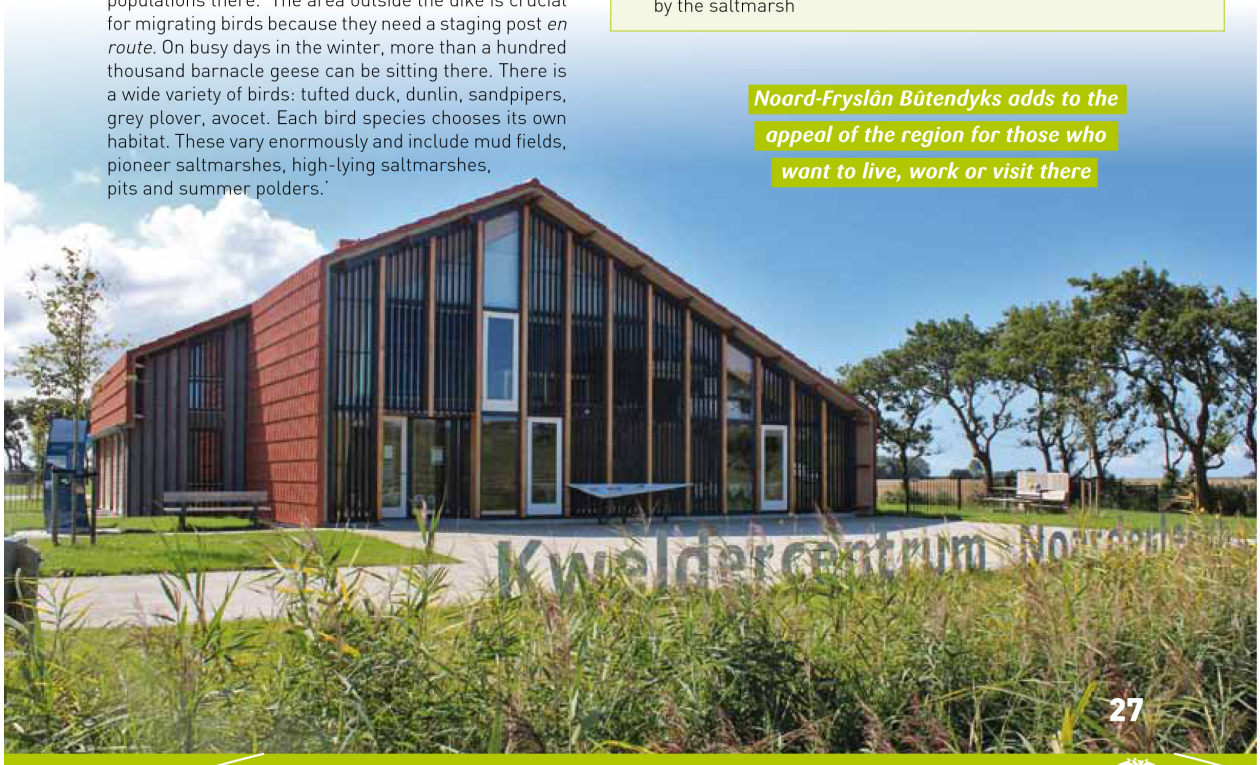
Wadden gold

Last spring, the *Kweldercentrum Noarderleech* received the regional hallmark of quality: Wadden gold. Tineke Schokker, a member of the provincial government of Friesland, presented the award. This is what Henk Pilat from the *Stichting Waddengroep* had to say about the prize winner. 'Our seal of approval stands for unique products, companies and services in the Wadden Sea area. The *Kweldercentrum Noarderleech* is one of these unique services.' The award, he feels, is not just for the visitor centre but also for the piece of nature outside the seawall, the saltmarsh management and the excursions over the saltmarshes. 'They make up a complete package,' said Pilat. He is delighted that *It Fryske Gea* is seeking to collaborate with local business people. 'We believe in a network economy in which companies and organisations in the Wadden Sea area pool their resources. The whole region is suffering from a weak economy so this sort of collaboration creates new opportunities. *It Fryske Gea* is working hard to secure this.'

Saltmarshes for nature and people

- **Local residents,** who go for a walk there
- **Leisure organisations,** who are attracting more and more customers
- **Holiday-makers and day-trippers,** who enjoy this nature conservation area
- **Birdwatchers,** who come to see a huge variety of birds
- **Tenant farmers,** who put their animals there to graze
- **Saltmarsh plants,** which have space to live there
- **Migrant birds,** who find a resting place and food there
- **Breeding birds,** that have a place to nest
- **Water board,** who speaks highly of the additional safety provided by the saltmarsh

Noard-Fryslân Bûtendyks adds to the appeal of the region for those who want to live, work or visit there



Colophon

Authors: Addo van der Eijk & Peter Esselink
Concept and interviews: Addo van der Eijk
Editors: Chris Bakker, Elske van der Kooi & Elsiena van Vliet
Translation: Everyman tolk & vertaalbureau
Layout: Michel Rozenberg

Illustrations:
Actueel Hoogtebestand Nederland (p. 10)
Roos Veeneklaas (p. 20)
Dick Visser (other)

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Gert Buter	2, 16, 22, 24, 28
Bildts Dokumintasysintrum	1 (middle), 8
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Peter Esselink	12, 18, 23 (middle)
Alma de Groot	19 (middle)
Steven Hannema	26
It Fryske Gea	4, 15
Hendrik van Kampen	1 (top), 14, 15, 16, 17, 20
Dico de Klein	3, 5, 6, 12, 21, 26 (inset), 27
Roel van Klink	1 (middle), 25 (top)
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It Fryske Gea

Ten Years of Saltmarsh Restoration
in Noard-Fryslân Bûtendyks

waddenfonds

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It Fryske Gea, society for nature conservation
in the province of Friesland
Van Harinxmaweg 17, 9246 TL Olterterp
P.O. Box 3, 9244 ZN Beetsterzwaag
Tel. no.: +31 (0)512 381448
E-mail: info@itfryskegea.nl
Website: www.itfryskegea.nl

Altenburg & Wymenga ecologisch onderzoek | Fryske Feriening foar Fjildbiology | Bosgroep Noord-Oost Nederland

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Coastal and Estuarine Restoration in China

중국의 연안 및 하구복원

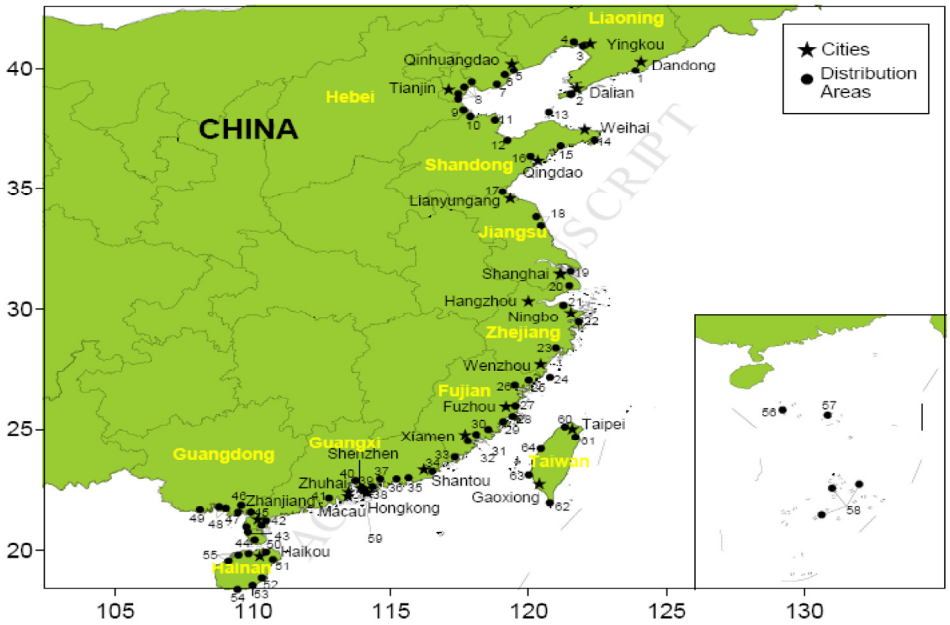
중국해양대학 이동영 교수

Coastal and Estuarine Restoration in China

Aug. 20, 2015

Dong-Young Lee
Ocean University of China

Distribution of main coastal wetlands in China (Ting-ting Jiang et al.(2014)



Characteristics of China's wetlands

Multiple types

31 types of wetlands & 9 types of artificial wetlands

Large area.

Area : about 65.94 million hectares, 10% of the world Wetland

Coastal Wetland: 10.85% of the total wetlands (SFA, 2014).

Wide distribution.

Obvious regional variation.

Abundant biological diversity.

2276 species of advanced plants,

724 species of wild animals

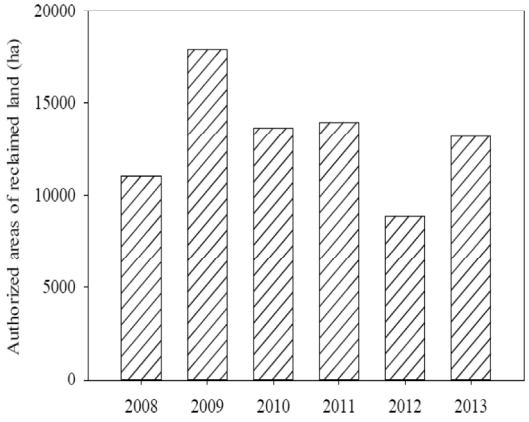
Problem of Wetlands

-Decrease of wetland area

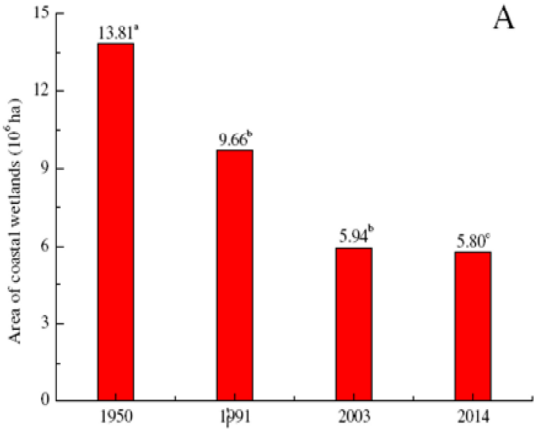
-Coastal erosion and sea-level rising

-Serious environmental pollution

-Damaged biological diversity

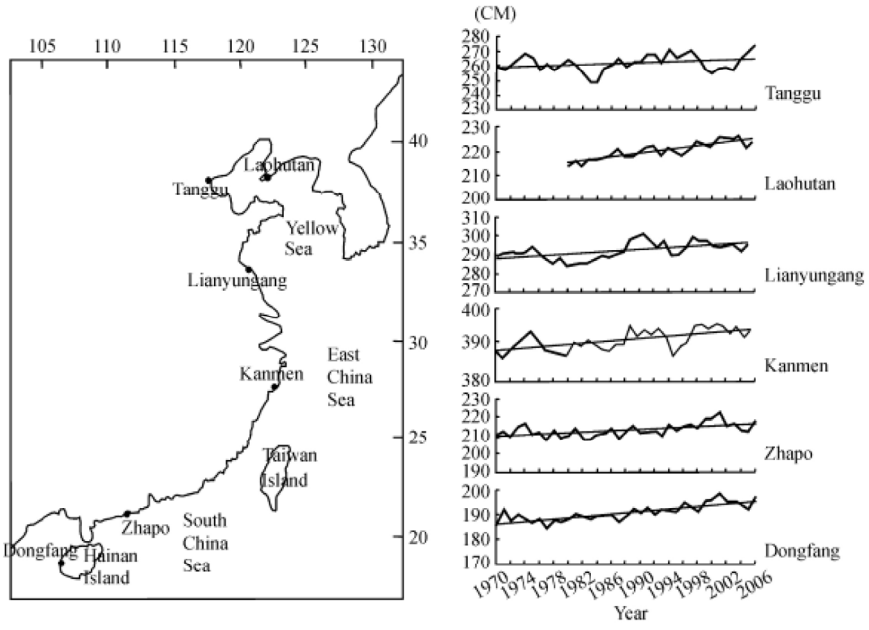


Authorized acreages of reclaimed wetland in China (data from SOA).



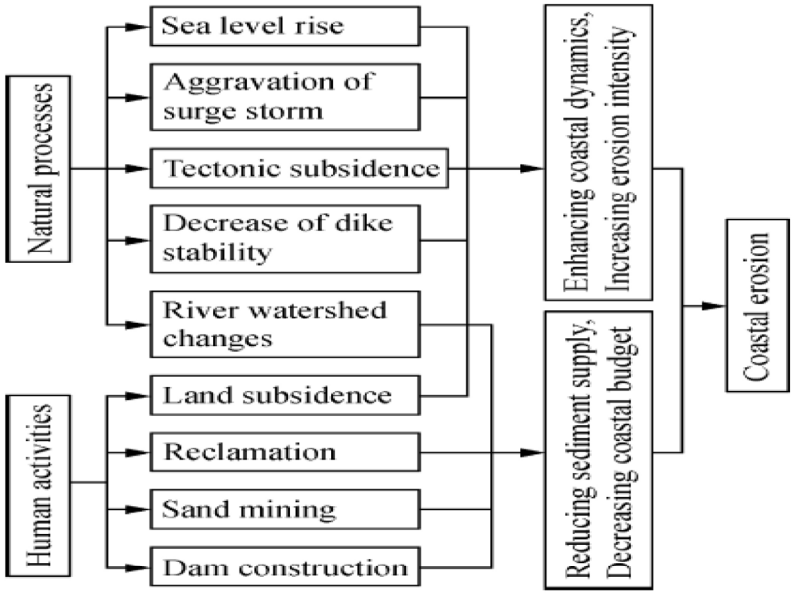
Past and present areas of the coastal wetlands Zhigao Sun(2015)

Sea level changes from 1970 to 2006 from observation stations along the coast of China (Feng Cai et al. (2014))



Man causes of coastal erosion

(Feng Cai et al. (2014))



Coastal wetlands Conservation History

(Zhigao Sun et al. 2015)

- **Un-protection stage (1950s–1970s)**
- **General attention stage (1980s–1991)**
- **Special attention stage (1992–2002)**
- **Effective protection stage (2003–2010)**
- **Overall implementation stage (2011–present)**

Conservation Achievements

(Zhigao Sun et al. 2015)

1. Coastal wetlands conservation and restoration

- Eleventh 5-Year Plan (2006–g2010)
- Twelfth 5-year Plan (2011–2015

2. Coastal wetlands nature reserve construction

- 15 Coastal wetlands listed in Ramsar Convention

3. Coastal wetlands survey and monitoring

- First national wetland resources survey: 1995-2003
- Second national wetland resources survey: 2009-2013

4. Scientific research of coastal wetlands

Many national wetland research institutions

- Wetland Research Center of SFA,
- Plateau Wetlands Research Center
- Wetland Protection & Restoration Technology Center

Many important national projects focused on wetland

5. Coastal wetland management policy and legislation

6. Public participation of coastal wetland conservation

7. International cooperation in coastal wetlands conservation

Ramsar Convention on Wetlands (joined in 1992)
WWFN, Wetlands International (WI),
European Union (EU),
United Nations Development Program (UNDP),
Global Environment Facility (GEF),
International Union for Conservation of Nature (IUCN)
Etc.

Example of Wetland Restoration

Inland Wetland (river & lake side)

Beijing Area，Taihu Area， etc.

Coastal Wetland

Mangroves Restoration

Southern Provinces

Estuary, River Delta

Yellow River, Yangtze River, Perl River

Ports & municipal area

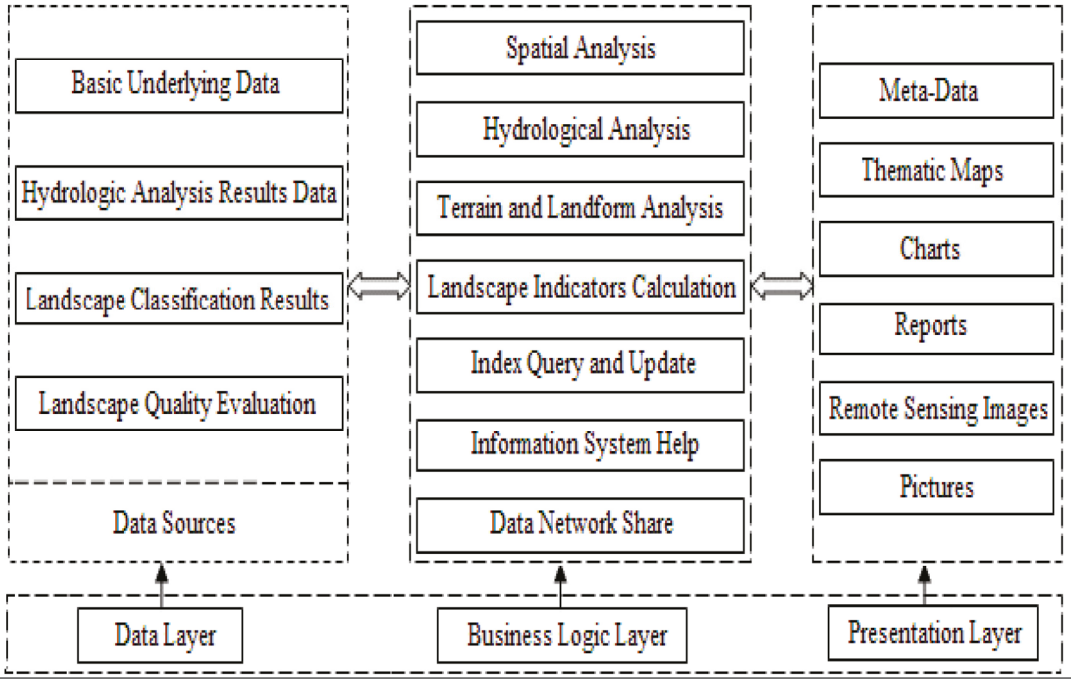
Tianjin, Xiamen, etc.

Beach Nourishment

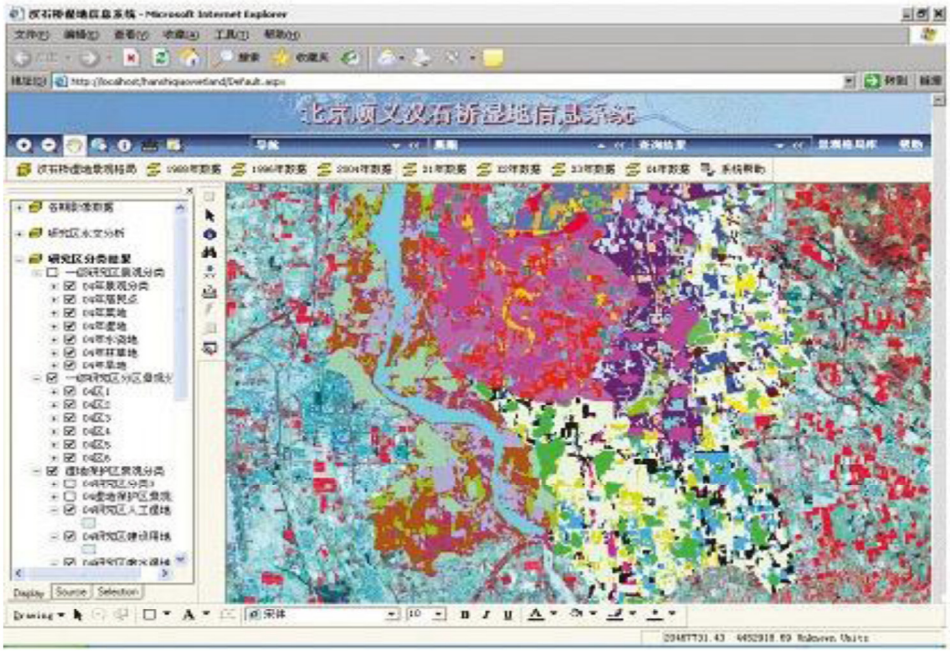
Mangroves Restoration

- A relatively complete system of mangrove restoration technologies has been established and is widely used in southern coastal areas
- Since the 1980s, many mangrove restoration programs and practices have been launched in Southern Provinces such as Zhejiang, Fujian Guangdong, Guangxi and Hainan.
- The mangrove area in China has consequently increased from 14,877 ha in 1997 to 23,081.5 ha in 2008 (Chen et al., 2009).

