EAS CONGRESS 2018
THE EAST ASIAN SEAS CONGRESS

Nov. 28, 2018
Iloilo, Philippines

Session 5.3: A Critical Review of 25 Years of Land Reclamation in East Asia

Forty years long changes in coastal land use and ecosystem services in the Yellow Sea

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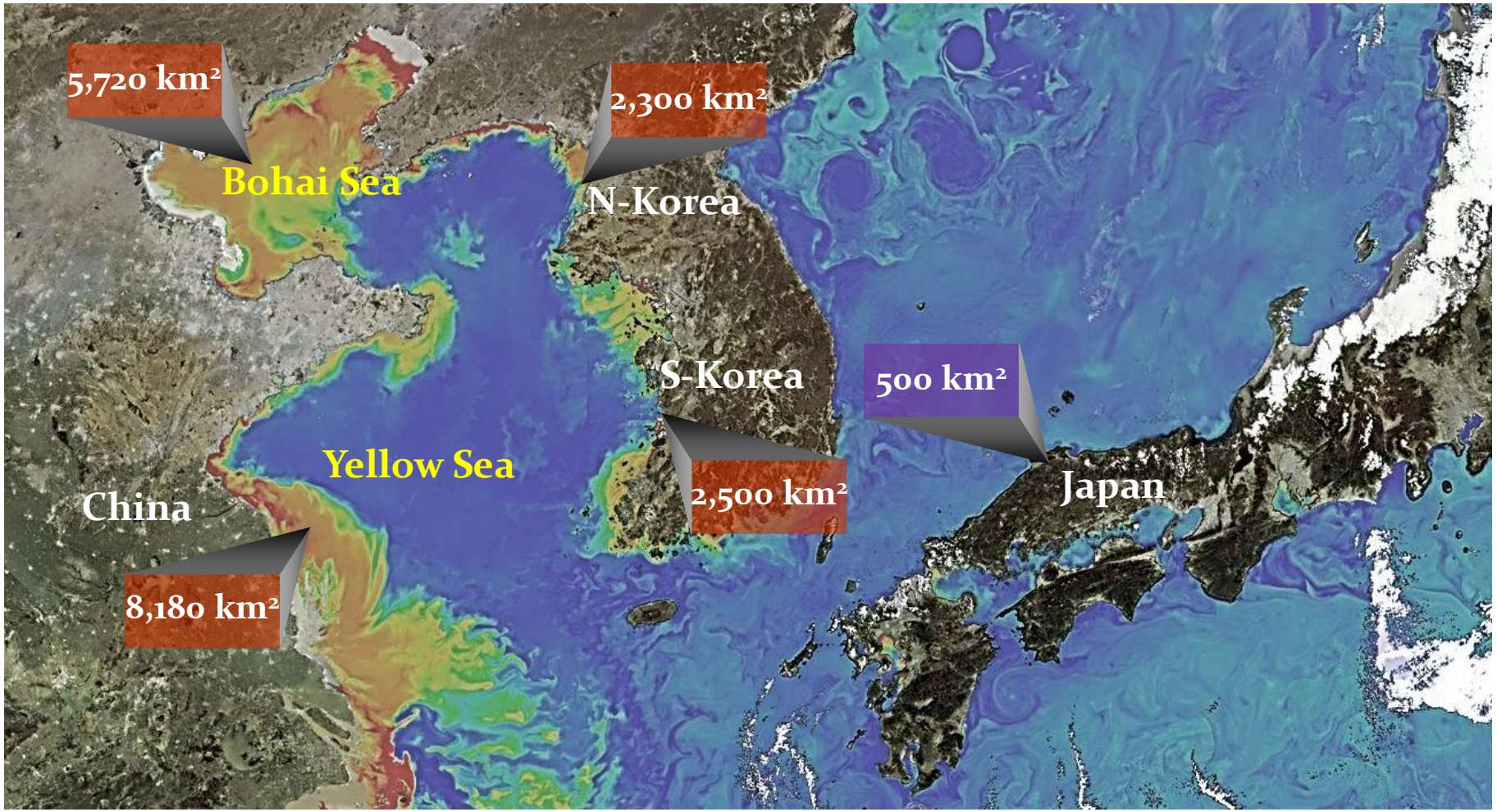
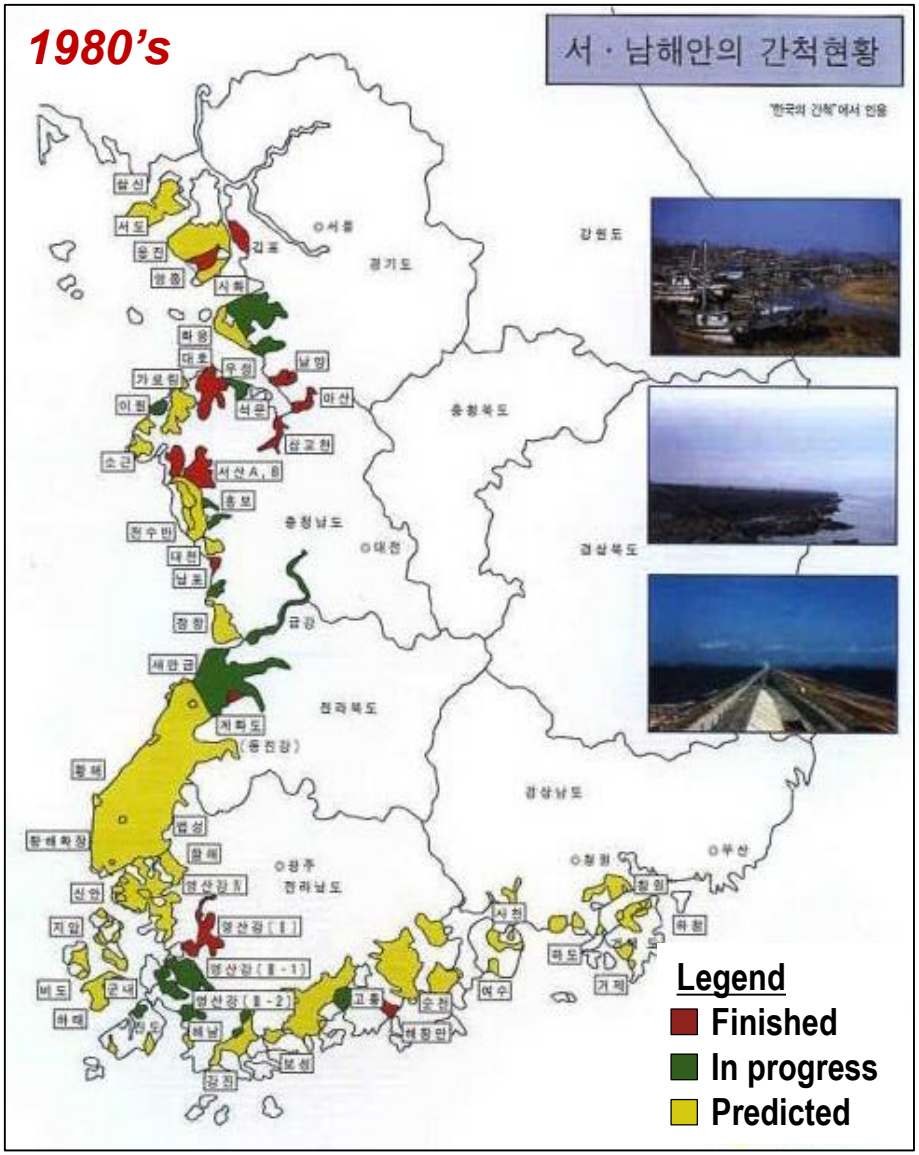
1. Introduction: Tidal flats in Yellow Sea