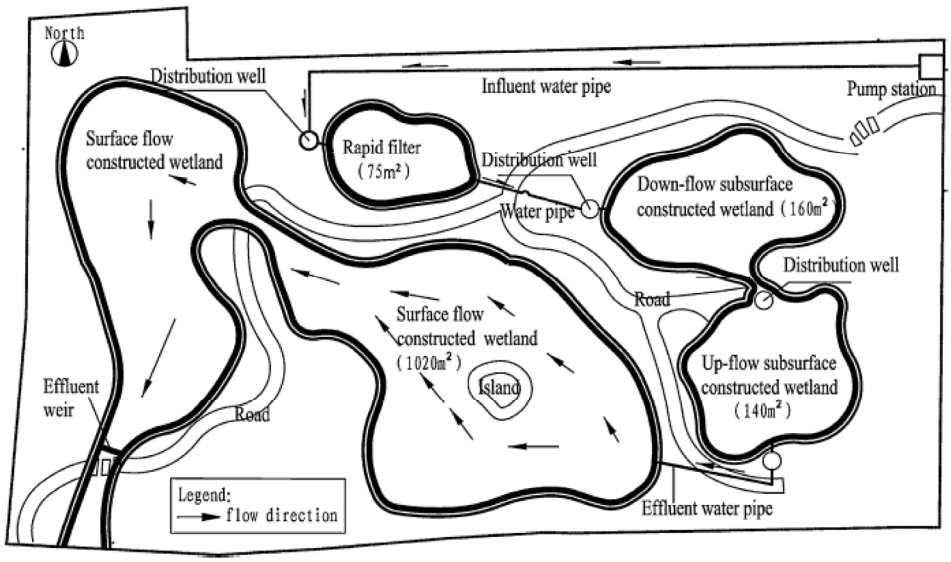
Structure of Beijing Hanshiqiao wetland information system Shiwei Dong et al. 2011



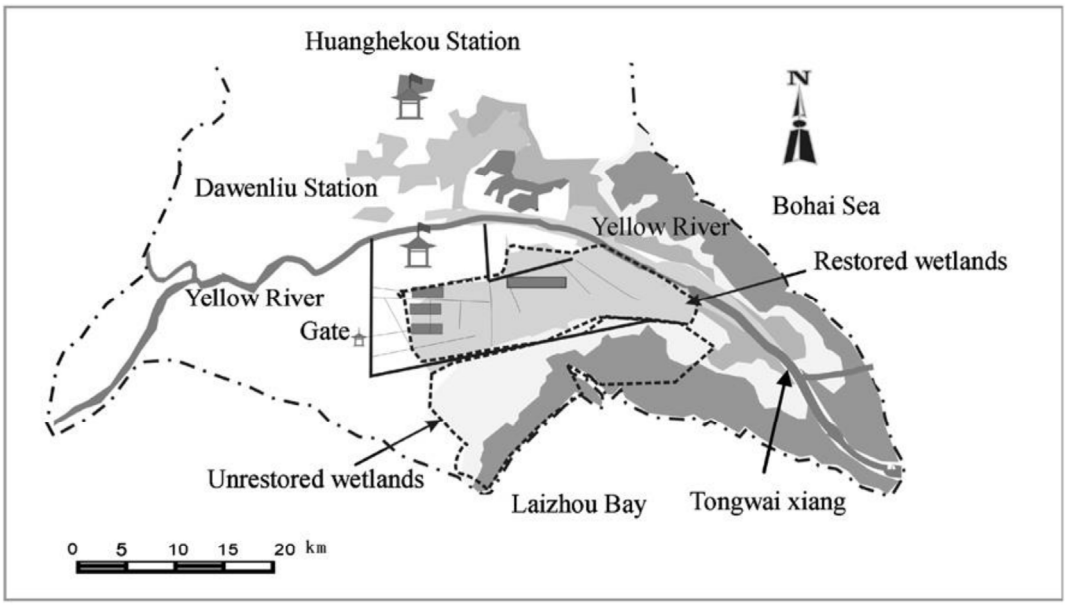
Beijing Hanshiqiao wetland network information system interface Shiwei Dong et al. 2011



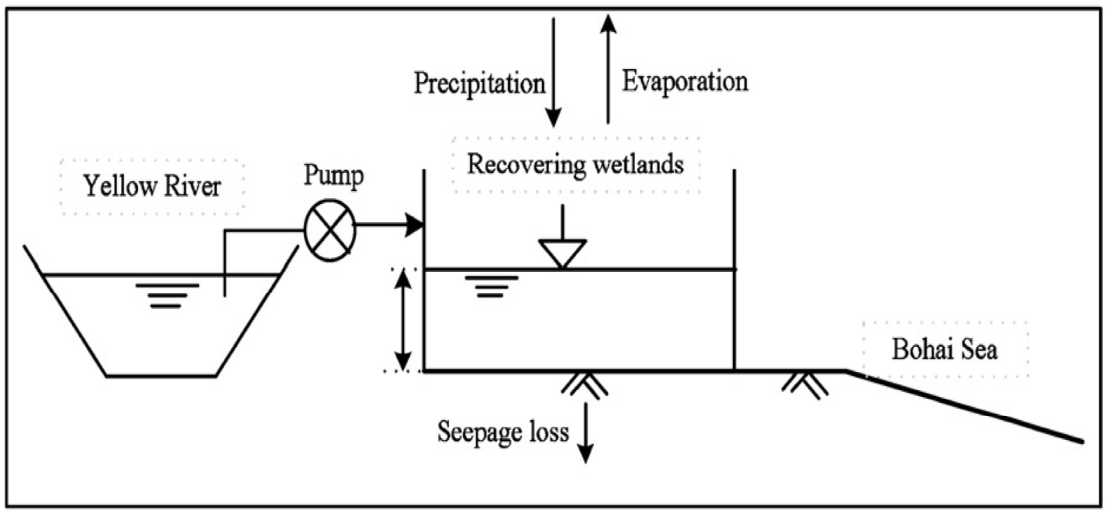
Zhijiashe four-stage constructed wet-land system (Haifeng Jia et al. (2014))



Restoration of wetlands in the Yellow River Delta Wei Yang et al. 2011



Water allocated from the Yellow River to the recovering wetlands Wei Yang wt al. 2011



- **In 2002, the government spent one hundred million yuan on the restoration of the Yellow River Delta wetland.**
- **During the project, water from the Yellow River was diverted into the wetland to improve surface runoff circulation and irrigation conditions and the ecological environment.**
- **After restoration, water quality improved, with reduced nitrogen and total phosphorus content (Cui et al. (2009)).**

The quality of soil also improved, with reduced salinity and increased organic matter accumulation

The vegetation of wetlands improved greatly after several years of restoration

Simulation for wetland utilization & protection based on system dynamic model C. Ma (2012)

A system dynamic model for wetland managem ent to find a balance between economic deve lopment and wetland protection in Tianjin Are a based on the analysis of 24 indexes and five subsystems

The statistical data in Tianjin from 1990 to 2008 to verify the model.

Selected six typical models for scenario simulati on in 2010, 2030 and 2050.

Suggested that ecological protection, population control and industrial structure adjustment are sustainable approaches

Beach Nourishment

Together with dunes and associated water bodies, the beach and tidal flats provide valuable habitat.

Sand dunes can serve as a natural buffer against high waves, preventing or delaying the intrusion of water and sedimentation

As compared with other hard engineering measures, dune nourishments and/or reconstructions are more preferred in a more demanding society.

Experiments to find the best possible way to build sand dunes that should be both economically, as well as ecologically, feasible.

Integrated coastal management(ICM)

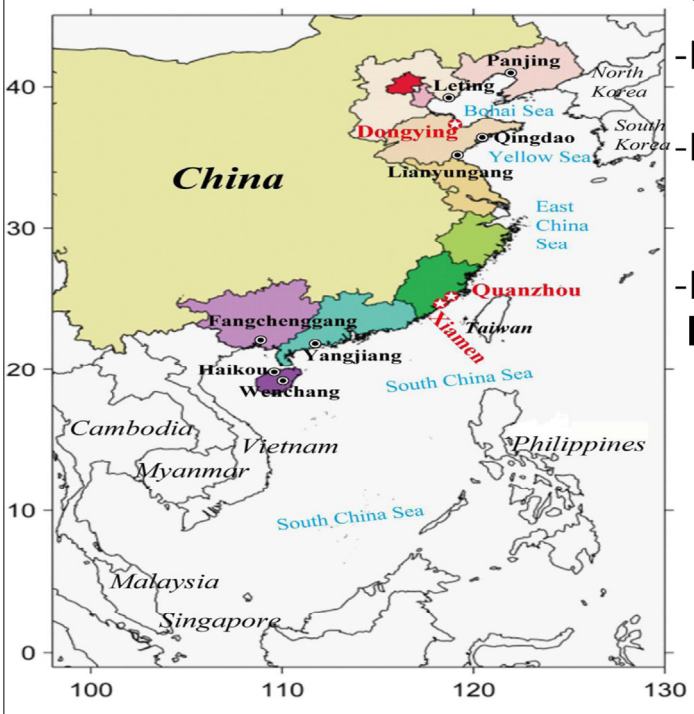
About 12% of China's coast line has now come under the ICM governance framework to address the environmental and management challenges.

The ICM indicators in terms of governance, environent and socioeconomic aspects were designed for quantitatively evaluating the ICM performance over a 9-year period from 2004 to 2012.

The results showed that ICM performance based on governance, coastal environment and socio-economic aspects in the three improved, indicating that the ICM approach can be effective in promoting the overall sustainability of China's coastal cities

3 studied ICM sites & eight other ICM cities

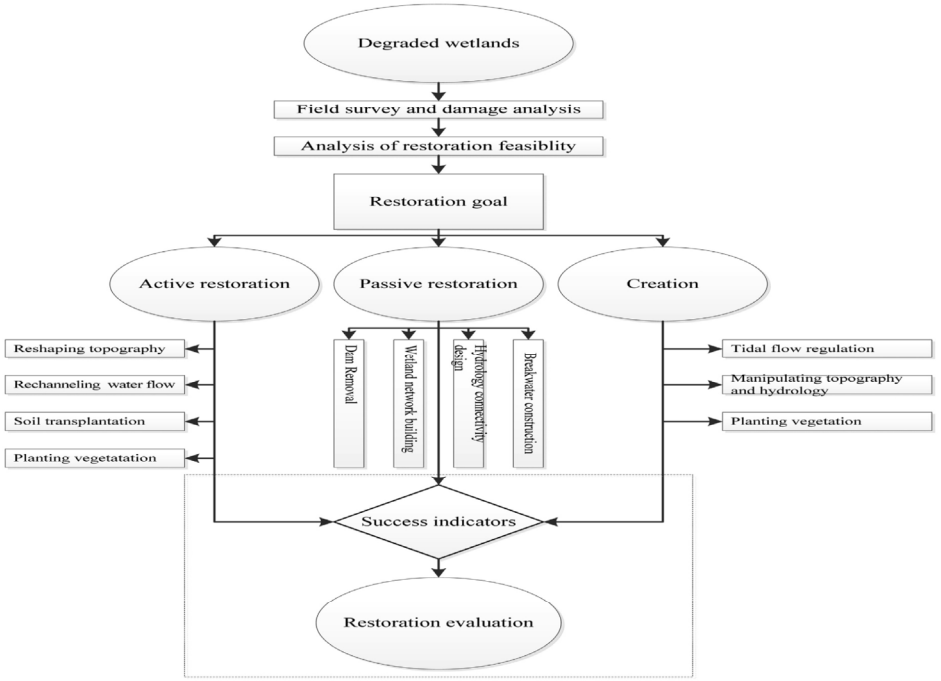
Guanqiong Ye et al. 2015



- **Mangrove restoration in Quanzhou bay**
- **Bay ecosystem restoration in Wuyuan Bay of Xiamen**
- **Eutrophic semi-enclosed bay restoration in Xiamen western waters)**

Flow chart for coastal wetland restoration.

Qingqing Zhaoa et al. (2015)



Barriers for success

-More comprehensive insights into ecological, socio-economic, political factors are necessary for setting-up clear project objectives and targets;

- More attention should be paid to ecological functions in order to restore the ecosystem vs values and benefits

- More scientific processes need to be conducted to evaluate the causes for ecosystem degradation and predict the probability for natural recovery

-Degradation causes diagnosis, restoration technology & methods, monitoring strategies and techniques, assessment and evaluation, adaptive management and results dissemination should be all emphasized during the restoration efforts.

- Problems of Overlapping Jurisdiction

Authorities responsible for coastal wetland protecting in China

- State Oceanic Administration (SOA) .
- Ministry of Environmental Protection (MEP)
- State Forestry Administration (SFA)
- State Fishery Administration
- Ministry of Agriculture
- Ministry of Transport

On March 2, 2010, MEP and SOA signed the "Framework Agreement on Setting up the Cooperation Working Mechanism on Improving Ocean Environment Protection Communication"

to solve the Problems of Overlapping Jurisdiction

Research for coastal restoration

Comprehensive and systematic scientific research, an integrated discipline, restoration and management should be carried out for the sustainable development of coastal wetlands.

. Physical
. Chemical
. Biological and
. Engineering
. Socio-economic

Water, Biota and Soil : 3 basic elements

Water

Chemistry of water: pollution
Movement of water: Hydro-dynamics

Soil(Sediment)

Chemistry of soil
Movement of Sediment: Morpho-dynamics

Biota

Adaptation of plants and animals
Biodiversity

- Observation, Analysis and Prediction of basic elements &
=> Prediction of the response of Coastal Restoration on ecological functions

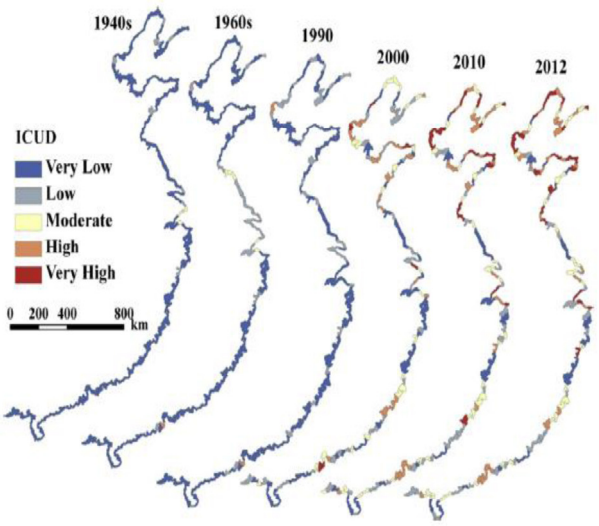
Monitoring of water, sediment and biota

-Fundamental databases should be established using in situ. data & remote sensing data

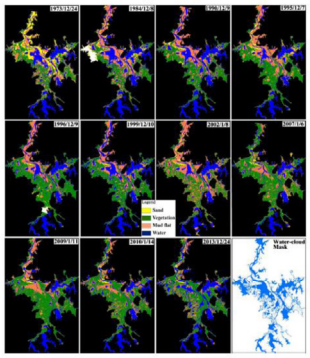
-Developments in restoration and monitoring technology are required to ensure long-term sustainability.

- Monitoring program for Pre-construction, construction and after construction

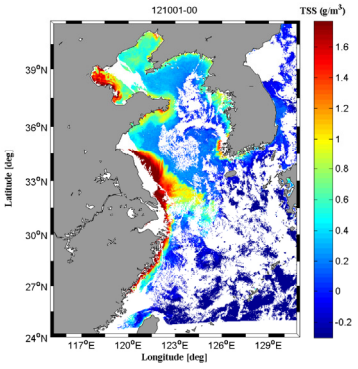
Example of application of Remote Sensing



Spatio-temporal *characteristics of the coastline utilizatio*n degree over the 70 years using LANDSAT data (Ting Wu(2014))



Example of App lication of RS W etland Change of Poyang Lake



Example of GOCI Data 2012-10-01 01:00

Sediment Transport Modeling

(Interaction between **Water** and **Soil**)

Lots of impacts of Sediment Transport on ecological functions of coastal area

- Environmental and Ecosystem at muddy coast with transport of fine cohesive sediment (pollutants stick to sediment and move together)
- Beach erosion and morphology change at sandy coast with transport of sand at swash-zone

=> Impacts of **Biology**

Hydro- & sediment dynamics at Surf-zone and Swash-zone

Conventional wave-averaged model
(ex. Delft3D, Mike System, Telemac model..)
-Coupling among wave, flow & sediment
-Not applicable for Swash-zone

Develop. of working model for swash-zone
- Trade off : Accuracy, Computation Time
- Preparation of Input information

Long-term Prediction of morphology change for Proper Design and Coastal Management

- Strong and wide demands all over the world
- But proper Processed Based long-term Prediction System is not available: need to be developed (big challenge)

Development of the system

1. Development of working model for swash-zone
2. Data Base based on long-term observation or hindcasting data for long-term Stochastic Prediction of forcing terms (cf:impact of global climate change?)
3. Modeling system for Fast but Accurate downscaling to coastal waters through combination of detailed models & fast simulation methods

Proper integration of above 3 elements

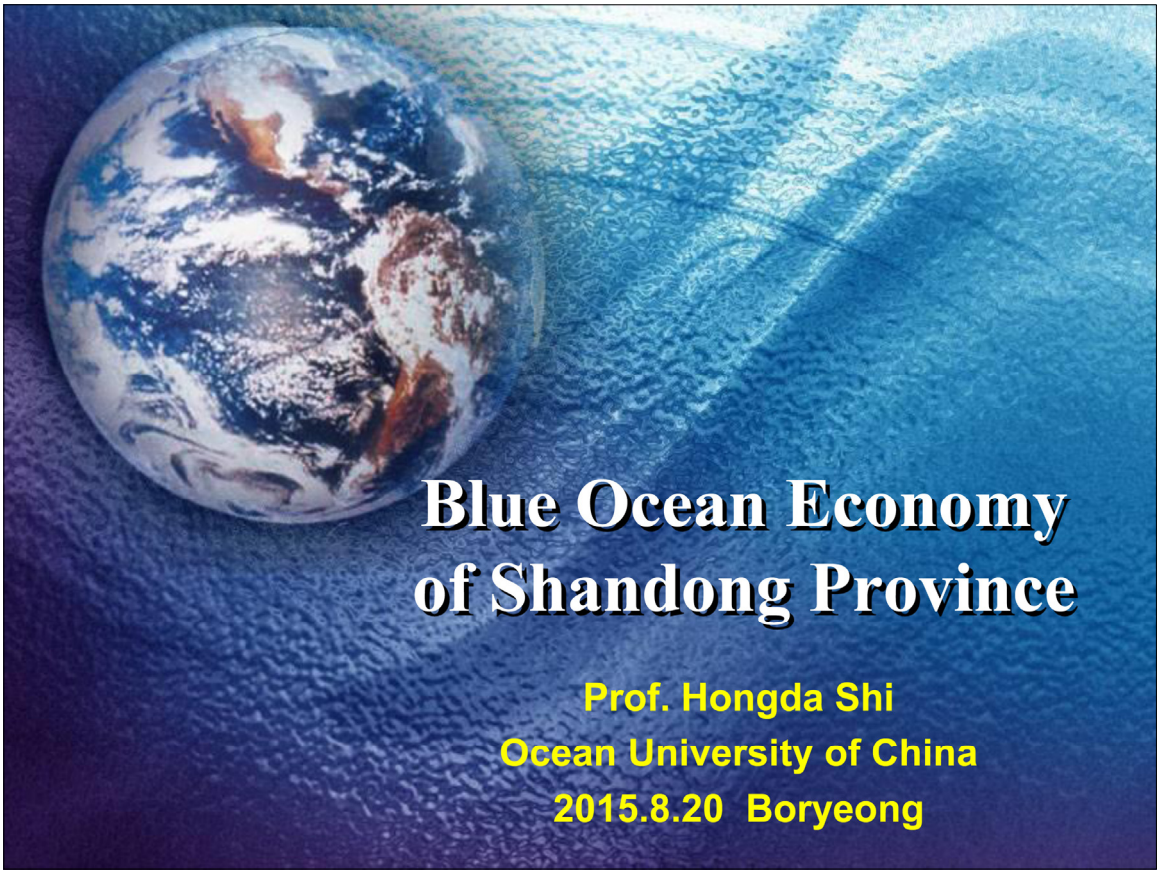
Conclusion

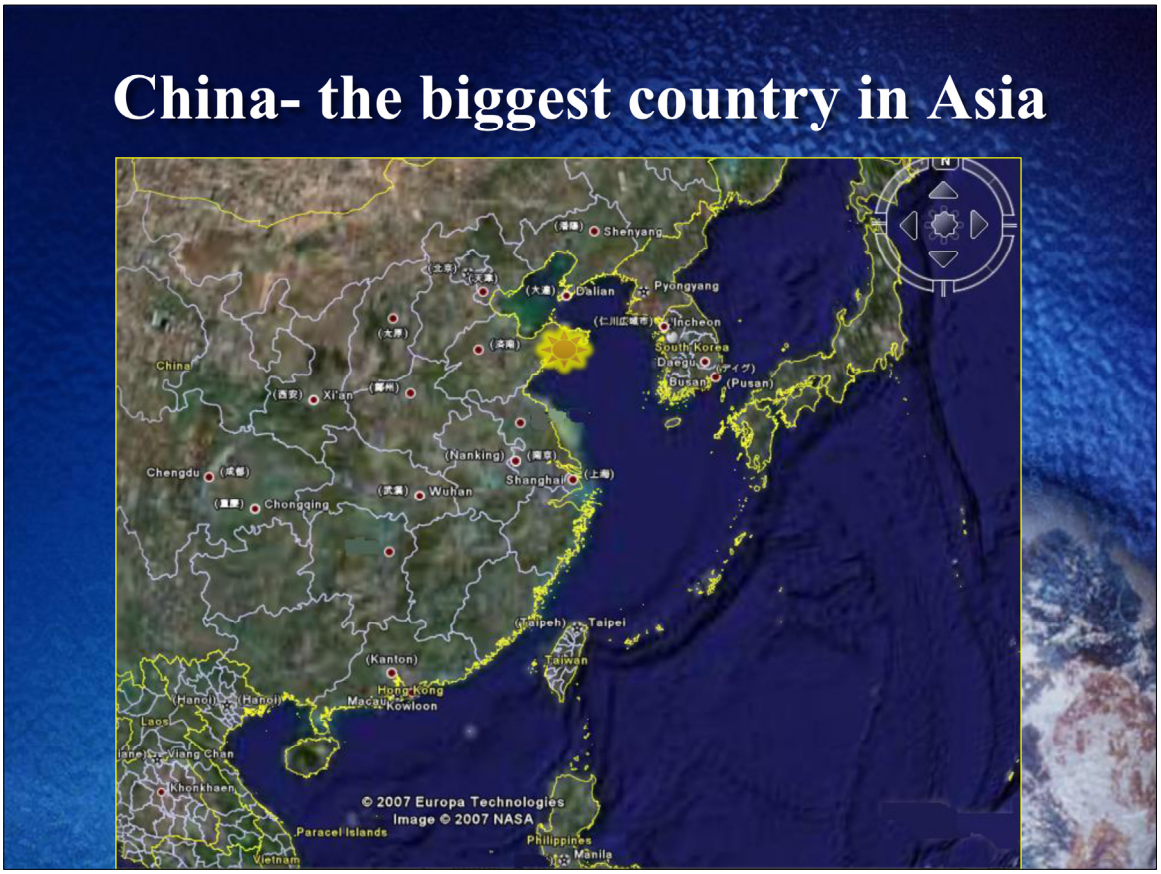
- **Coastal wetlands are seriously threatened by natural and anthropogenic factors and lots of Coastal Restoration Programs have been and are being implemented in China.**
- **The experiences, technology developments and lessons gained in China would be helpful in planning, designing and implementing similar programs in Korea**
- **Proper monitoring and inter-disciplinary scientific research is necessary for the sustainable development of coastal wetlands.**

Blue Ocean Economy of Shandong Province

중국 산동지역의 연안관리사업

중국해양대학 Hongda Shi 교수


Blue Ocean Economy
of Shandong Province
Prof. Hongda Shi
Ocean University of China
2015.8.20 Boryeong


China- the biggest country in Asia
Shenyang
Dalian
Pyongyang
Incheon
South Korea
Daegu
Busan
(Pusan)
China
Xi'an
(Nanking)
Shanghai
Chengdu
Chongqing
Wuhan
Taipei
(Kanton)
Hong Kong
Macau
Kowloon
Laos
Khonkhaen
Paracel Islands
Vietnam
Philippines
Manila
© 2007 Europa Technologies
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National Ocean-related Strategies in China

- China's 12th five-year Plan for National and Social Development (2011—15) included “Development of the Ocean Economy”
- Jan. 2011, the State Council of Chinese Government approved the establishment of the Shandong Peninsula Blue Economic Zone (as one three pilot zones and later extended to eight)

- Shandong Province is a lead Province of Development of Blue Ocean Economy in China

Shandong-with the second longest coastline in China

Blue Economy of Shandong Peninsula: Challenge and opportunity

- Sustainable and scientific development of the coastal zone.
- Harmonic development of Economy, Culture, Society, and Ecosystem.
- Emphasizing the importance of harbors, ocean industries, and environmental protection projects.
- Making the peninsula of reasonable long term plan and powerful competitiveness.

Blue Economy of Shandong Peninsula: Challenge and opportunity

Sea area :160,000km^2 Land area: 64,000km^2
Length of coast line: 3000km

Blue economy cities:
Qingdao,
Dongying,
Yantai,
Weifang,
Weihai,
Rizhao
Binzhou.

Blue Economy of Shandong Peninsula: Challenge and opportunity

Northern part: Yellow river delta ecologic area
Dongying, Binzhou, and Weifang

Eastern part: hi-tech ocean industry clusters
Weihai, Yantai

Southern part: Port-side industry clusters
Qingdao, Rizhao

What do we want?

Sea area

Sea area is essential to the ecologic zone in Northern part of Shandong peninsula, particularly in Yellow river estuary.

Coast line

Coast line is adequate in the Eastern part of Shandong, for example, Weihai, but it was not well planed and needs restoration.

Seaside land

Seaside land has strong attractive force for industries, especially for port and processing enterprises.

How can we get?

How can we get?

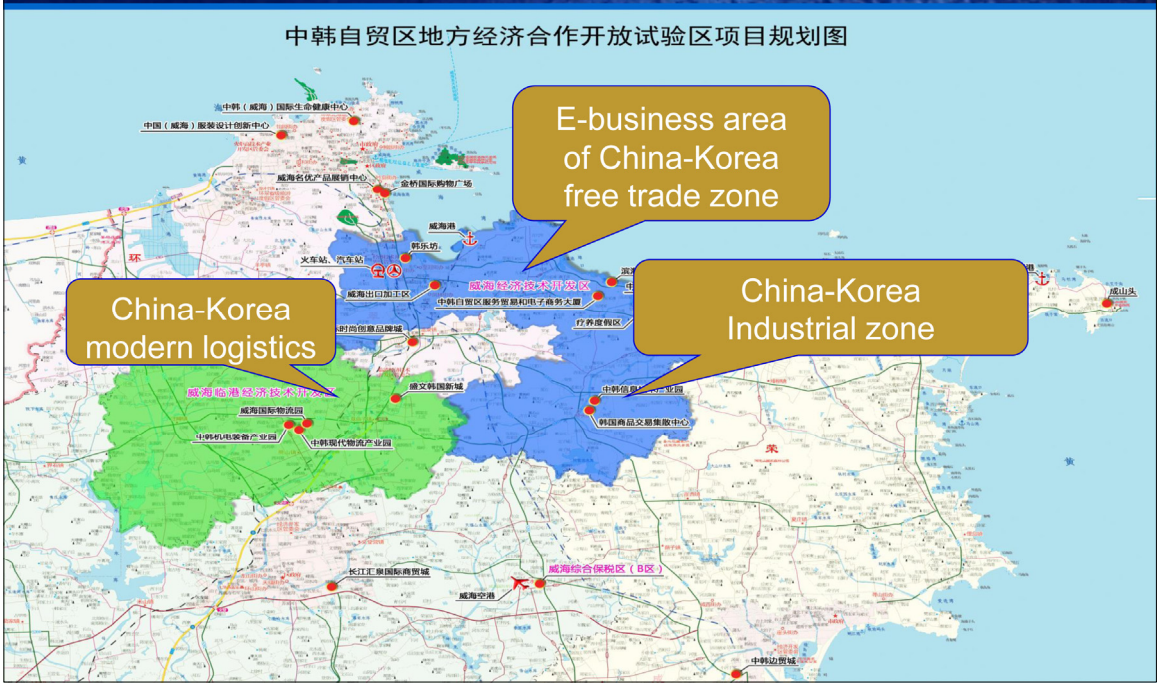
Yellow river estuary delta has abundant resource of fresh water, mudflat, and land area.

The development of this part aims at agriculture and fishery.

The environment protection is the key point here.

Shallow water, fine sediment, mild slop.

How can we get?



How can we get?

Weihai has the longest coast line in Shandong province. It has transactional relations with Korea and Japan.
Ocean engineering and shipbuilding were once the main industries in this city. But they occupied lots of coastline.
The reorientation and restoration are needed to adjust to the hi-tech industries.
China-Korea free trade zone is established.

How can we get?

How can we get?

Qingdao has the biggest port in Shandong. It has Jiaozhou Bay, which is appropriate for even larger development.

But the land is not enough. We need land reclamation to give area for investment of port-side industries.

Land reclamation gives impact to ocean environment, so, we move it to the open sea area, Dongjiakou.

Qingdao port is the 8th largest port in the world, 2014.

Role of Ocean Science and Engineering in developing "Blue" Ocean Economy

Two main objectives of Blue Ocean Economy

- Ocean environment protection for Sustainable Development
- More profit and contribution to National Economy

Some developers have tendency to ignore conservation of coastal environment and focus on short-term economic development, which is not "Blue".

What ocean scientists and engineers need to do for the development of "Blue" Ocean Economy ?

1). Proper guidance and suggestion to policy makers

2). Technical support for Development & Conservation

i) Planning & development stage

- Proper environmental impact analysis
- Proper design of coastal development and conservation

ii). Operation Stage

- Support for efficient operation (Sea transportation, fishing, construction,..) for more profit an Role of Ocean Science d prevention of coastal hazards
- Proper protection of coastal environment
  . Beach protection
  . Proper combat against Oil Spill, Red-tide, Green-tide, Sea outfall

iii). Post development stage (if serious problems occur)

-Technical support for proper coastal restoration

Main Challenges: Long-term prediction of

- Coastal environment change (cf. morphology change)
- the impact of global climate change

Shandong Provincial Key Laboratory Ocean Engineering

Engineering support for the Blue Ocean Economic Development of Shandong Province is one of main objectives of the Key Lab.

- Environmental impact analysis
- Design of coastal & ocean structures
- Prevention of coastal hazards
- Beach protection
- Impact of global climate change
- Development of low CO2 Ocean Energy
- etc.

Shandong Provincial Key Laboratory of Ocean Engineering

Qingdao- a city by the sea

Qingdao- a city with mountains

Qingdao- a city with modern fashion

Qingdao- a city with tradition

Qingdao- a city of ocean science

Qingdao- a city of ocean science

Qingdao- a city of ocean science

Thank You

College of Engineering

Know each other and collaborate

충청남도 연안 및 하구 생태복원방안

충남연구원 이상진 연구실장

발표순서

Ⅰ 하구의 의미 및 특성

Ⅱ 하구현황 및 문제점

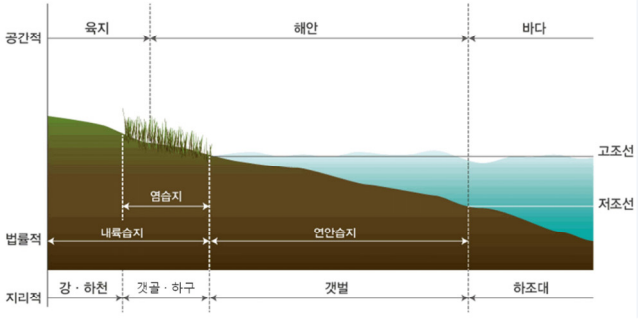
Ⅲ 하구복원의 필요성

Ⅳ 연안 및 하구 생태복원방안

I 하구의 의미 및 특성

01 하구의 의미(1)

하구
(estuary, 河口)



- 바다와 연결되어 해류순환이 있고, 하천이 유입되는 곳
  - 하구는 민물과 바닷물이 혼합되는 전이수역으로 담수에 의한 염분의 희석(기수역)과 조석의 영향을 받는 지역(감조역)
  - 넓은 의미에서 하구는 담수에 의한 염분분포의 변화와 조석의 영향을 받는 하구수역이라 정의

3

02 하구의 의미(2)

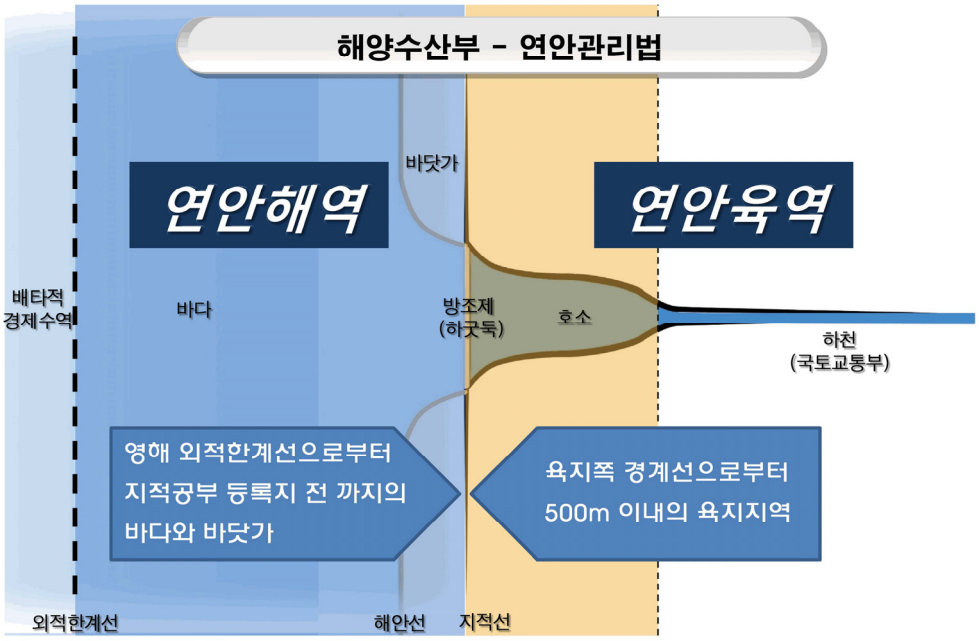
- 일반적/보편적/법률적 정의는 없는 실정
  - 법적 정의를 내릴 때 하구의 물리/화학적 특성이 반영
  - 하구 환경을 구성하고 특성을 결정짓는 요소가 다양

- 선진외국에서의 하구의 정의
  - 하구 보전 및 관리정책의 주요 목적, 하구의 자연·생태·지형적 특성을 고려
  - 사회·경제·문화적 여건과 실정을 고려

- 따라서 관리적 측면에서의 하구의 정의는
  - 하구수역 뿐만 아니라 영향육역을 포함한 하구의 공간적으로 관리영역 설정이 필요

4

03 하구의 위치(1)



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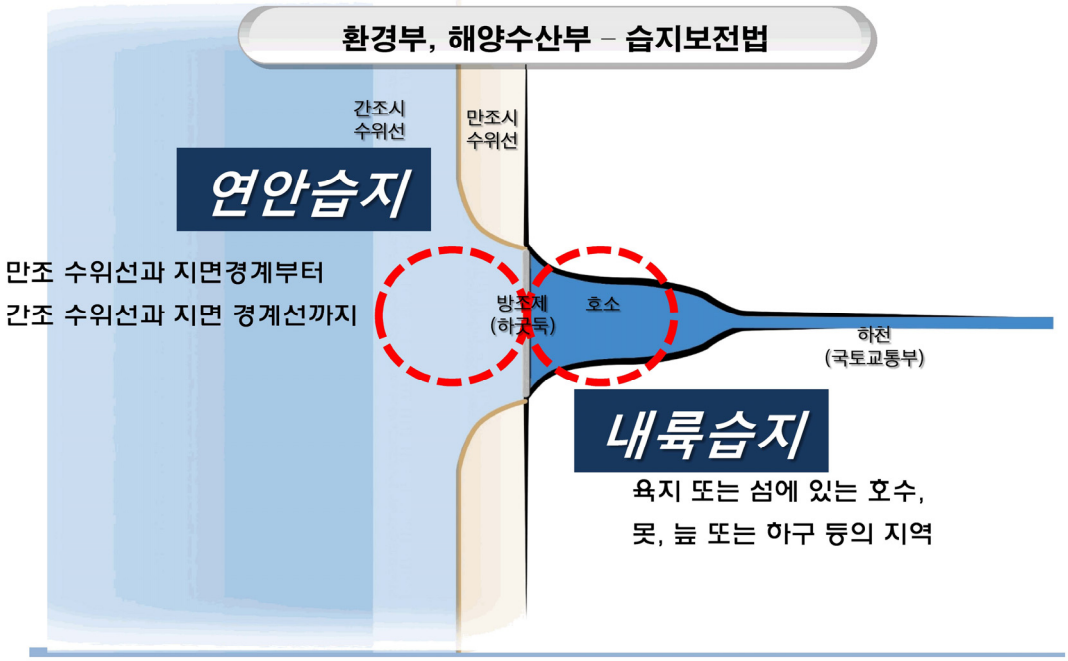
04 하구의 위치(2)



6

05 하구의 특성(1)

- **하구별 물리적, 화학적 특성에 따른 분류**
  - **쐐기형 하구**(salt-wedge estuary) : **하천 유량 영향이 많은 하구**
  - **완전혼합형 하구**(well-mixed estuary) :
    조석영향이 큰 하구, 한강, 금강, 영산강 등
  - **부분혼합형 하구**(partially-mixed estuary) :
    쐐기형과 완전혼합형의 중간적인 하구
- **하구의 보편적인 특성**
  - **하구는 담수와 염수가 혼합되는 자연환경과 생태계 형성**
  - **해양의 조석주기와 간만의 차, 하천수량 변동, 지형적 조건 등 주변 환경의 구성요소 등에 따라 상이**

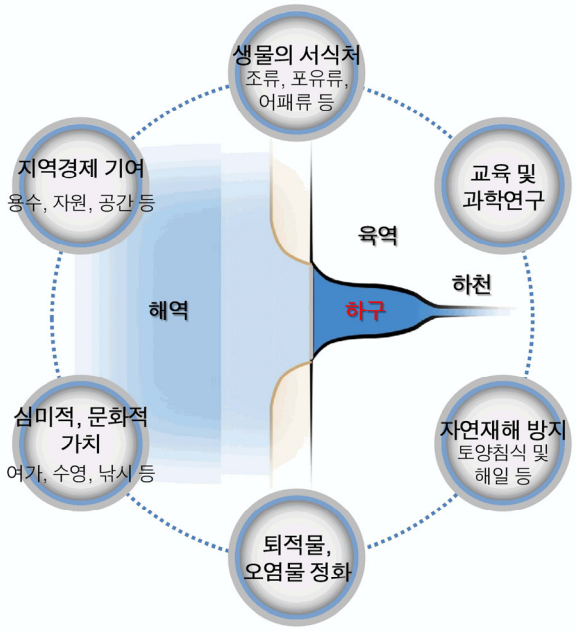
7

06 하구의 특성(2)

- 역동적인 생태계 형성
  - 하구는 위치, 시간에 따른 환경변화폭이 커 **생물 구성도가 다양**
- 생태적으로 보호가치가 높음
  - 특히, 충남을 비롯한 우리나라 서해안 하구습지는 높은 조수 간만 차와 위치, 지형적 특성 때문에 보호가치가 높음
    → 하천 상류와 연안지역에서 유입되는 퇴적물, 각종 영양염류 (질소, 인), 조석에너지가 풍부하여 넓은 하구습지를 형성
- 하구 자체로서 가치와 기능을 지님
  - 오염물질 정화, 홍수 및 해일 피해 저감, 심미적 기증, 위락 및 휴식장소 제공, 해상운송 등 사회적・경제적 가치

8

07 하구의 기능(1)



9

08 하구의 기능(2)

- 수산물 생산지 역할
  - 하구생태계는 생물에게 다양한 서식처와 풍부한 영양물질을 제공하고 있어 **생물다양성과 생산성이 높음**
- 오염물질 정화기능
  - 하구의 기능 중 가장 중요한 것이 **오염물질 정화활동**으로 흔히 하구와 갯벌을 '자연의 콩팥' 이라 부름
    → 하구(갯벌)에 서식하는 많은 생물들이 **정화기능** 수행
  - **우리나라 서·남해안 하구와 갯벌**은 질소와 인을 정화하는데 있어 **영국 염습지**보다 **15~200배까지 우수**한 것으로 나타남

10

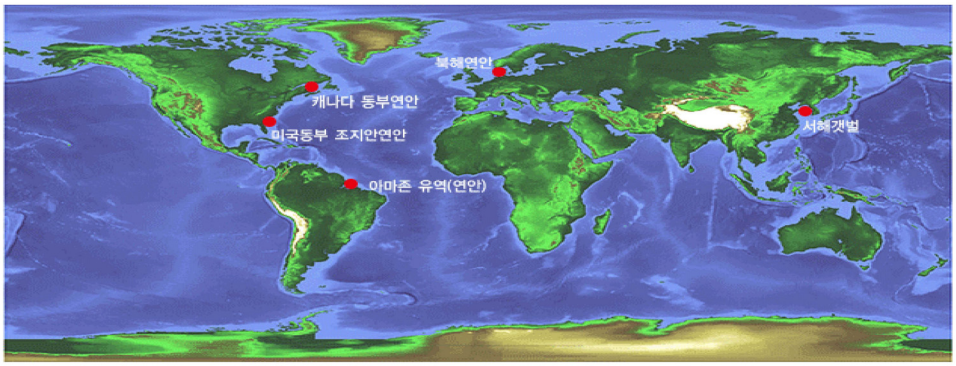
09 하구의 기능(3)

- 생태 서식지 기능
  - 하구는 담수와 해수의 완충지대로 풍부한 영양염류를 바탕으로 저서생물, 회유성 어종 등이 서식하는 생태계 보고
    → 영양염류와 각종 유·무기물이 풍부하여 1차 생산량이 높아 생물의 종류가 매우 다양함
  - **우리나라 하구와 갯벌**은 유네스코 세계유산으로 지정된 **와덴해 갯벌**에 비해 **4.3배 많은 생물이 서식**함
    → 해양 무척추동물, 미생물, 미세조류 등에게 서식지 제공
    → 미국에서는 현재 멸종위기에 처하거나 위협받고 있는 생물종 약 3분의 1 이상이 습지생태계에서만 발견된다는 보고

11

10 하구의 기능(4)

- 관광 및 교육적 기능
  - 우리나라 총 갯벌 면적의 83%가 서해안 지역에 분포하며, **서해 갯벌**은 **세계 5대 갯벌 중 하나**로 매우 중요한 자연유산임
  → 하구는 자연탐구, 조류관찰, 학술연구의 장으로 활용



자료) 바다생태정보나라(http://www.ecosea.go.kr)

12

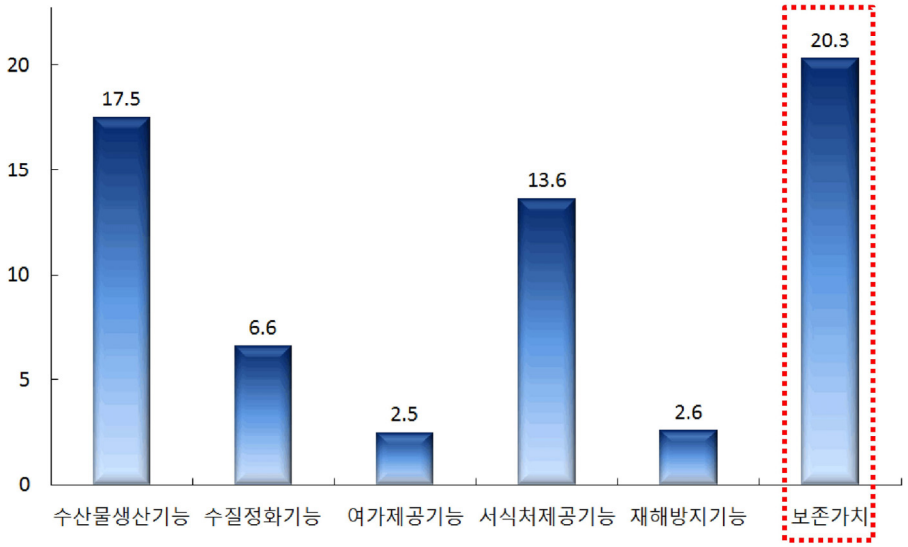
11 하구의 가치(1)

- 하구의 생태가치
  - **기수역**의 단위 면적당 생태적 가치는 **농경지의 250배**에 이름
  (갯벌의 단위면적당 생태적 가치는 농경지의 100배)
  → 단위 면적(1 km^2)당 가치(US$)(Nature, 1997) :
  기수역 2,283,200 / 갯벌 990,000 / 농경지 9,200
  - 우리나라 하구와 **갯벌**의 경제적 가치 : **약 16조원**(해수부, 2013)
  → 단위 면적(1 km^2)당 연간 제공가치 : 63억원

항목	인천/경기	충남	전북	전남(서부)	전남(동부)	경상/제주
경제 가치 (억원/년)	55,155	22,676	7,439	47,476	18,056	-

13

12 하구의 가치(2)



하구의 기능별 경제적 가치(억원/km²/년, 2012년 12월 기준)

14

Ⅱ 하구현황 및 문제점

01 우리나라 하구역 현황

- 하구역 현황 : 328개소
  - 국가하천 규모 : 13개

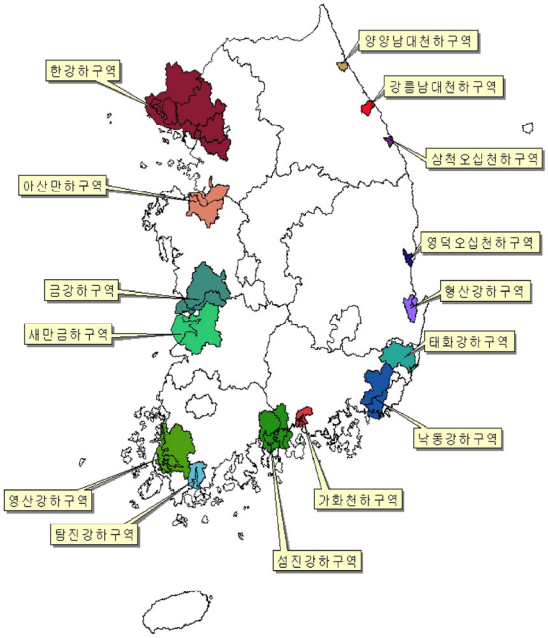
    한강, 안성천, 삽교천,

    금강, 만경강, 동진강,

    영산강, 탐진강, 섬진강,

    가화천, 낙동강, 태화강,

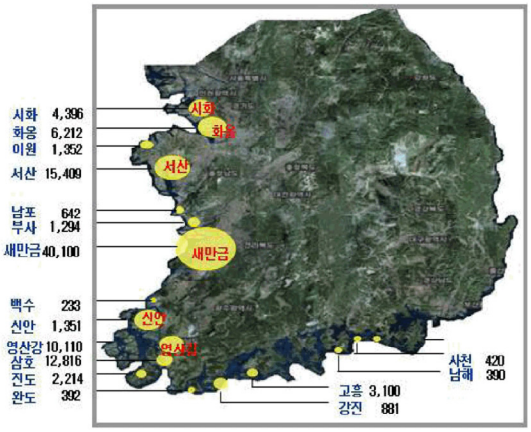
    형산강
  - 지방하천 규모 : 315개



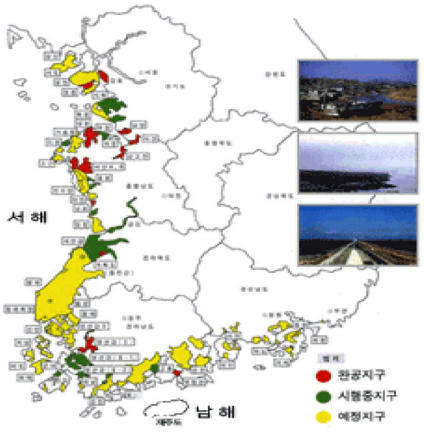
16

02 간척(갯벌매립) 현황

- 간척현황
  - 방조제 및 하굿둑 축조와 갯벌 매립은 하구형 갯벌과 만입형 갯벌 (폐쇄성, 반폐쇄성)에서 주로 시행



주요 간석지 매립현황

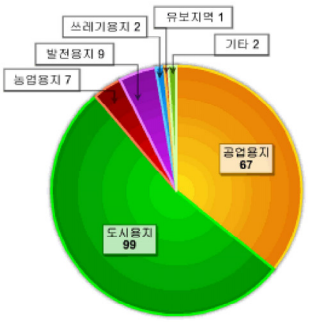


주요 간석지 매립 예정지구

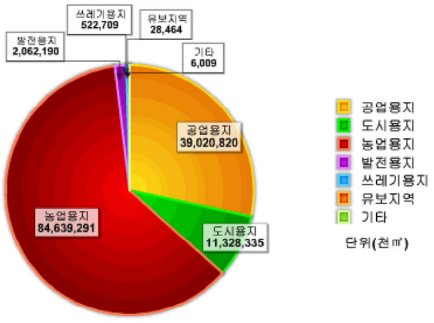
17

03 간척지의 방조제 및 하굿둑 건설

- 방조제 및 하굿둑 건설
  - 방조제와 하굿둑 건설은 홍수 및 해일 피해예방과 생활, 농업 및 공업용수 확보를 해결한다는 장점으로 전세계적으로 추진
    → 우리나라 갯벌 매립건수는 도시용지 및 공업용지가 많으나, 매립면적은 농업용지, 공업용지, 도시용지 순으로 나타남



매립용도별 준공건수



매립용도별 준공면적

18

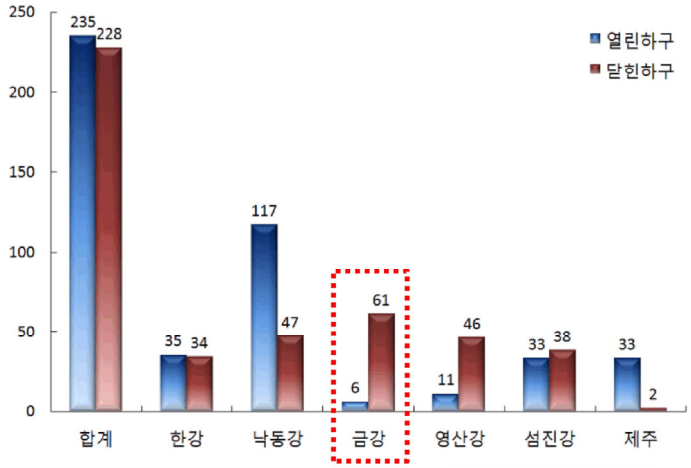
04 방조제 현황

- 방조제 현황
  - 방조제의 관리는 규모에 따라 국가관리방조제와 지방자치단체관리방조제로 구분
  - 우리나라 방조제는 총 1,611개소로, 충청남도에 준공된 방조제는 279개소로 전라남도(989개)에 이어 2번째로 많음
    → 충남지역 방조제는 국가 20개소, 충남(지방자치단체) 250개소, 미지정 9개소이며, 그 외 미준공된 방조제 1개소(부사지구)는 보령시와 서천군간 행정구역 미결정으로 사업준공이 지연
  - 방조제 축조지역에 모두 담수호가 존재하지는 않고, 하천의 유무, 토지이용계획, 용수이용계획, 공사비용 등에 따라 담수호 조성

19

05 권역별 하구관리 현황

- 전국 463개 하구 가운데 228곳(49%)이 닫힌하구로 방조제, 항만 개발, 매립 등으로 물 순환 차단 및 생태계 단절
  - 특히, 충남이 속한 금강권역은 92.4%가 닫힌 하구



20

06 충청남도 하구현황 및 분류(1)

- 충청남도 하구현황
  - 닫힌하구는 하구이용 및 개발이 집중된 하구로 해수 순환이 차단되어 하구 본래의 특성을 기대할 수 없는 곳
  - 충청남도 서해 연안에 위치한 하구는 총 34개소이며, 이 가운데 열린하구는 6개소, 닫힌하구는 28개소

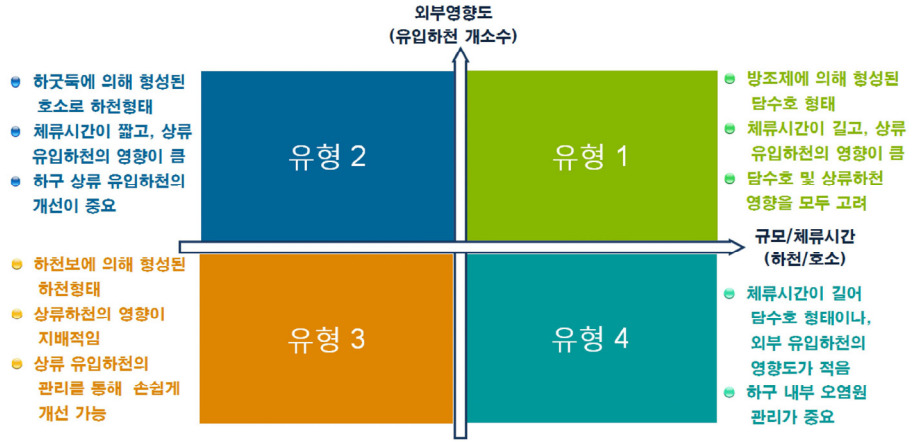
→ 간월호, 갈두천, 교성천, 금강호, 남포천, 당정천, 대천천, 대호, 밀두천, 반계천, 방길천, 보령호, 봉당천, 부남호, 부사호, 비인천, 삭선천, 삽교호, 상황천, 서원천, 석문호, 솔리천, 송내천, 송천천, 신대천, 아산호(평택호), 어은천, 용요천, 이원호, 종천천, 차동천, 초대천, 판교천, 홍성호

※ 특히, 닫힌하구 내 갇힌하구(하천)가 27개소 존재

21

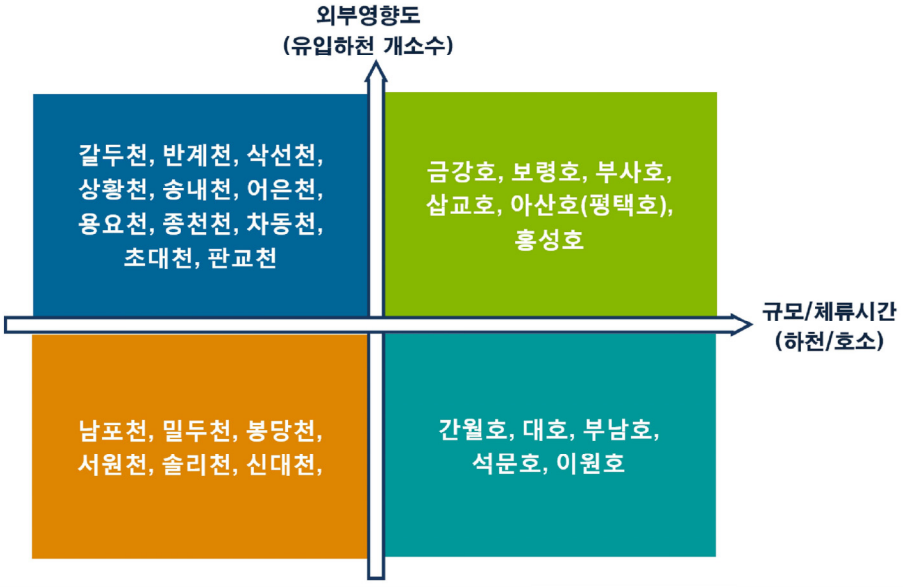
07 충청남도 하구현황 및 분류(2)

- 닫힌하구 유형분류 기준 및 방법
  - 하구는 유형분류 시 **유입 하천**(또는 하천의 수질과 유량의 영향정도)과 **담수형상 및 체류시간**에 따라 구분



08 충청남도 하구현황 및 분류(3)

- 닫힌하구 유형분류



09 하구호의 문제점(1)

- 해안선 및 생태계 변화 가속화
  - 조류와 조석의 침식에너지를 강화시켜 **침식을 가속화**
    → 해안의 침식과 침수 등으로 **해안선 및 생태계의 변화** 초래
- 갯벌의 변화
  - 유속 증감에 따른 **갯벌의 변화** 초래
    → 갯벌의 환경변화는 매우 느리고, 장기적으로 나타나므로 변화정도 및 피해영향의 심각성이 쉽게 인식되지 않음
- 하구지역의 토사결핍
  - 인공구조물(하굿둑) 건설로 인한 **퇴적물(토사) 공급량 부족**

24

10 하구호의 문제점(2)

- 물 순환이 차단된 하구호의 문제점
  - 수질악화 및 빈 산소층에 의한 생태계 파괴
  - 퇴적물 오염에 따른 악취발생 및 산소부족 현상 발생
  - 녹조현상 발생으로 생태계 파괴 및 하구기능 손상
  - 유속감소에 따른 퇴적율 증가로 퇴적물 오염 야기
  - 기수역의 파괴로 생태계 순환의 고리 차단
  - 육상기원의 퇴적물 차단으로 연안침식, 해양생물 서식지 및 산란지 파괴 등 연안환경에 장기적 피해발생
  - 하굿둑 하류 측에 세립질 퇴적물의 축적으로 연안수질 악화
  - 퇴적물의 지속적인 준설비용 및 처리에 따른 다른 환경재해 발생

25

Ⅲ 하구복원의 필요성

01 하구복원의 필요성

하구기능 약화

- 하굿둑과 방조제는 자연재해에 대한 강력한 방어수단
- 하굿둑 및 방조제로 물순환 차단, 수질오염으로 인해 본래 기능(수자원 가치)이 크게 악화

인식의 전환

- 하구와 갯벌의 생태적, 경제적 가치가 크다는 사실을 인식
- 해수순환에 대한 국민적 관심 증가
- 주요 선진국들은 이미 복원사업을 추진완료 및 추진 중

연안 및 하구복원 관심증대

- 국토해양부에서 2008년 하구 및 갯벌 복원 대상지를 조사
  - 전국 15개 시·군이 81곳(32.12km²)이 복원 희망 (전남이 42곳 (22km²) 으로 가장 많았음)
  - 복원사업 추진(전북 고창, 2012년까지 159억)

추진체계 확립 및 사업 추진시기

- 우선, 하구의 해수순환 및 습지복원을 위한 추진체계 확립
- 복원대상 하구와 폐염전, 폐양식장 등 목록화 및 선별적 사업을 추진할 시기가 도래

27

02 하구복원의 한계

- 여전히 진행 중인 중앙정부와 지방자치단체의 선점식 개발
- 하구의 공간단위 관리개념 부재
- 분절적 관리체제로 인한 정책 통합성 결여
- 하구 정책과 집행에 관한 과학적 기초자료 및 지식기반의 취약
- 지역주민의 실질적 · 자발적 참여를 위한 제도적 장치 미비
- 지역의 이해 정도와 의견을 반영할 수 있는 창구의 미흡

28

Ⅳ 연안 및 하구 생태복원방안

01 하구 담수호의 복원방안

오염된 하구호의 수질개선과 해수순환 없이는
하구 생태복원이 사실상 불가능

- 객관적이고 과학적 평가를 수반한 주장이 필요
  - 수질오염이 악화된 하구 담수호를 대상으로 우선 추진
  - 하굿둑 유지 → 배수 갑문의 운영방법 고려(계절적 순환)
  - 해수 순환율 증가 필요 시 갑문 확장 등의 구조개선 도입 추진
  - 상시 해수순환 체계로 전환 시 다기능적 요소 도입
    (소수력, 조력, 어선 및 마리나 항 등)

30

02 하구유역의 통합관리

필요성

- 하구는 관리적인 측면에서 공간적 · 기능적으로 분산되어 일괄적인 **통합관리가 매우 어려움**
- 하구는 다양한 이해당사자가 존재하고, 이들 사이에 갈등이 표출되는 지역

방향성

- 분화된 관리체계의 부조화 극복을 위해 통합성 확보
- 이해당사자 간 상충되는 이해를 조정할 수 있는 **협의 및 조정체계의 구축**에서 출발

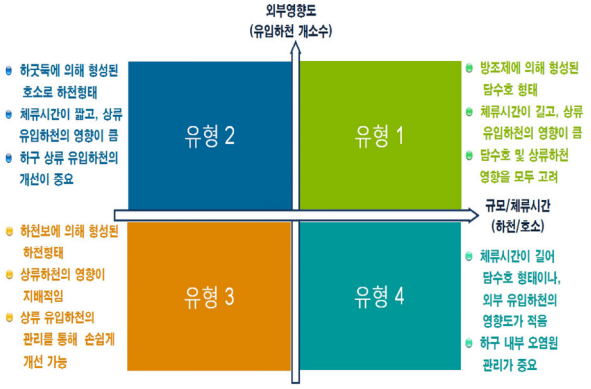
성공 요인

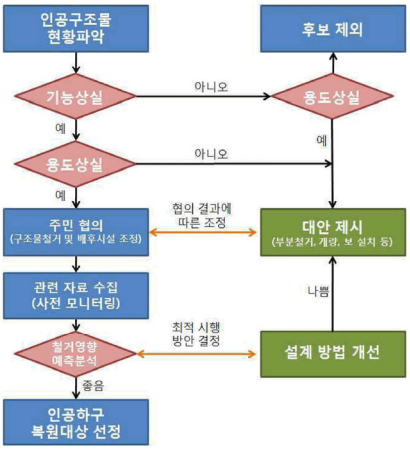
- 지역이용자 및 관리자의 참여의지를 기반으로 복원
- **행정, 조직, 단체, 법률, 비용** 등이 모두 유기적 통합
- **하구중심의 유역별 통합관리** 방식으로 전환 필요

31

03 하구복원 대상지 선정절차

- 하구 현황조사 및 **하구호 유형(하구 및 하구특성)** 분류 및 평가
- 하구호 복원의 **타당성 평가** 및 **우선순위 설정**
- 하구호 복원의 **계획 및 시행**, 복원과정의 **모니터링 및 평가관리**





32

04 협력적 거버넌스 구축

[해외사례]

- 파트너쉽 강조
- 관리조직 구성을 원칙
- 주정부 및 연방기관의 지속적이고 긴밀한 협의를 위한 법 규정
- 프레이저 하구프로그램
- 호주의 다윈트하구프로그램

다양한 이해당사자의 참여를 보장하고 합의를 도출해 낼 수 있는 논의 구조와 절차를 지역실정에 적합하게 개발

[비법정 하구관리프로그램 구축]

이행당사자 간의 다양한 활동 보장,
논의의 활성화, 참여의 제고

지역포럼 및 정책협의회 구성

하구를 구성하는 다양한 공간과 부문 간의 연계성 확보를 위한 기본 정책방향을 수립

33

05 하구복원에 대한 홍보와 교육

- 주민들은 **하구습지의 가치와 경제적 손실**에 대하여 인식 못함
- **하구와 습지의 기능과 가치**에 대한 **교육과 홍보 활성화** 필요
- 사업 추진에 대한 공감대 형성 및 지역민들의 자발적 참여 유도

하구와 습지에 대한 보전 및 관리방안 수립시 지역주민의 교육 · 홍보를 통한 하구별 자발적 관리 및 보호체계 확립

34

06 보호구역 및 개선지역 지정

필요성

- 현행 개별 법률상 지구 · 지역지정은 대부분 **이용과 보전에 관리에 관한 내용**이며, **복원내용은 제한적**

현황

- 훼손된 하구와 염습지의 개선과 복원을 위한 법률은 **『습지복원법』**의 **"습지개선지역"** 지정
- **『연안관리법』**의 특수연안해역 중 해양환경 및 생태계 복원사업을 위해 필요한 구역을 **"해양환경 복원구"**로 지정할 수 있는 정도

방안

- **하구복원 개념의 지구 · 지역 지정제도 도입 필요**
- **보호구역 및 복원지구**의 지정기준 및 절차의 조사 및 연구와 이해관계자 참여를 제도화(하구관련법 제정)

35

07 연안 및 하구복원의 선도적 추진

현재까지 충남의 움직임

- ✓ 연안 및 하구생태복원 추진방안 모색을 위한 워크숍
- ✓ 연안 · 하구생태복원 입법지원 간담회 개최
- ✓ 충남도 민선 6기 핵심사업으로 선정
- ✓ 제5회 연안발전포럼 유치

민선6기 핵심사업 선정

충남, 연안 · 하구생태 복원 입법지원

(아시아뉴스통신=박상길 기자)

정책 및 학술적 워크숍 중심

앞으로 진행사항

- 시설물 조사
- 타당성 검토
- 시범대상지 계획 수립

- ✓ 기술적 검토
- ✓ 정량적 수치 분석
- ✓ EFDC 분석 등

"충남 연안 및 하구 생태복원계획 수립"

기술적 접근

08 연안 및 하구 생태복원 체계(1)

연안 및 하구생태복원을 위해 하구별 특성 조사

조사결과를 바탕으로 해수순환과 복원 우선순위를 설정

시범사업(소규모/대규모) 추진을 통한 점진적 복원사업의 추진

닫힌 하구 (하구호)	- 닫힌 하구 중 수질저하 및 용수공급 등의 본래의 목적이 미흡한 지역 선정 - 기능 및 지역여건에 맞춰 하구호 해수순환 시범사업지(대상지) 선정 - 닫힌하구 배수갑문의 부분/단계적/완전 개방을 통해 수질개선 및 생태계 회복
폐염전 폐양식장	- 폐염전 및 폐양식장을 대상으로 방치된 지역을 염생습지로 복원방안 마련

09 연안 및 하구 생태복원 체계(2)

현황조사	기능재평가 및 대상지 발굴	복원방안 마련	시범사업실시
- 방조제 - 하구호 - 폐염전 폐양식장 - 방파제, 해안사구, 해빈	시범사업 복원대상지 선정 (방조제, 폐염전, 폐양식장)	수리수문 분석 파급효과 분석 선호도 조사 복원방안 마련	시범대상지 마스터플랜 수립

38

10 연안 및 하구 생태복원 체계(3)

	방조제 및 하구호	폐염전	방파제, 해빈, 사구
현황조사 및 D/B 구축	279개소 방조제 조사 및 D/B구축	폐염전 현황조사 및 D/B구축	방파제, 해빈, 사구 현황조사 및 D/B구축
기능재평가 및 대상지 발굴	하구호 기능재평가를 통해 복원가능지 발굴	습지가치평가를 통해 복원가능지 발굴	방파제로 인한 지형변화 평가
시범대상지 발굴	**시범대상지 선정(하구호, 방조제, 폐염전)**		주요 연안경관자원의 관리방안 마련 (연안통합관리계획)
대상지 복원방안 마련	수리수문, 파급효과분석, 선호도조사를 통해 복원방안 마련		
생태복원계획 수립	대상지 마스터플랜 수립		
생태 · 환경 모니터링	대상지 생태 · 환경 모니터링 실시		

39

충청남도 연안 및 하구 생태복원의 중장기 전략

전체전략

충남 연안 및 **하구생태복원계획** 마스터플랜 마련

단 기

- 현황조사 및 분석
- 대상지 선정 및 생태모니터링 (시범사업 시행)
- 연안 및 하구복원 마스터플랜 수립
- 연안 및 하구복원 전국적 시행

중 기

- 닫힌 하구호 D/B 구축
- 기능평가를 통한 대상지 선정
- 연안 및 하구 관리방안 마련
- 대상지 연계지역 경제거버넌스
- 황해광역 해양생태계 지원
- 대상지 생태환경 모니터링

장 기

- 닫힌 하구호 해수순환
- 갯벌 및 습지 생태복원
- 복원지역 보호지역 지정
- 연안 및 하구 장기모니터링
- 국가 지원사업 시행

- (가칭)연안 및 하구 생태복원 법안 제정
- 연안 및 하구 생태복원사업 전국 확산
- 서해 연안 및 해양의 건전화

40

영산강 하구역 종합관리시스템 개발사례

인하대학교 우승범 교수

2015년 연안 및 하구 생태 복원 국제포럼 : 영산강 하구역을 중심으로

영산강 하구역 종합관리 시스템 개발사례

발표 : 우승범

일시 : 2015년 8월 20일 (목)

장소 : 보령 웨스토피아 동백홀

목차

1. 배경 및 목적

2. 주요 연구 결과
   (모니터링, 수치모델링)

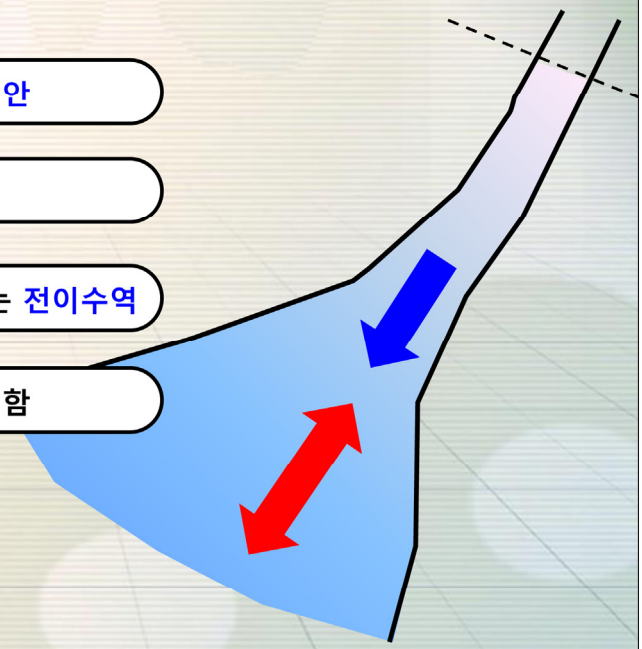
3. 연구 성과 요약

2

1. 배경 및 목적

1.1. 연구 배경: 하구 정의

- 하구 (河口, estuary)
  - 개방해역과 연결된 반폐쇄 해안
  - 담수/염수 혼합이 발생
  - 담수 유출과 조석 영향을 받는 전이수역
  - 수역의 배후지를 포함하기도 함



4

1.2. 연구 배경: 국내 하구 현황

열린 하구
- ❖ 235개 (51%)
- ❖ 동/남해안/제주도
- ❖ 소유역 하천

닫힌 하구
- ❖ 228개 (49%)
- ❖ 서해안
- ❖ 대유역 하천

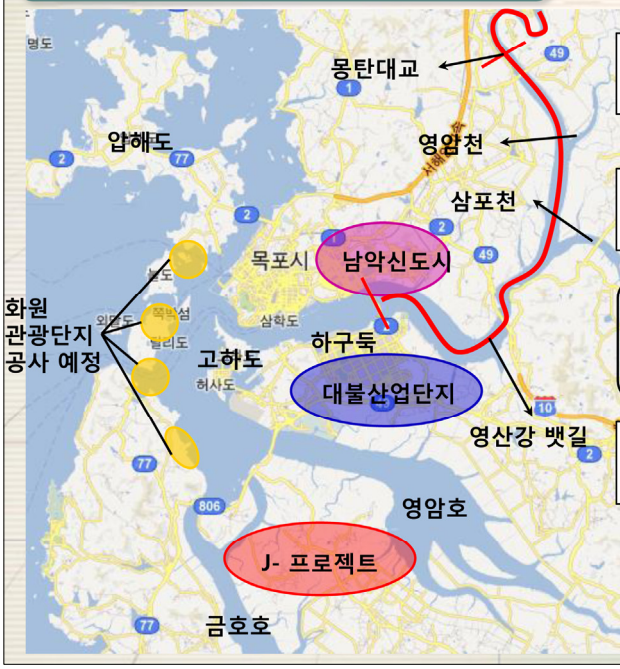
닫힌 하구의 문제점
- ❖ 하구 순환 차단
- ❖ 하구 습지 훼손

수생태 환경문제 발생

5

1.3. 연구 배경: 갈등 사례

하구 이해당사자 간
갈등사례: 영산강 하구



1997~현재	영산강 뱃길 복원 사업

관광위락 용수(2급수)에 비적합

2002	대통령 정책 공약

지속발전위 "해수유통 검토"

2005	지자체의 지역개발 구상 하구호 수질 문제

전라남도청 "준설 요구"	⇔	환경부 국토부 농림부 부처간 회피

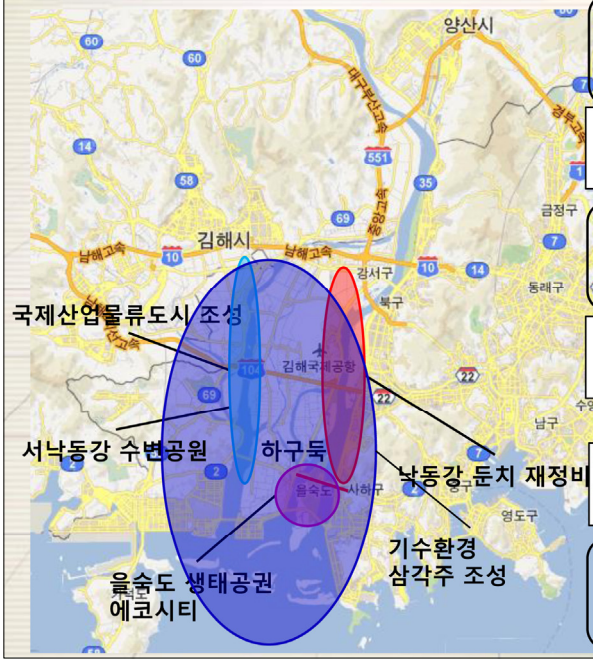
2010	하구둑 구조 개선 사업

농어촌공사 "저층수 배제"	⇔	신안군 어민 환경단체 "유통 반대"

6

1.3. 연구 배경: 갈등 사례

하구 이해당사자 간 갈등사례: 낙동강 하구

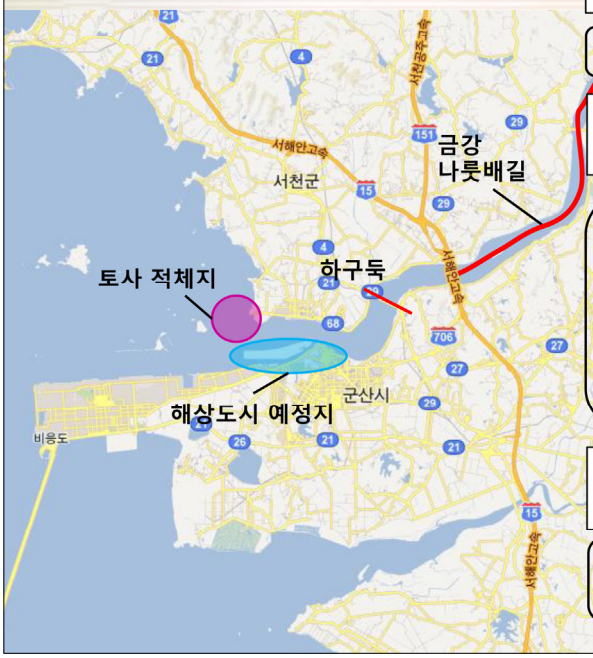


1980~1997	하구둑 건설, 갯벌매립 산업화·도시화
철새도래지 기능 약화 ⇔	염수침입 방지 홍수조절 농지확보
2003~현재	을숙도 주변 개발과 보전 낙동강하구에코센터
보전 철새 서식지 복원 ⇔	개발 준설토 적치장 쓰레기 매립장
2006	기수환경 조성, 삼각주
지속발전위"상시 유통, 여수로 조성" 검토	
1997~현재	하구둑 해체, 해수유통
환경단체 하구 생태복원 종다양성 확보 ⇔	수자원 공사 염수피해,홍수 과다한 사업비

7

1.3. 연구 배경: 갈등 사례

하구 이해당사자 간 갈등사례: 금강 하구



1990	하구둑 건설
농·공업용수 공급, 홍수조절, 염해방지	
2007~현재	하구둑 개방 해상도시, 금강 나룻배길
충남 서천군 "유통 찬성" 생태계 복원 하천기능 회복 수질 개선 ⇔	전북 군산시 "유통 반대" 담수호 상실 홍수 취약 막대한 사업비
2009~2011	금강하구역 생태계 조사 및 관리체계 구축용역
"용수 확보 없는 해수유통 불가" "막대한 사업비 소요"	

8

1.4. 하구 갈등 발생의 배경

1960 1970 1980 1990 2000 2010

개발 위주의 전략

- 하구둑 건설 = 담수호 조성
- 공유수면 매립 = 농지/대지 확보
- 도심 개발 etc.

제도적 미비
기술적 시스템 부재

보전·복원 관심 증대

- 하구개발 폐해 인식
- 하구관련 갈등 발생
- 기수역 복원 움직임
  - i.e. 3대강 해수유통 추진협의회 발족
  - 19대 총선 부산지역 공약과제

9

1.5. 하구 관리의 난점

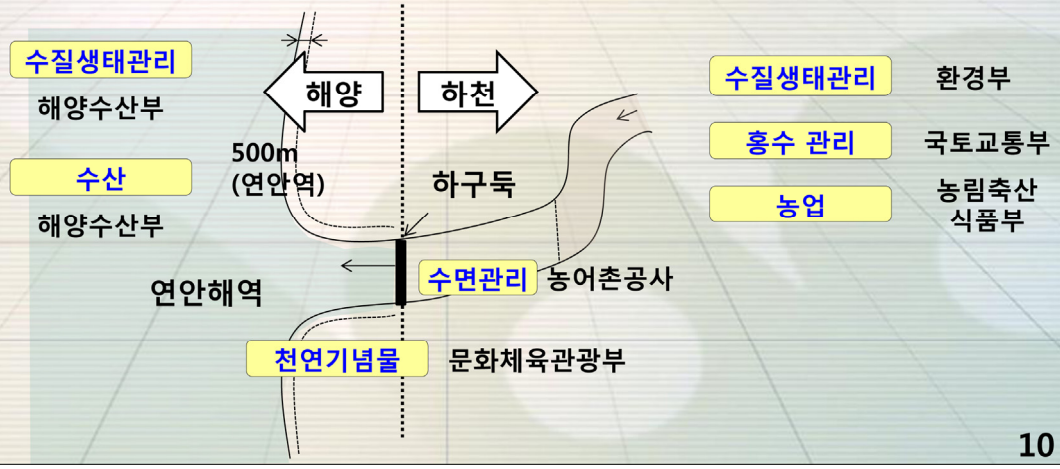
하구 관리의 난점 1: 기능·공간별로 분화된 관리

기능별로 분화된 하구관리 체제

공간별로 분화된 환경관리 체제

→ **이해 당사자간 이해상충/갈등**

부처 관리목표에 입각한 행위가 분쟁 유발



10

1.5. 하구 관리의 난점

하구 관리의 난점 2: 지식기반 취약 및 기술시스템 부재

지식기반 취약

관측자료 부족
→ 단편적, 단발성, 취합정리 부족

과학적 이해부족
→ 하구별 프로세스 이해 미비

대응 역량 부족
→ 신규수요/환경변화 발생시

기술지원 시스템 부재

통합예측시스템 부재
→ 유역-하천-하구 연계 미반영

정보시스템 부재
→ 조사자료 및 관련정보 공유 및 접근성 부족

이해 당사자 의견 충돌 및 갈등 증폭

11

1.6. 종합관리시스템 개발

하구관리 난점의 해법: 하구역 종합관리시스템 개발

12

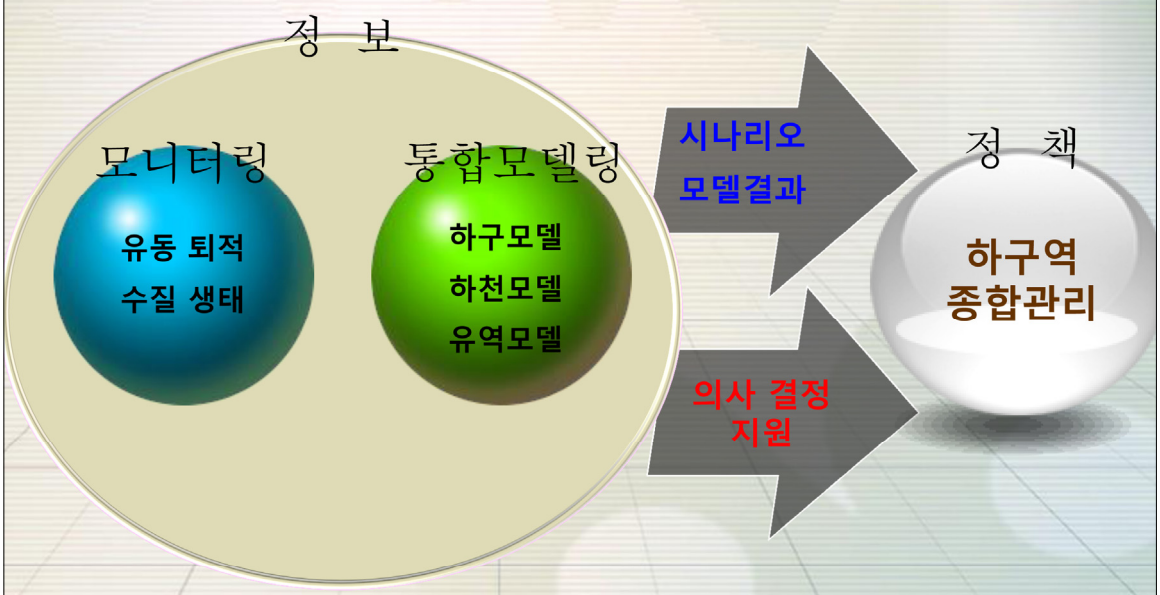
1.7. 연구 목표

통합적 **하구관리 체제** 및 이를 지원할 수 있는
하구역 종합관리시스템을 개발함

하구역 종합관리시스템은 **모니터링, 모델링,**
정보 시스템으로 구성됨

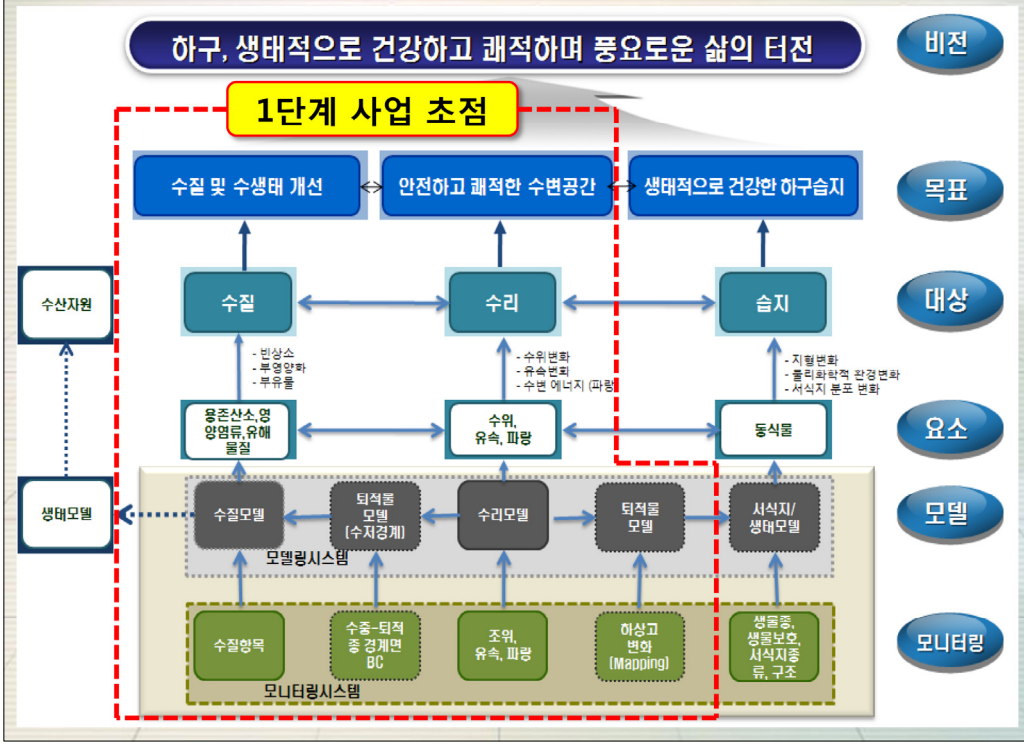
13

1.8. 하구역 종합관리시스템 구성



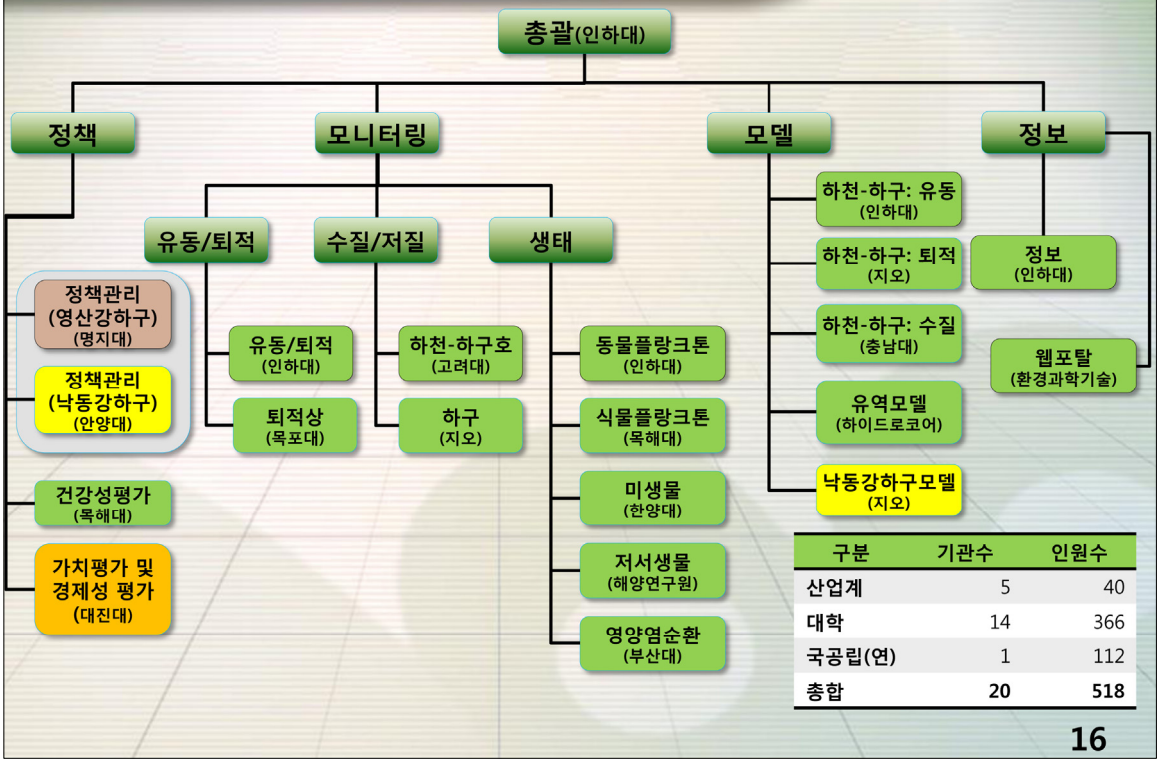
14

1.9. 하구역 종합관리시스템 설계



15

1.10. 연구진 구성



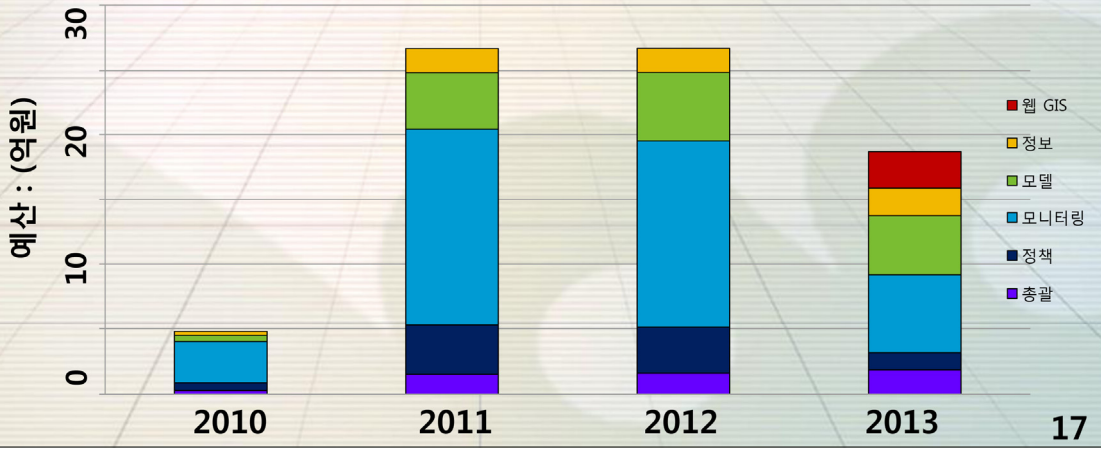
구분	기관수	인원수
산업계	5	40
대학	14	366
국공립(연)	1	112
총합	20	518

16

1.11. 추진 전략

2010	2011	2012	2013
현황 파악	개별 시스템 개발	통합시스템 구축	통합 시스템 완성

정 책	하구관리 제도기반 확보
모니터링	하구관리 지식기반 확충
모 델 링	예측모델링 시스템 구축
정 보	GIS 기반 통합정보시스템 구축



17

1.12. 영산강 하구 잠재적 위해 요인

유역/하천 여건 변화

- 녹조 발생 빈도의 증가
- 연안 유역 오염 부하 증가
- 만성적 빈산소 수괴 발생
- 방류량 규모 및 빈도 증가

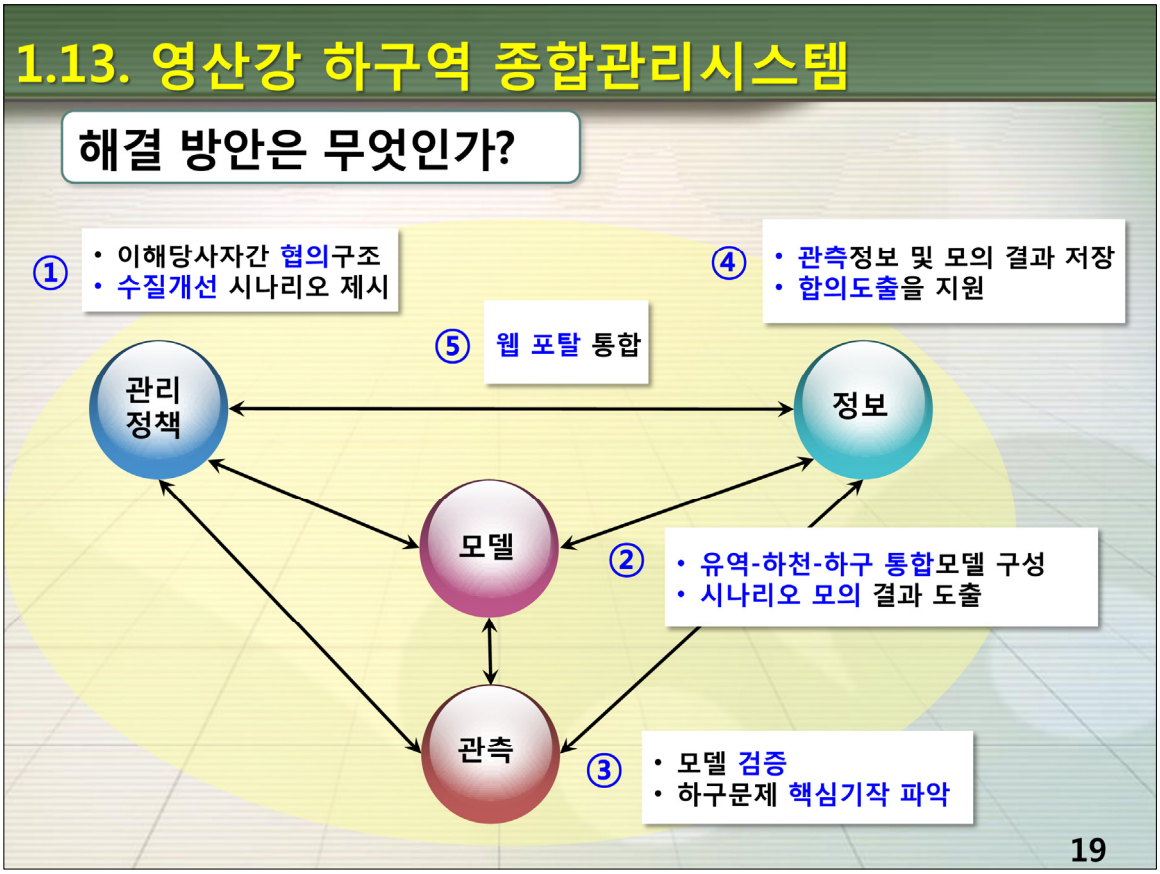
기후변화

- 강수의 규모 및 빈도의 변화
- 가뭄 / 홍수

하구 이용 욕구의 다변화

- 영산강 뱃길 복원 구상: 수로 준설 욕구 증가
- 상/하류 지역 간의 갈등: 방류로 인한 해역 수질 저하

18


1.13. 영산강 하구역 종합관리시스템
해결 방안은 무엇인가?
① • 이해당사자간 협의구조
• 수질개선 시나리오 제시
④ • 관측정보 및 모의 결과 저장
• 합의도출을 지원
⑤ 웹 포탈 통합
관리 정책
정보
모델
② • 유역-하천-하구 통합모델 구성
• 시나리오 모의 결과 도출
관측
③ • 모델 검증
• 하구문제 핵심기작 파악
19


2.1. 주요 연구 결과
- 모니터링 -

2.1.1. 연구배경 및 목표

기존 연구 진행 현황

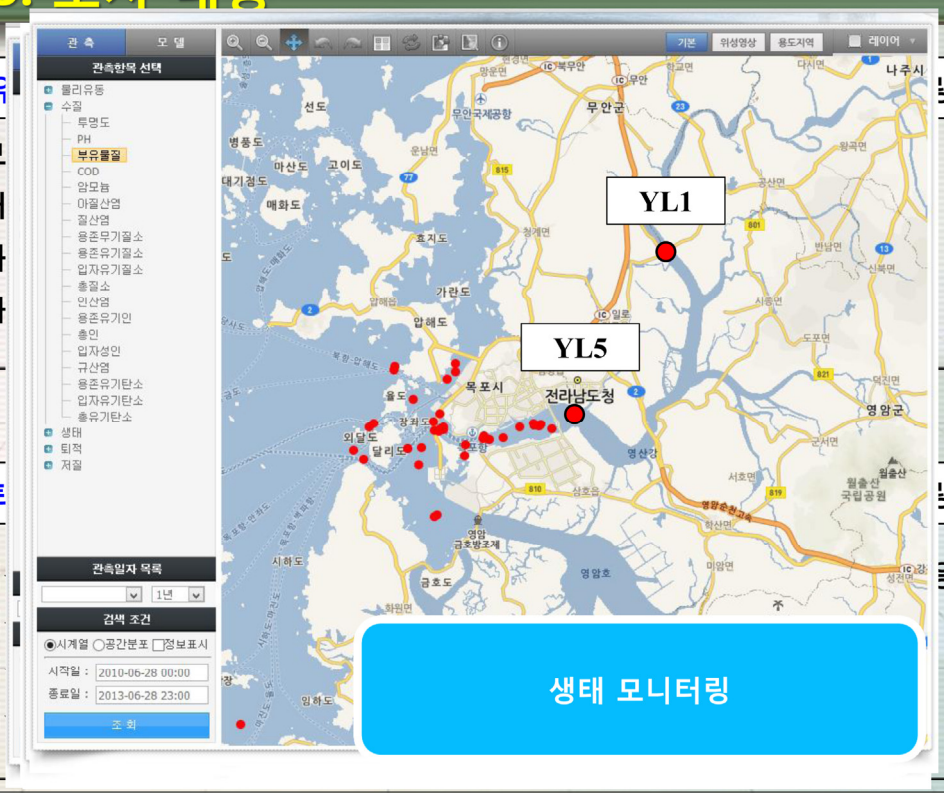
- ✓ 하구둑 건설의 부정적 영향 추정 및 단편적 조사 위주로 진행
- ✓ 하구환경 개선에 대한 조치를 취하기에는 불확실성이 큰 상황임
- ✓ 하구역의 체계적인 관리 및 정책결정을 위해서는 생지화학적 물질순환에 대한 연구 필요

21

2.1.2. 연구 내용

22

2.1.3. 조사 내용



✓ 모
✓ 내
✓ 하
✓ 하

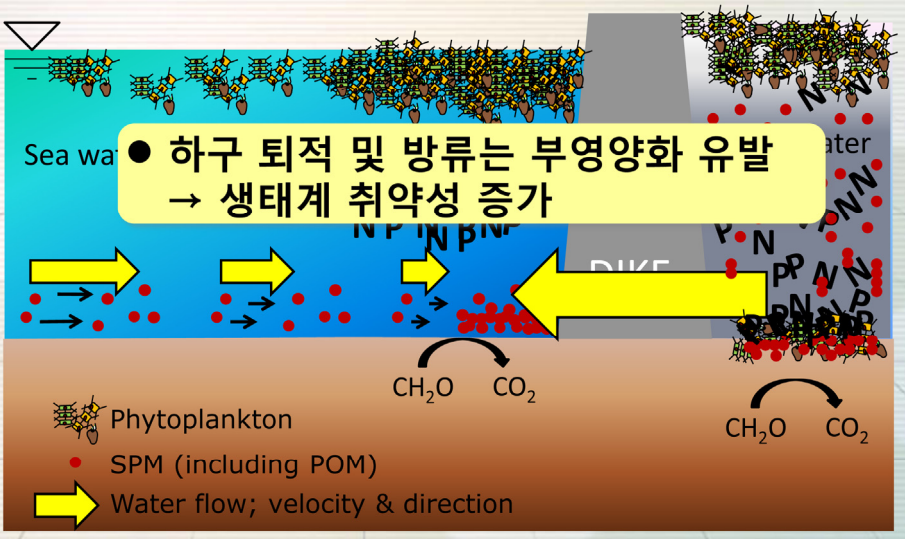
✓ 퇴
✓ 퇴
✓ 퇴
✓ 퇴

특성

23

2.1.4. 하구둑: 한국적 특수성

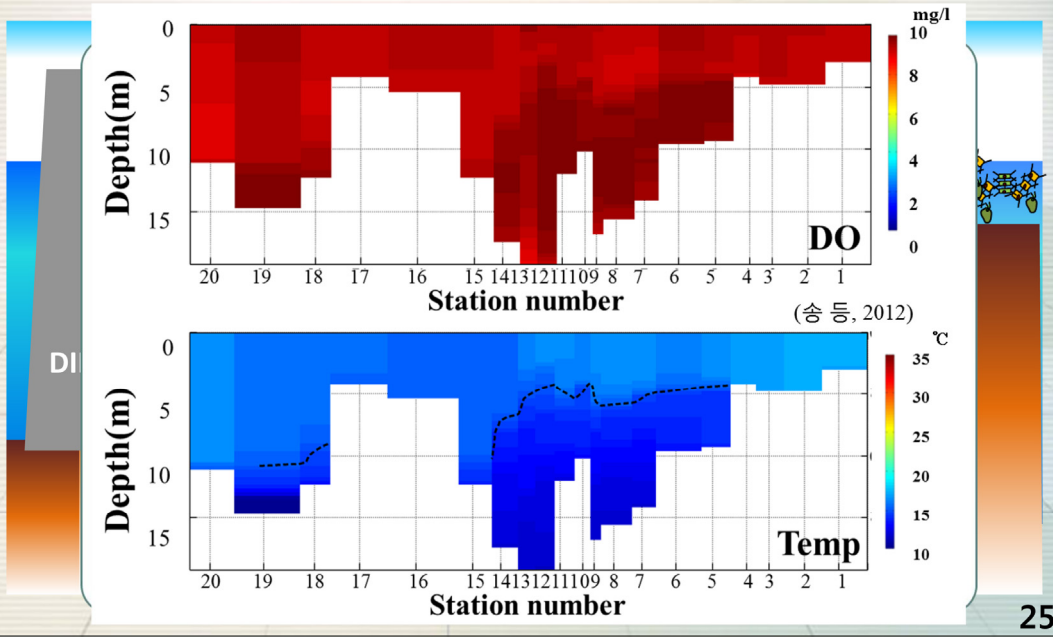
하구역	하구둑 근처 유동 감소 및 유기물 퇴적	영양염 용출 및 식물플랑크톤 증식	유기물 침전, 퇴적
하구호	유기물 분해 및 영양염 용출 증가	방류로 인한 영양염 대량유입	빈산소 시 인산염 용출증가



24

2.1.5. 연구 결과

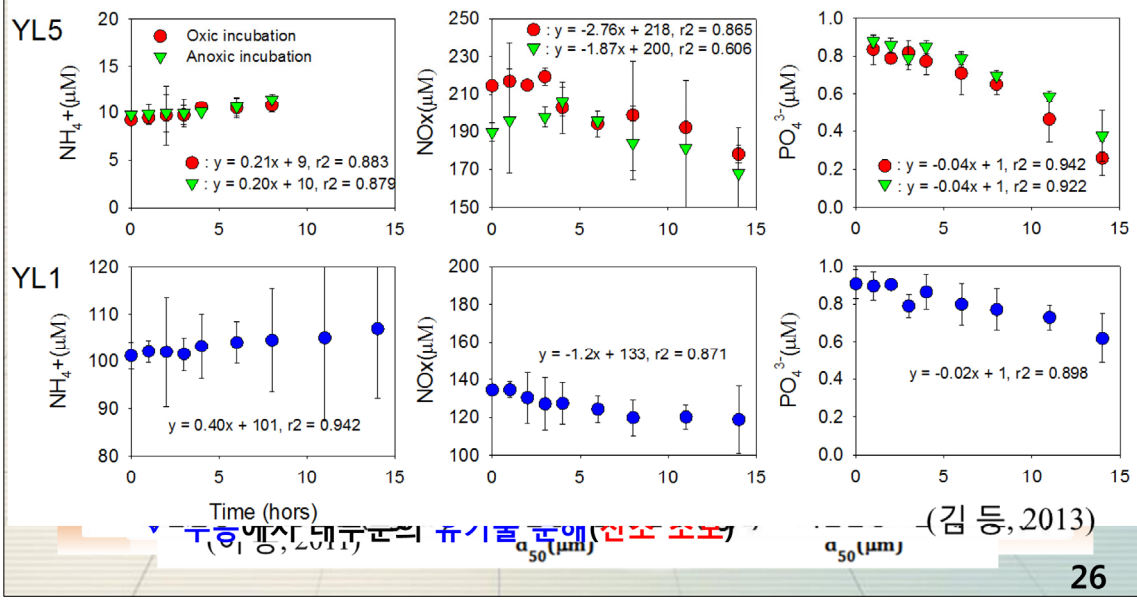
동계/춘계/추계 → 낮은 수온 높은 용존 산소 → 호 상단 상시 부영양화



25

2.1.5. 연구 결과

빈산소 환경 : Fe-P 로부터 해리 → Al-P 로 재흡착 → 빈산소 환경임 P의 용출 불가 → 식물플랑크톤 증식



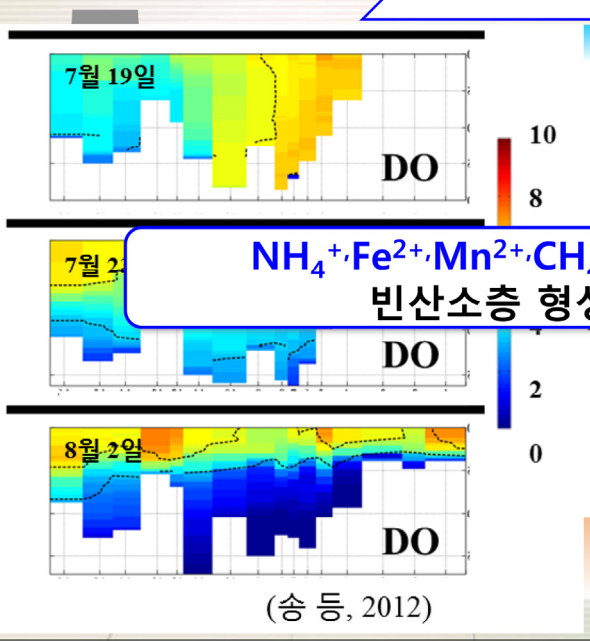
(김 등, 2013)

26

2.1.5. 연구 결과

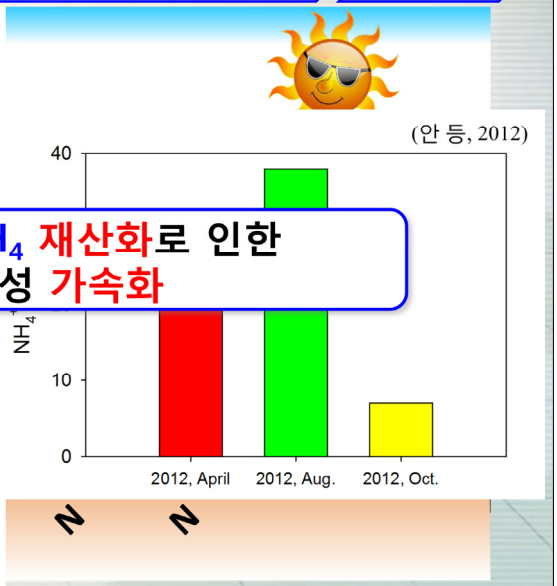
하구둑 방류 종료 → WOD로 계산한 잠재적 빈산소화 시간 7~19일

관측자료에서 나타난 빈산소화 시간 4 일



(송 등, 2012)

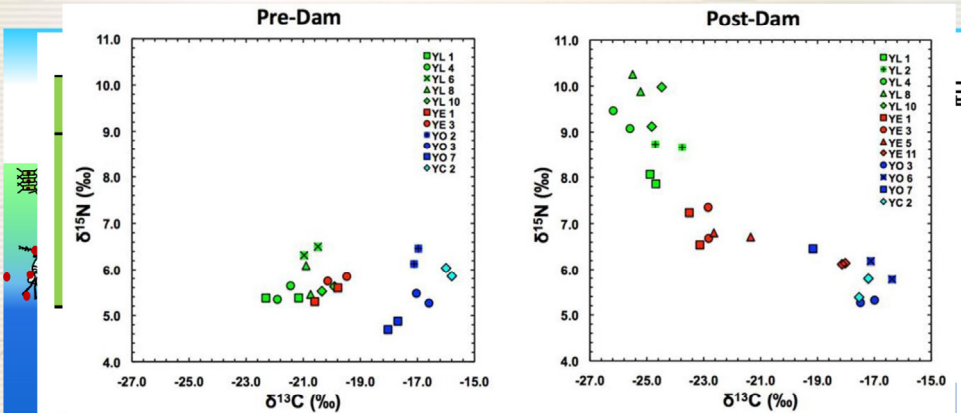
NH_4^+, Fe^{2+}, Mn^{2+}, CH_4 재산화로 인한 빈산소층 형성 가속화



27

2.1.5. 연구 결과

하구둑 건설 전 → 부유사 농도 감소 → 소광계수 감소 → 플랑크톤 개체수 증가



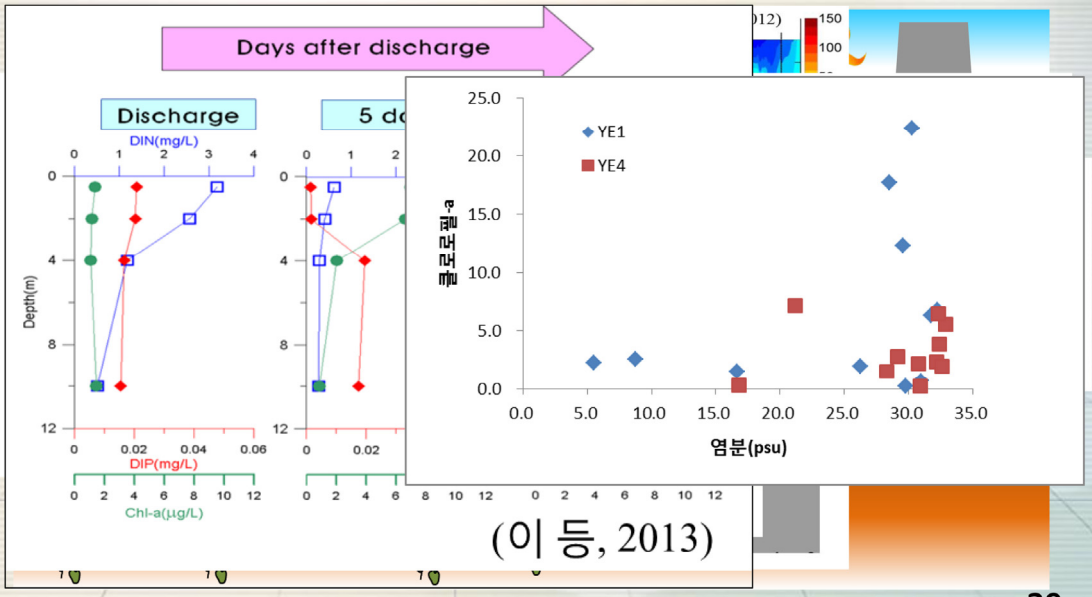
- Pre-Dam Samples → Marine Signal
  Tidal exchange far inland
- Post-Dam Samples →Terrestrial Above Dam
  Inner Estuary Mixed
- Construction of Dam Significantly Changed the Distribution of OM Sources

(Josh et, 2013)

28

2.1.5. 연구 결과

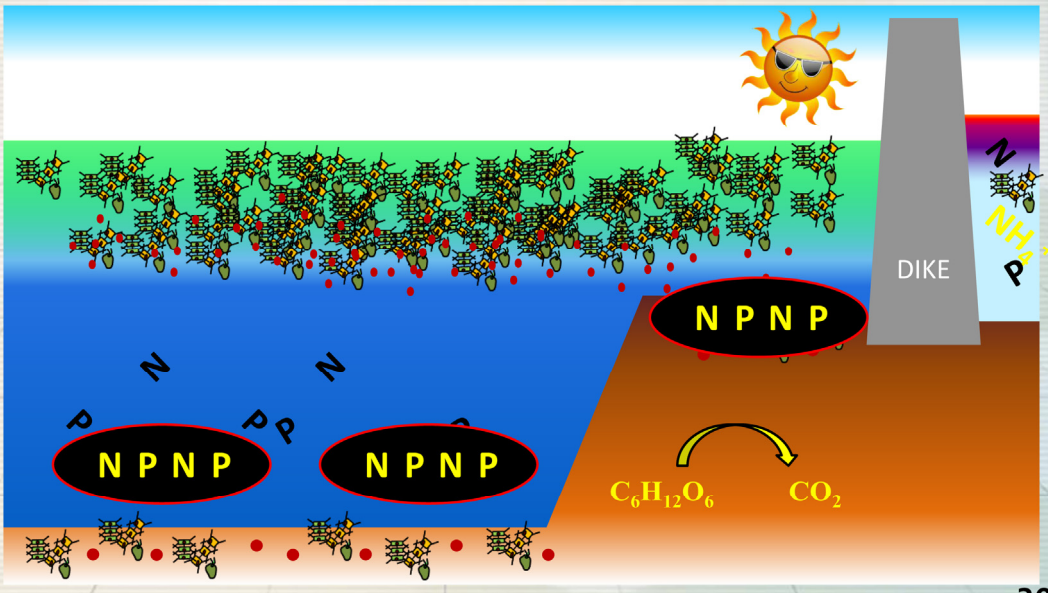
방류 종료 → 다층흐름구조 발생 → N, P, 암모니아 흡수 → 식물플랑크톤 대증식



29

2.1.5. 연구 결과 (Case 1)

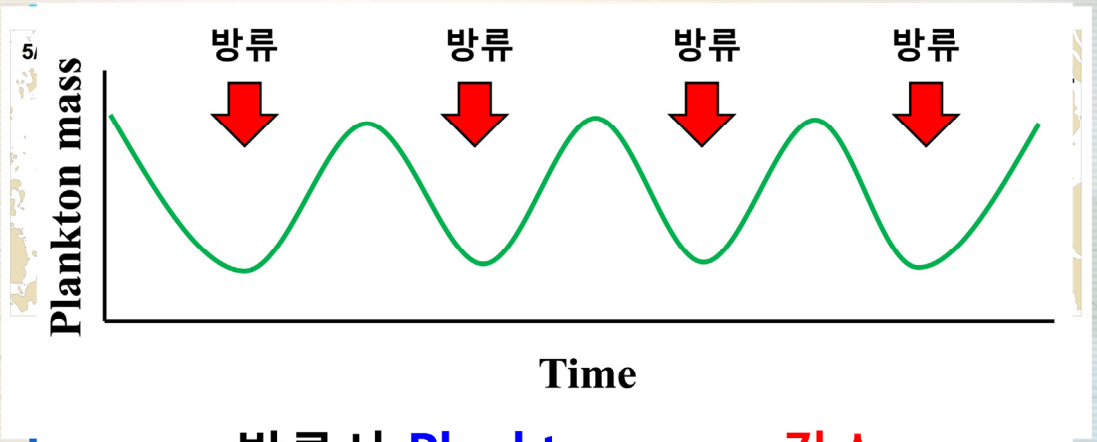
유기물 퇴적 → 유기물 분해 → N, P, 용출



30

2.1.5. 연구 결과 (Case 2)

유기물 퇴적 → 하구둑 방류 → flushing



방류시 Plankton mass 감소

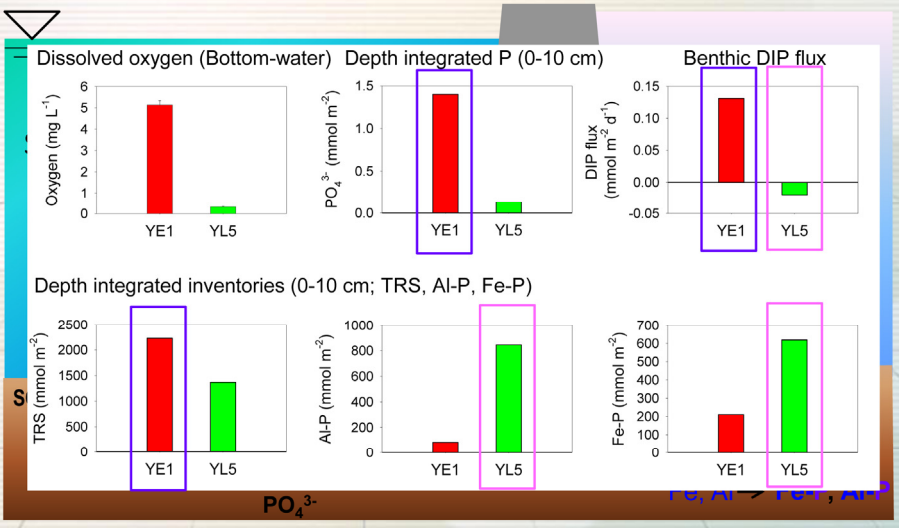
→ 하구생태계 취약성

영산강 하구역의 경우 Case 2 에 해당됨

31

2.1.5. 연구 결과 (인의 용출과 유입)

하구역	황화수소 생성	황화수소와 금속결합	인의 해리 및 용출
하구호	황화수소 생성제한적	Metal-S 생성 제한적 (인과 금속결합)	인의 용출이 제한

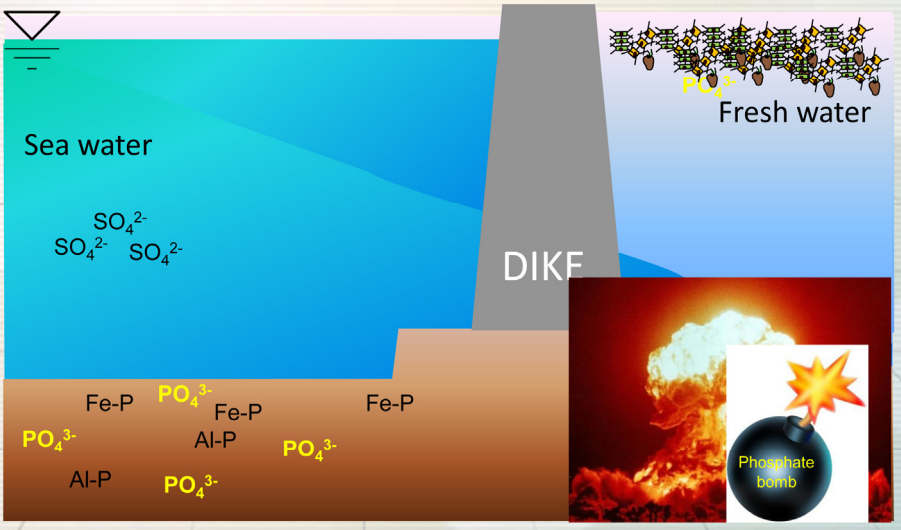


32

2.1.5. 연구 결과 (하구둑 개방 → 인의 증가요인)

하구역 : 인의용출 → 하구호 : 인의유입 → 하구둑 개방

황산염 공급 → 황화수소와 금속결합 → 인산염 폭발적 증가 (육상유입 P 조절 중요)



33

2.1.6. 연구 결과 요약

하구둑 건설 영향

- ✓ 영산강 하구역은 부영양화 프로세스와 2차적 영향이 호 내-외측에서 상이함
- ✓ 부영양화 발생 주요 인자
  하구호 내측 : 유속감소 / 하구역 : 저탁도로 인한 유광층 증가

빈산소층 발달 및 소멸 기작

- ✓ 내측의 경우 부영양화로 인한 2차적 영향은 빈산소 수괴의 형성으로 나타남
- ✓ 수온성층과 수심증가로 인한 무광층 확대가 빈산소 수괴 형성의 핵심 인자

방류에 따른 물리/퇴적 환경 변화 및 생태계 변동 특성

- ✓ 방류나 조석으로 인한 수괴 교란이 부영양화의 2차 효과를 조절하는 핵심 인자

영양염 순환 기작

- ✓ 하구호에서는 퇴적물로 유입, 하구역에서는 용출
- ✓ P는 육상유입과 퇴적물 내 금속-황-인 상호작용의 결과
- ✓ N은 육상유입에 따른 퇴적물로의 유입결과

34

2.2. 주요 연구 결과
- 수치모델링 -

2.2.1. 연구 목표

하구 **환경변화 적기 대처**를 위한 과학적 모델 확보

해양환경 변화 양상 **예측**을 위한 수치모델 시스템 구축

모델 통합 (유역 + 하천 + 하구, 유동 + 퇴적 + 수질)

통합모델시스템 구축 및 운영

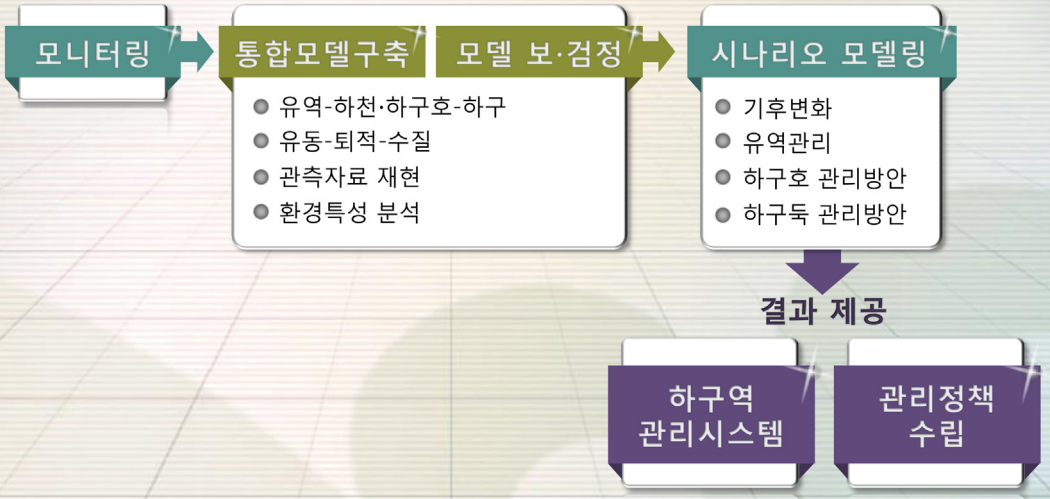
효과적인 **하구역 정책 수립**을 위한 **정보 제공**

하구역 관리시스템에 모델링 결과 제공

36

2.2.2. 연구 내용

모델링 연구 흐름도



37

2.2.2. 연구 내용

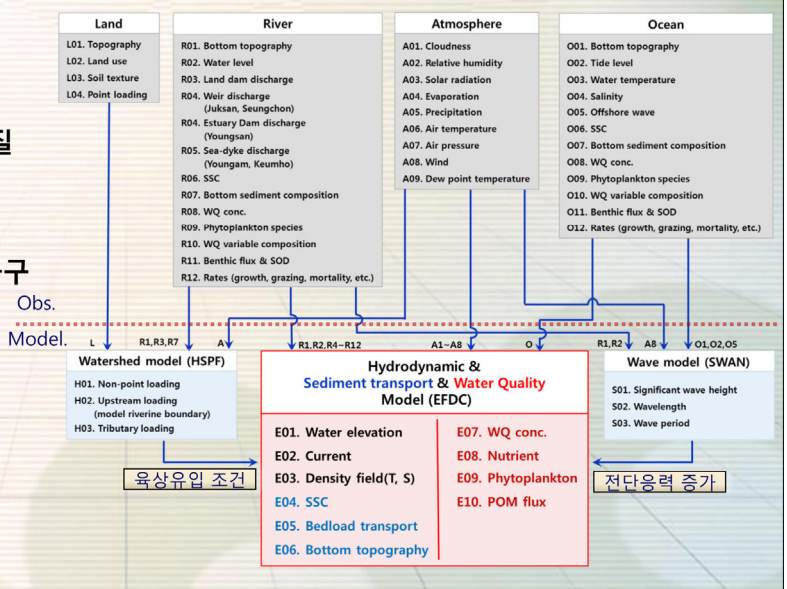
모델 연계

기능적 연계

: 유동 + 퇴적(파랑) + 수질

공간적 연계

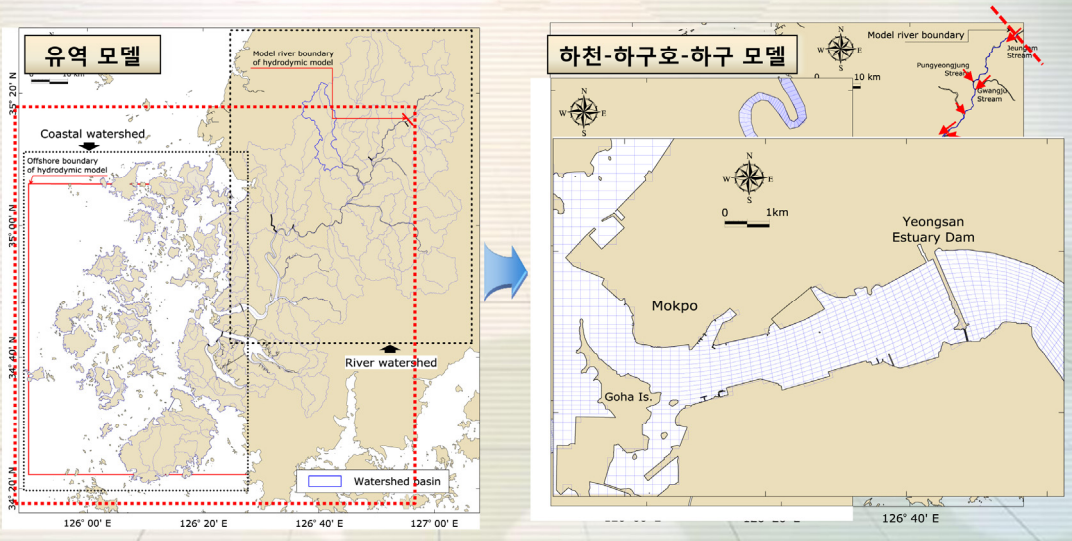
: 유역 + 하천·하구호 + 하구



38

2.2.2. 연구 내용

모의 영역 - 하천-하구호-하구모델 통합 및 유역과 연계



39

2.2.3. 연구 결과 - 유역모델링

유역모델 구축

사용모델 : HSPF

입력자료

공간자료 :

DEM, 토지이용도, 토성, 유역도, 하천도, 기상 및 수위/수질 관측소 위치도 등

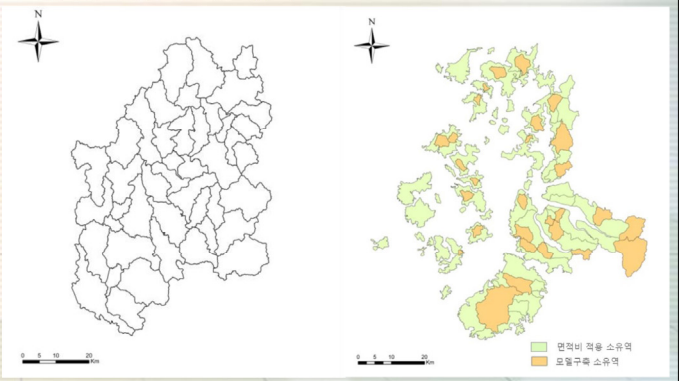
시계열 자료 :

기상, 유량, 수질, 댐 방류량, 점오염원 배출 부하량 등

보·검정

유량, 퇴적물 및 수질 보·검정

<영산강과 연안유역 소유역도>

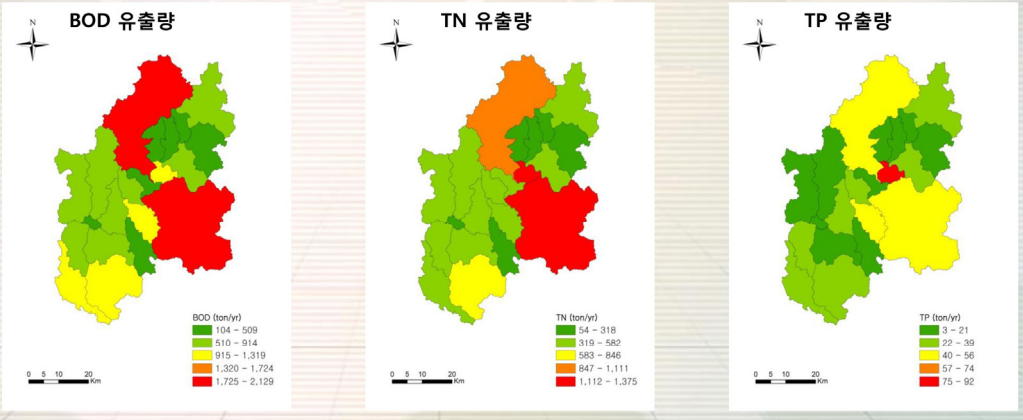


영산강유역: 45개 소유역
연안유역: 96개 소유역 (29개 모델구축, 67개 면적비 적용)

박민혜, 조홍래, 구본경, "개념적 유역모형을 이용한 영산강 하구해역의 육상기인 오염부하 유입량 평가", 2012년 추계 해양학회.
박민혜, 조홍래, 구본경, "기후변화에 따른 영산강 유역의 오염부하 유출량 변화 분석", 2013년 추계 해양학회.

40

2.2.3. 연구 결과 - 유역모델링



- 황용강 유역 : BOD 부하량 최다
- 광주 및 화순 유역 : TN, TP 부하량 최다

박민혜, 조홍래, 구본경, "개념적 유역모델을 이용한 영산강 유역 오염부하 유출량의 시공간적 분포평가", 한국물환경학회지
박민혜, 조홍래, 정의상, 구본경, "개념적 유역모형을 이용한 영산강 하구지역의 비점오염부하 평가", 2011년 추계 해양학회

41

2.2.4. 연구 결과 - 유동모델링

유동모델 구축

사용모델 : EFDC (유동, 퇴적, 수질모델링)

입력자료

수심, 외해 조석, 기상, 육상유입 유량, 바람

모델 기능 개선

가동보 및 하구둑 갑문 고려 (수체간 동적연결)

방류시 운동량 부여 기능

모델 구성

격자 크기 20~400m, 격자수 27,773개, 수직 11층

모델 보·검정

하구 조위·조류 · 수온 · 염분, 하천-하구호 수위, 유속, 수온 보·검정

42

2.2.4. 연구 결과 - 유동모델링

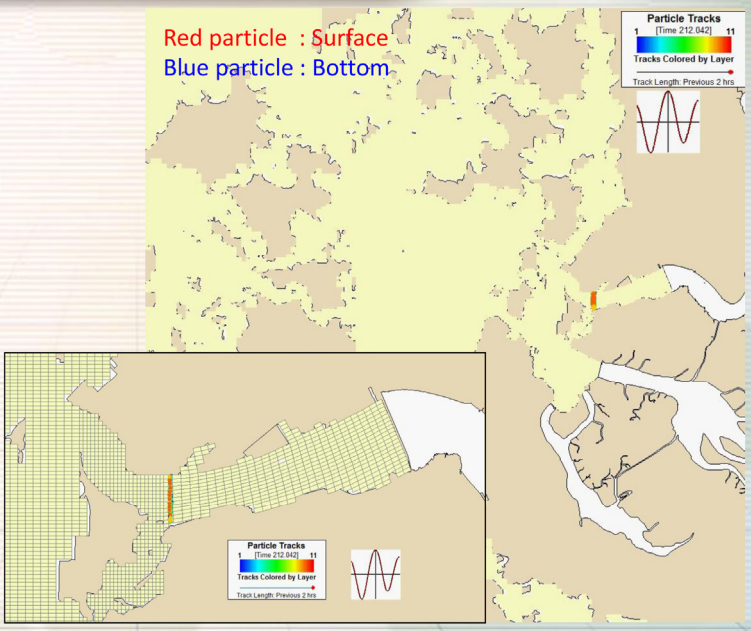
3차원 순환특성 재현

2층 순환구조 재현

방류시 표층은 급격히 배제

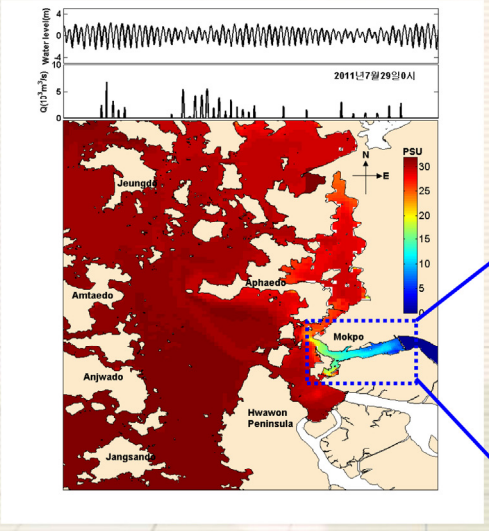
저층은 약 10일 동안
내측으로 이동

하구 물질순환 및
저층 저산소 형성에 영향



Cho, C.W., Woo, S.B., Song, Y.S., Kim, T.I., Choi, H.S., and Han, J.S., "Modeling of hypoxia formation in Yeongsan River Estuary, Korea (Using 3-D Model)", 2012 Ocean Science Meeting.
조창우, 송용식, 김태인, 우승범, "3차원 수치모델의 입자추적 기법을 이용한 영산강 하구의 저층수 거동 특성 연구" 2011년 추계 한국해양학회.
Cho, C.W., Song, Y.S., Kim, C.K., Kim, T.I., Han, J.S., and Woo, S.B, "A Modeling Study on Hypoxia Formation in the Bottom Water of Youngsan River Estuary, Korea", JOURNAL OF COASTAL RESEARCH

2.2.4. 연구 결과 - 유동모델링



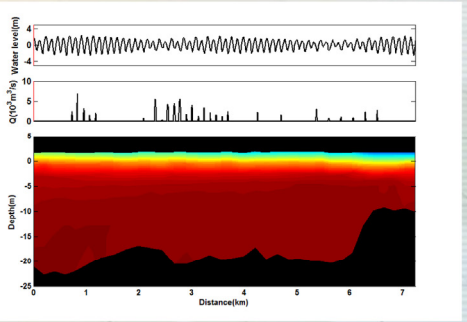
홍수기 염분분포

홍수기 방류에 의하여 두께 약 10m의 강한 성층형성

목포 내만 염분특성

표층에서 20psu 이하의 저염 유지

해면하 10m 이하에서는 30psu 이상의 고염수 분포



김종욱, 윤병일, 송진일, 임채욱, 우승범, 김종욱, "방류 유무에 따른 영산강 하구역의 시공간적 잔차류 및 염분 변화", 한국해안·해양공학회, 25(2)
Kim, J. W., Woo, S.B., Yoon, B.I., Lee, D.W., "Spatial and temporal variation of river flow and vertical stratification due to sea gate operation in the Yeongsan River, South Korea" 2012 Ocean Science Meeting.

44

2.2.5. 연구 결과 - 퇴적모델링

퇴적모델 구축

사용모델 : EFDC

외력조건 : 실시간 유량, 조석·조류, 파랑 등

모의입경 : 모래, 실트, 점토

입력자료

외해 부유퇴적물 조건 : KOEM, NIER

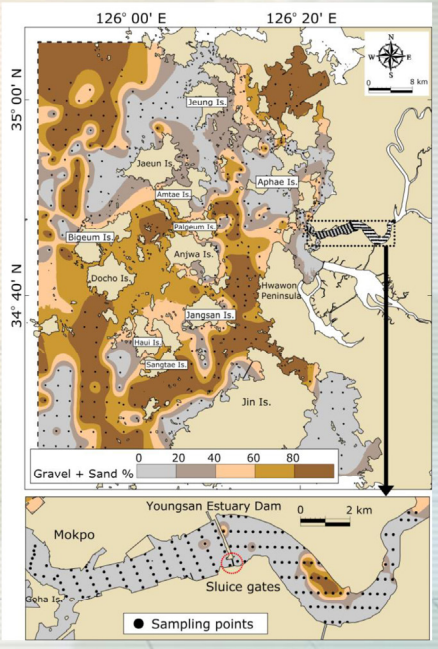
유역 부유퇴적물 조건 : 본 연구 유역모델 결과

저면퇴적물 조건 : 기존 및 본 연구 관측

모델 보·검정

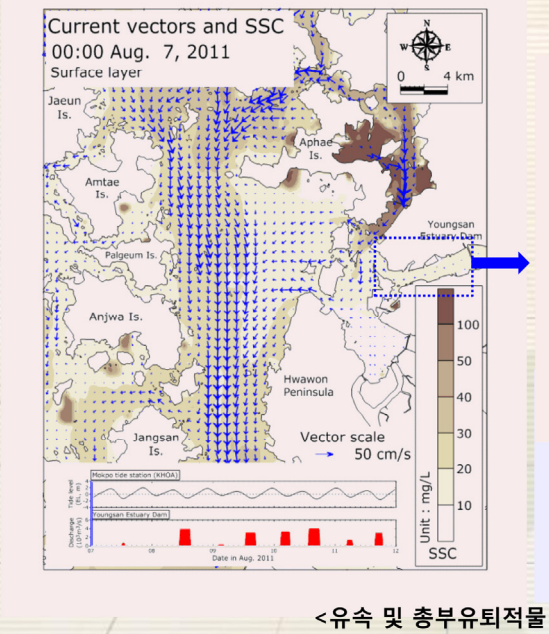
부유사농도 시계열, 퇴적율

박수경, 서동일, "EFDC를 이용한 영산강 부유물질 이동 모델링", 2012 한국수자원학회.

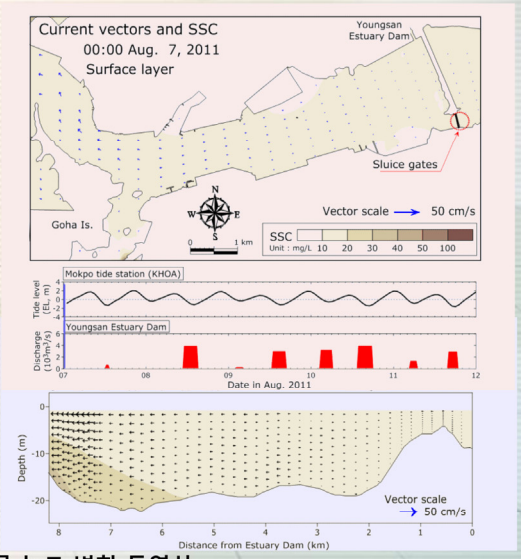


<하구 및 하구호의 자갈+모래 함량 분포>

2.2.5. 연구 결과 - 퇴적모델링



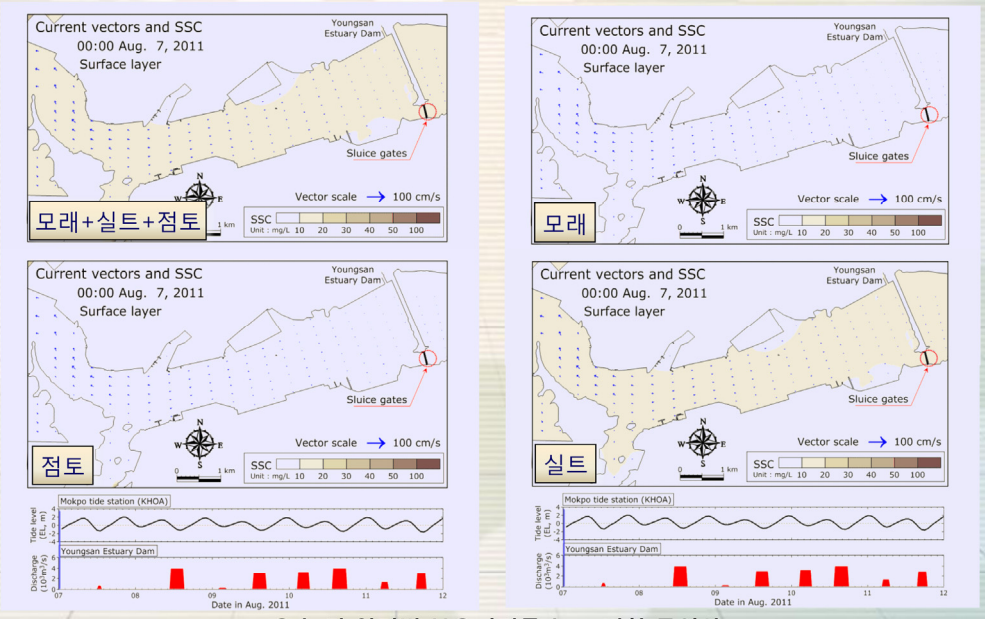
방류시 하구둑 전면 부유사농도 증가,
방류영향 지속시간은 짧음



<유속 및 총부유퇴적물 농도 변화 동영상>

2.2.5. 연구 결과 - 퇴적모델링

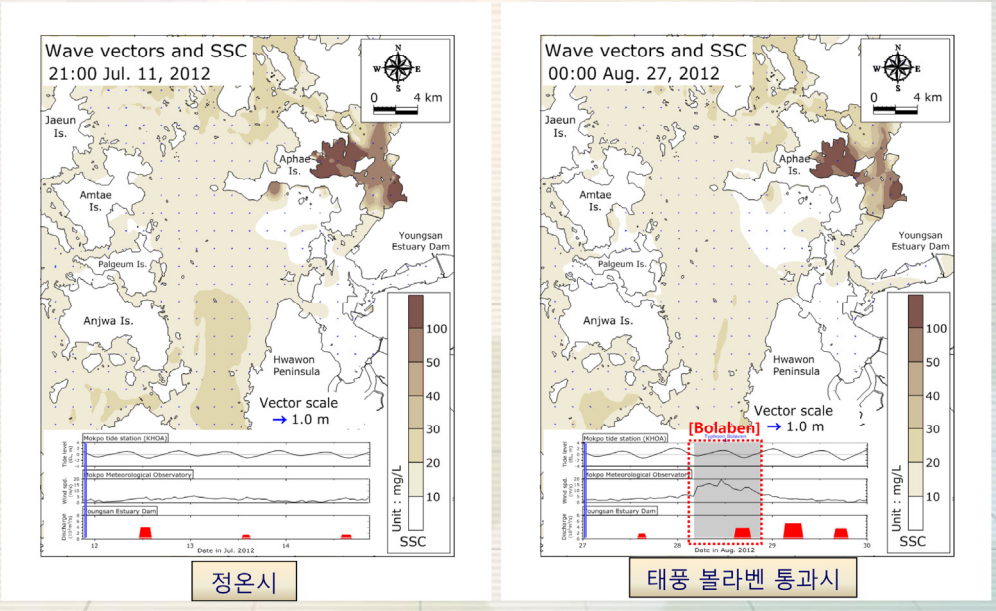
하구둑 전면은 대부분 실트에 의한 퇴적물 이동



<유속 및 입경별 부유퇴적물 농도 변화 동영상>

2.2.5. 연구 결과 - 퇴적모델링

파랑모델과의 연계 → 고파랑 내습시 부유사 재부유 효과 재현



<부유사농도 변화 동영상>

2.2.6. 연구 결과 - 수질모델링

수질모델 구축

사용모델 : EFDC

수질변수 : 23개 수질 항목

입력자료

초기조건 : 본연구 관측, KOEM, NIER

개방경계조건 : 본연구 관측, KOEM

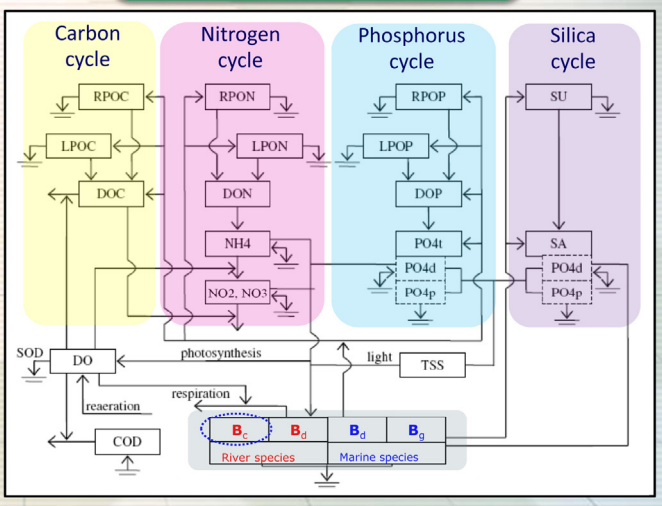
Benthic flux : 본연구 관측

유역 및 지천 : 본연구 유역모델 결과

모델 보·검정

하천-하구호-하구 보·검정 (33정점)

수질상태변수 구성 및 변수간 관계



Seo, D.I., Song, Y.S., Bae, S.Y., "Application of 3-D hydrodynamics and Water Quality Model of Youngsan River, Korea", IWA

2.2.6. 연구 결과 - 수질모델링

방류에 의한 chl-a 변동

부유사, 영양염 및 chl-a의 관계 및 단주기 변동 재현

수직 혼합, 외해 배제

방류

↓

Flushing, 혼합

↓

영양염 및 부유사농도 증가

↓

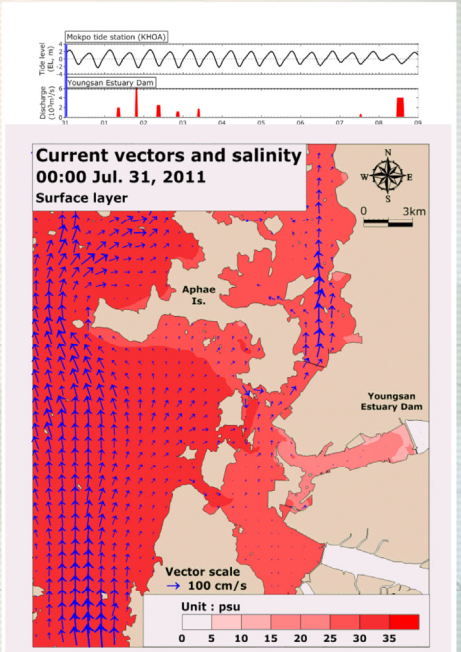
약 1일후 부유사농도 감소

↓

chl-a 증가

↓

영양염 감소



송용식, 서동일, 한종수, 이정현, 방기영, 조창우, 배순임, 김태인, 우승범, 박민혜, "3차원 수치모델을 활용한 2011년 영산강-영산호-영산강하구의 수질재현", 2013년 추계 한국해양학회.

2.2.6. 연구 결과 - 수질모델링

방류에 의한 chl-a 변동

외해 배제, 광제한 증가 → 식물플랑크톤 증식 억제

방류

↓

Flushing, 혼합

↓

영양염 및 부유사농도 증가

↓

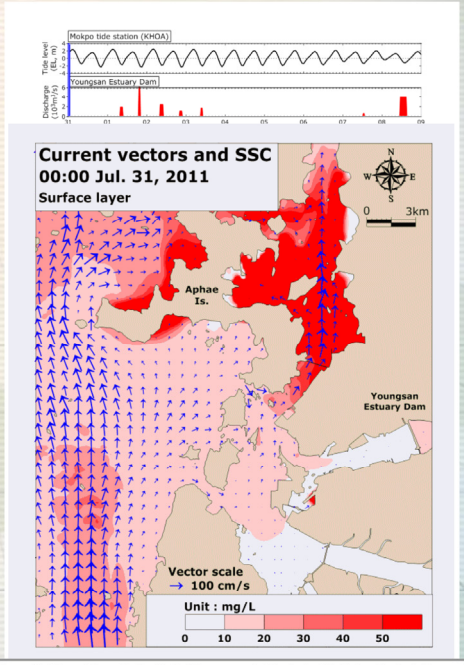
약 1일후 부유사농도 감소

↓

chl-a 증가

↓

영양염 감소



송용식, 서동일, 한종수, 이정현, 방기영, 조창우, 배순임, 김태인, 우승범, 박민혜, "3차원 수치모델을 활용한 2011년 영산강-영산호-영산강하구의 수질재현", 2013년 추계 한국해양학회.

2.2.6. 연구 결과 - 수질모델링

방류에 의한 chl-a 변동

식물플랑크톤 증가

방류

↓

Flushing, 혼합

↓

영양염 및 부유사농도 증가

↓

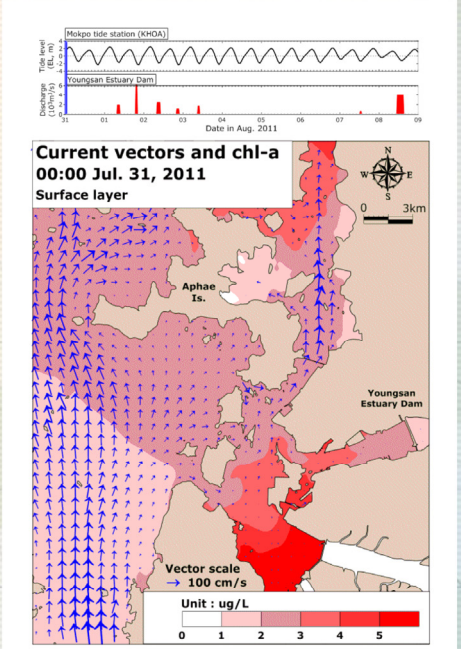
약 1일후 부유사농도 감소

↓

chl-a 증가

↓

영양염 감소



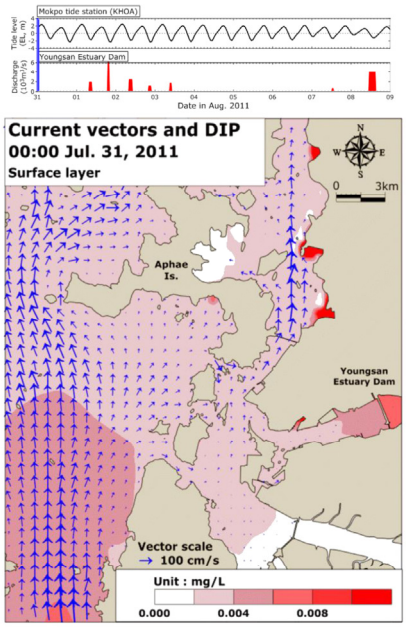
송용식, 서동일, 한종수, 이정현, 방기영, 조창우, 배순임, 김태인, 우승범, 박민혜, "3차원 수치모델을 활용한 2011년 영산강-영산호-영산강하구의 수질재현", 2013년 추계 한국해양학회.

2.2.6. 연구 결과 - 수질모델링

방류에 의한 chl-a 변동

플랑크톤 증가로 인한 영양염 감소

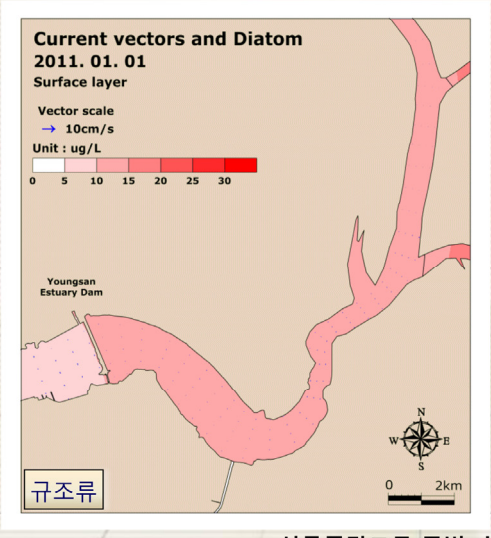
방류
↓
Flushing, 혼합
↓
영양염 및 부유사농도 증가
↓
약 1일후 부유사농도 감소
↓
chl-a 증가
↓
영양염 감소

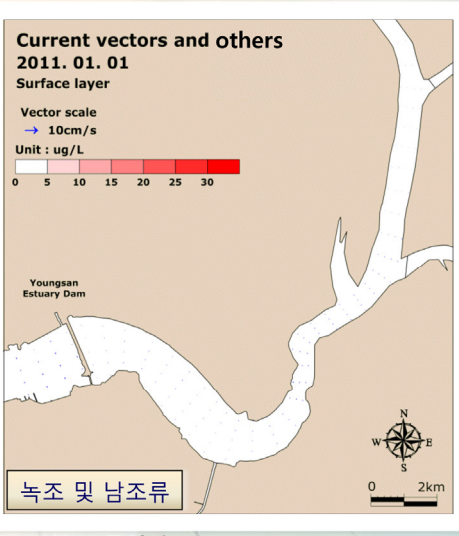


송용식, 서동일, 한종수, 이정현, 방기영, 조창우, 배순임, 김태인, 우승범, 박민혜, "3차원 수치모델을 활용한 2011년 영산강-영산호-영산강하구의 수질재현", 2013년 추계 한국해양학회.

2.2.6. 연구 결과 - 수질모델링

하구호에서 동계 규조류, 하계 녹조류 우점 재현



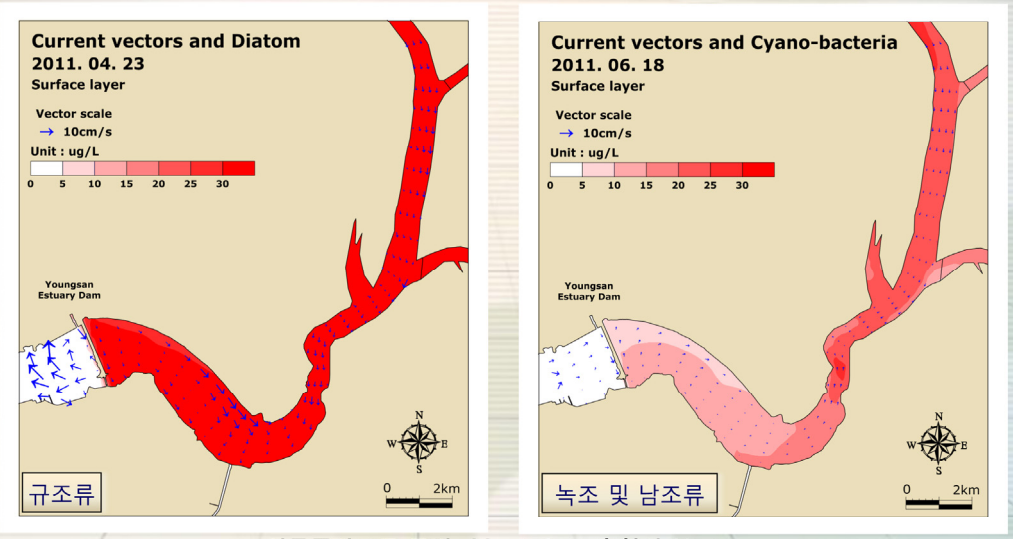


<식물플랑크톤 종별 chl-a 농도 분포 동영상>

Seo, D.I. and Kim, M.A., 2011, "Application of EFDC and WASP7 in series for Water Quality Modeling of the Yongdam Dam, Korea", JOURNAL OF KOREA WATER RECOURCES ASSOCIATION, 44(6), 439-448.

2.2.6. 연구 결과 - 수질모델링

하구호에서 동계 규조류, 하계 녹조류 우점 재현



<식물플랑크톤 종별 chl-a 고농도 출현시 분포>

Seo, D.I. and Kim, M.A., 2011, "Application of EFDC and WASP7 in series for Water Quality Modeling of the Yongdam Dam, Korea", JOURNAL OF KOREA WATER RECOURCES ASSOCIATION, 44(6), 439-448.

2.2.7. 연구 결과 - 시나리오모델링

시나리오 구성

목적 : 하구호와 하구의 관리방안 수립 및 환경 변화시 수환경 변화 예측

방법 : 기본 시나리오 구성 → 개선효과가 있는 시나리오를 조합하여 복합시나리오 구성

갑문운영 및 연안유역 부하량조절에 따른 수질개선효과 추가 검토

기본 시나리오	복합 시나리오	갑문운영 시나리오	추가 시나리오
• 유역 유출특성 변화 • 퇴적물 관리 • 저층수 배제 • 해수유통 • 방류특성 변화	• 담수호 유지안 • 기수호 1안 (유역관리 + 해수유통) • 기수호 2안 (유역관리 + 준설 + 해수유통)	• 하계 사전 방류 • 녹수발생시 분산방류 • 방류 시기 조정	• 연안유역 부하량 변화
(15개)	(11개)	(11개)	(3개)

56

2.2.7. 연구 결과 - 시나리오모델링

시나리오 모델링 결과 요약 (기본 시나리오)

유역관리
- 영양염 농도 감소

하구호 준설
- 체류시간이 긴 동계, 춘계, 추계에 수질개선 효과가 큼
- 춘계 하구와 하구호에서 DIN 평균농도가 약 20% 감소

해수유통 – 상시개방
- 하구호 chl-a 평균농도 40~70% 감소 (영양염은 40% 이상 감소)
- 배수갑문 인근에서 침식발생. 하구호와 하구의 평균퇴적율은 증가
- 하구호 대부분의 수역에 염분 침투

해수유통 – 부분유통
- DIP 평균농도 20% 이상 감소. DIN은 춘계와 하계에 감소
- 하계 하구호 Chl-a 평균 농도 50%이상 감소, 타계절은 유사하거나 증가
- 하구둑 전면 침식. 하구의 평균퇴적율 감소 (하구호는 현상태와 유사)

57

2.2.7. 연구 결과 - 시나리오모델링

시나리오 모델링 결과 요약 (복합 시나리오)

담수호유지안
하구에서 chl-a 의 변화가 작으며, 하구호는 비슷하거나 다소 낮음

기수호1~2안
기본시나리오 부분 해수유통안의 결과와 유사 (영양염 감소, 하계 chl-a 감소)

시나리오 모델링 결과 요약 (갑문운영 및 육상부하 조절)

하계 사전방류
하계 풍수기에 수질 일시 개선. 사전 방류량이 증가할수록 효과 큼

녹조 분산방류
방류 횟수에 따라 하구 chl-a 농도 변화 (회수증가시 평균농도 증가, 최고농도 감소)

방류시기 조정
안별 차이 적음

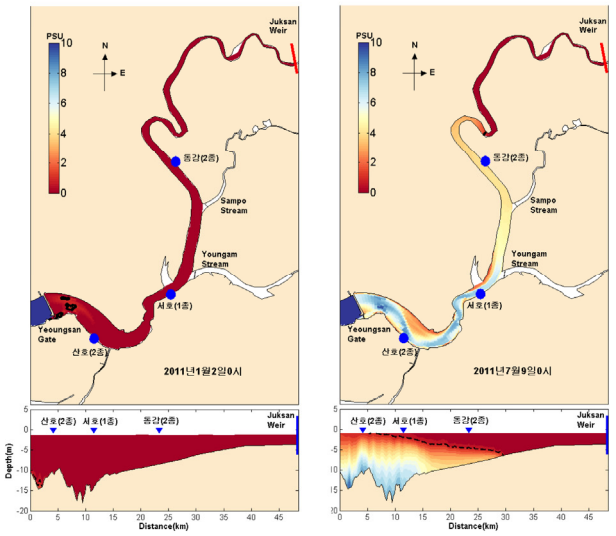
육상부하 감소
유역 부하량 증가시 광제한 영향으로 chl-a 농도 다소 감소

58

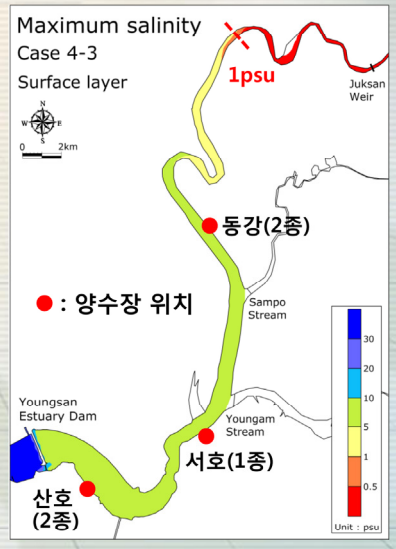
2.2.7. 연구 결과 - 시나리오모델링

하구호 대부분 수역에 염분 침투
주요 양수장에 모두 영향을 줌

<갈수기> <홍수기>



<하구둑 개방시 하구호 염분변화 동영상>

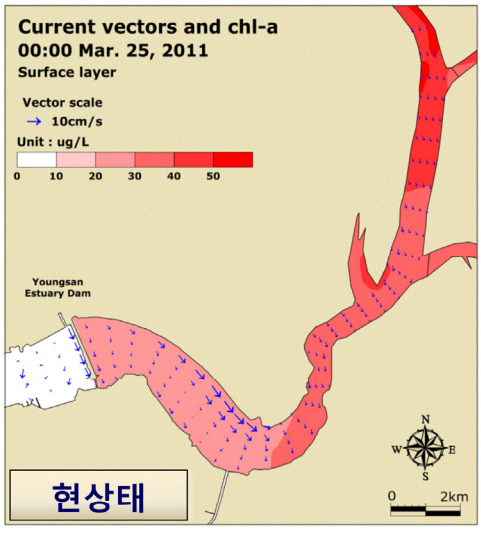


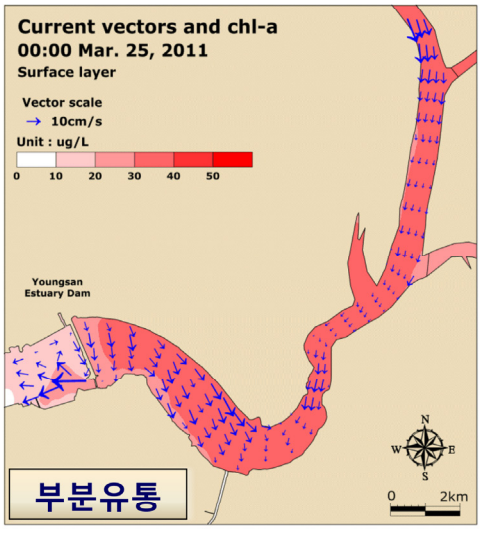
<하구둑 개방시 하구호 염분침투 범위>

Kim, J.W., Yoon, B.I., Song J.I., Woo S.b., "A numerical study of relationships between freshwater discharge and horizontal isohaline in Yeoungsan River Estuary, South Korea" 2013 21st Biennial Conference of the Coastal and Estuarine Research Federation.

2.2.7. 연구 결과 - 시나리오모델링

일부 계절에 하구호 하류에서 chl-a 농도 증가 ∵ 해수 식물플랑크톤의 호내 유입시 증식 호조건 형성
→ 영양염 풍부, 외해혼합 제한 및 체류시간 증가



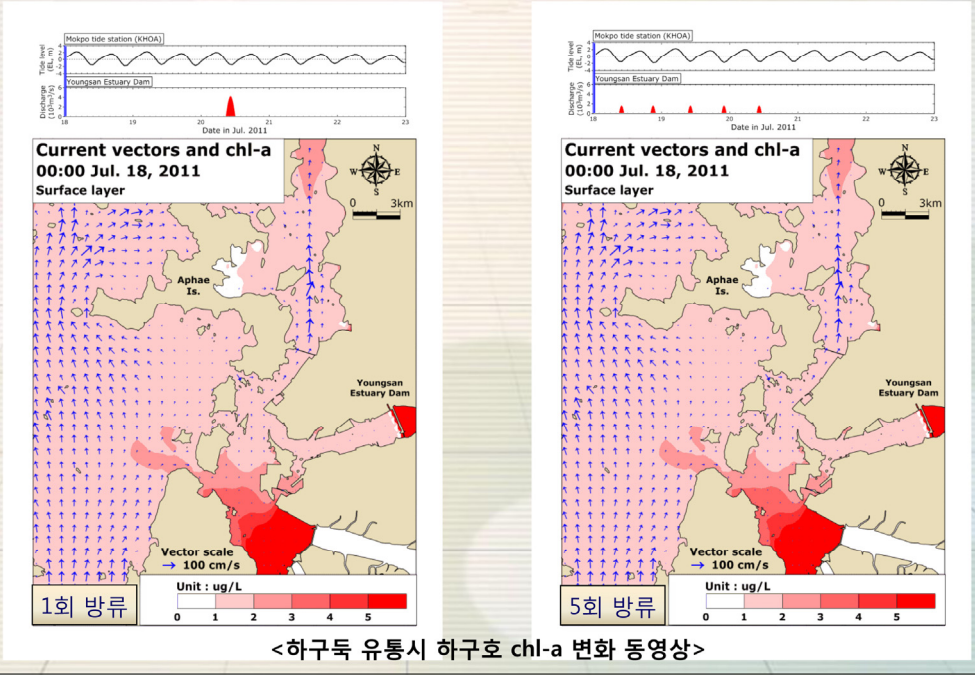


<하구둑 유통시 하구호 chl-a 변화 동영상>

60

2.2.7. 연구 결과 - 시나리오모델링

하구호 녹수발생시 하구둑 방류 횟수가 증가할수록 → 최고농도 하강, 평균농도 상승



<하구둑 유통시 하구호 chl-a 변화 동영상>

61

2.2.8. 연구 결과 요약

유역-하천·하구호-하구 통합모델 구축

관측자료 재현을 통한 모델 보정 및 검정 수행

40개의 시나리오 수립 및 모델링 수행

- 유역관리시 영양염 농도 감소. 준설시 하구호에서 질소 농도 감소
- 해수유통시 수질개선 효과가 있으나 염분침투, 일부 안에서 chl-a 농도 증가
- 해수유통을 통한 하구호 환경개선을 위해서는 보다 면밀한 사전조사와 분석 필요

향후 보다 정도 높은 모델링을 위해서 성층재현 성능개선, 퇴적물내 속성작용 모의, 적조 원인생물 재현성능 고도화 등의 연구가 필요함

62

3. 연구 성과 요약

3. 연구개발 성과의 우수성

연구기간 별로 예산의 배분 및 집행

- 전반기 : 지식기반 확충에 초점을 두고 관측분야 예산 중점
- 후반기 : 시스템 구축 및 통합에 초점을 두고 예산 배분 및 집행

정책 및 과학기술 분야의 협업을 통한 시스템의 구축

- 정책 분야가 제시한 현안을 기반으로 연구방향을 정립
- 유동, 퇴적, 수질, 생태 등 하구 프로세스의 통합적 규명

하구호-하구를 포괄한 관측조사 및 모델 구축

- 하구호-하구 연계를 고려한 연구 추진방향을 고수/관철

이해당사자간 대화를 지원하는 영산강 하구역 종합관리 시스템 구현

- 모델-정보 연계시스템을 통해 신규 시나리오 모의 가능 (특허 등록)
- 모델결과를 Web GIS 상에서 시각화
- 의사결정지원시스템을 활용하여 시나리오 대안별 비교 및 고려 우선순위 도출

64

3. 연구개발 성과의 우수성

모니터링

- 하구둑 방류에 영향을 받는 순환특성 및 생지화학적 프로세스 이해
- '닫힌하구'의 관리에 특화된 모니터링 방안 제시

모델링

- 유역-하구호-하구의 동적 연계를 고려한 공간적 통합 구현
  - → 죽산보, 하구둑 갑문 운영을 고려한 연계 구현
- 물리유동(파랑, 조석, 방류), 퇴적, 수질, 생태 등의 기능적 통합을 구현

모델-정보 연계 및 시각화 시스템 구축

- Web Portal 을 통해 모델 결과를 동적으로 시각화 하는 시스템을 구현
- 시나리오 모의 결과를 계절 혹은 구역 단위로 비교할 수 있는 시스템 구현

65

3. 연구결과 기대효과 및 활용성

'닫힌하구' 관리에 활용 가능한 하구관리 시스템 구축, 노하우 축적 및 특허 등록

- 하구관리 정보시스템 구축으로 특허 출원 1건, 등록 1건 달성

하구복원 등 잠재적 수요에 대응할 수 있는 역량 구축

- 하구복원에 대한 사회적 관심사 증대, 부처간 벽 허물기에 대한 중앙정부의 강조 등을 고려할 때 통합적 하구관리에 대한 정부차원의 수요가 증가할 것으로 보임

지역 이해당사자 협의체와 시스템 시범운영 시도

- 현행법제 하에서 시스템 운영 주관조직을 위한 예산 및 인원 확보는 쉽지 않음
- R&D 예산(2단계 사업) 일부를 시스템 시범 운영에 투입하는 것을 고려할 필요 있음
- 이때 지역 이해당사자 협의체 이니셔티브 부여 중요: i.e. 연구진 일부로 참여

66

3. 연구결과 기대효과 및 활용성

시범하구(영산강)에 대한 시민사회의 인식을 제고 할 수 있는 통로 확보

- Web Portal을 통해 연구조사 및 시나리오 모의 결과를 일반인에게도 일부 공개
- 하구에 대한 시민사회의 관심을 제고할 수 있는 계기가 될 수 있음

최종성과물이 DB 형태로 Web Server에 탑재되어 정보 검색/조회/공유가 용의

- Server 운영만 보장된다면 기본적인 정보 검색/조회/공유는 가능
- R&D 형태로라도 유지보수 예산이 확보되면 시범운영도 가능

67

영산강 하구역 종합관리 시스템 개발사례