Total area of Tidal Flats in the East Asia: ~19,000 km²
(*cf.* Wadden Sea: ~4,700 km² or Australian Mangroves: ~11,500 km²)



1. Introduction: History of reclamation



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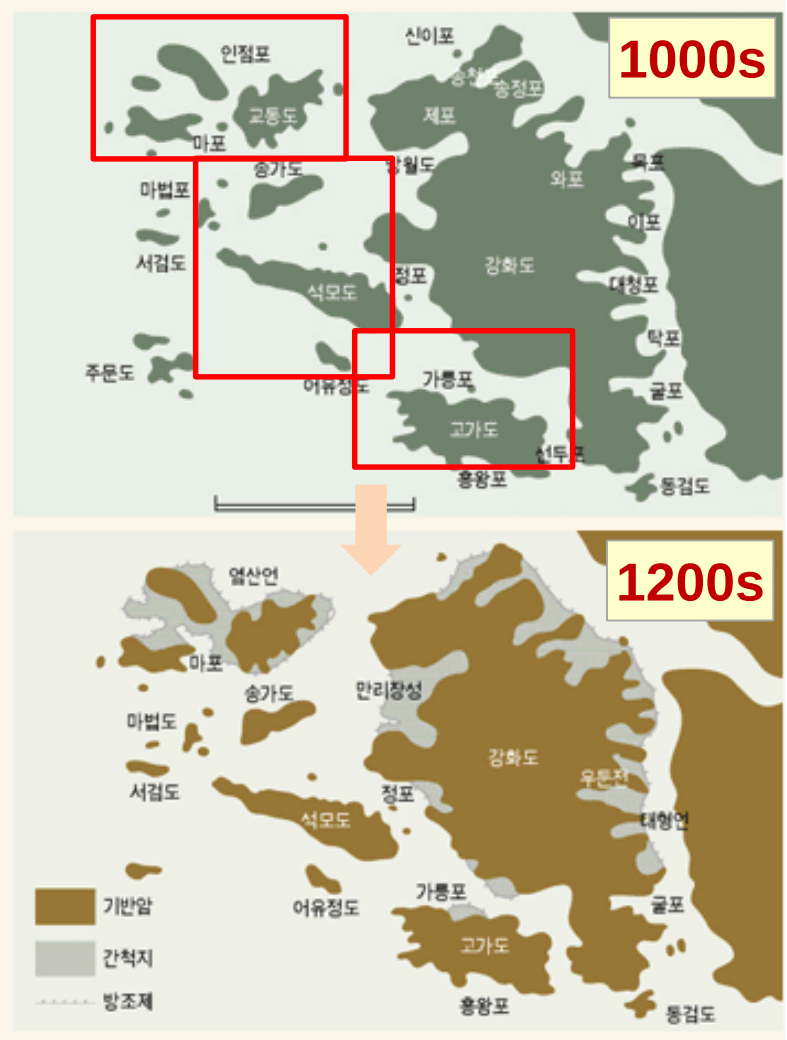


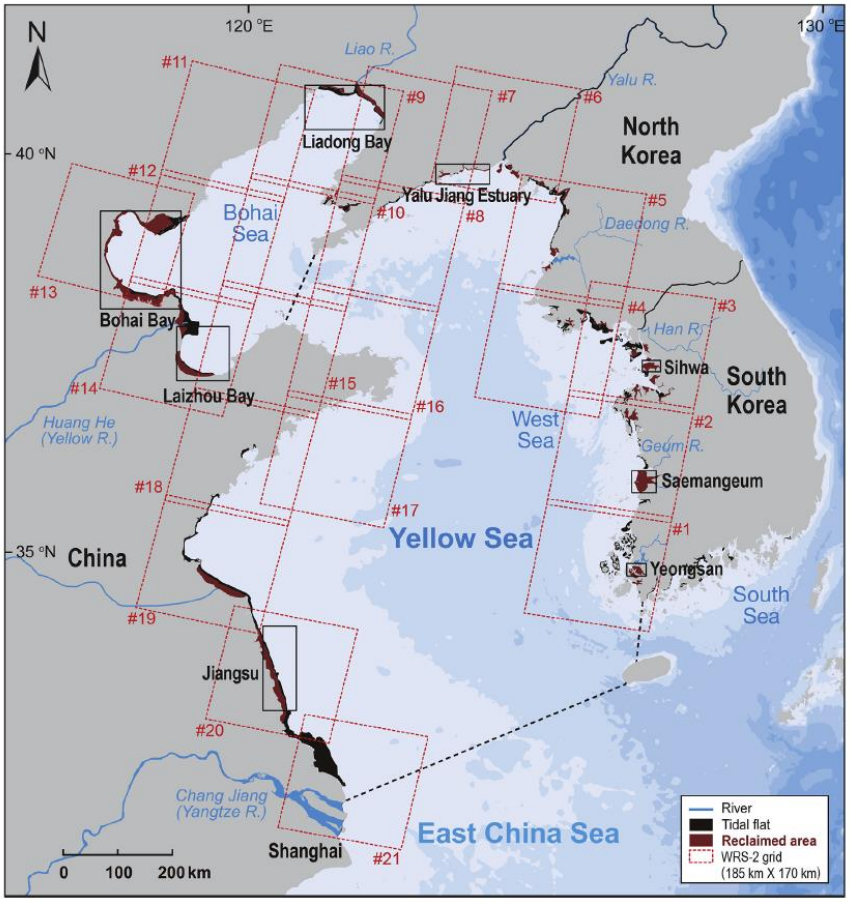
1. Introduction: Reclamation and Restoration

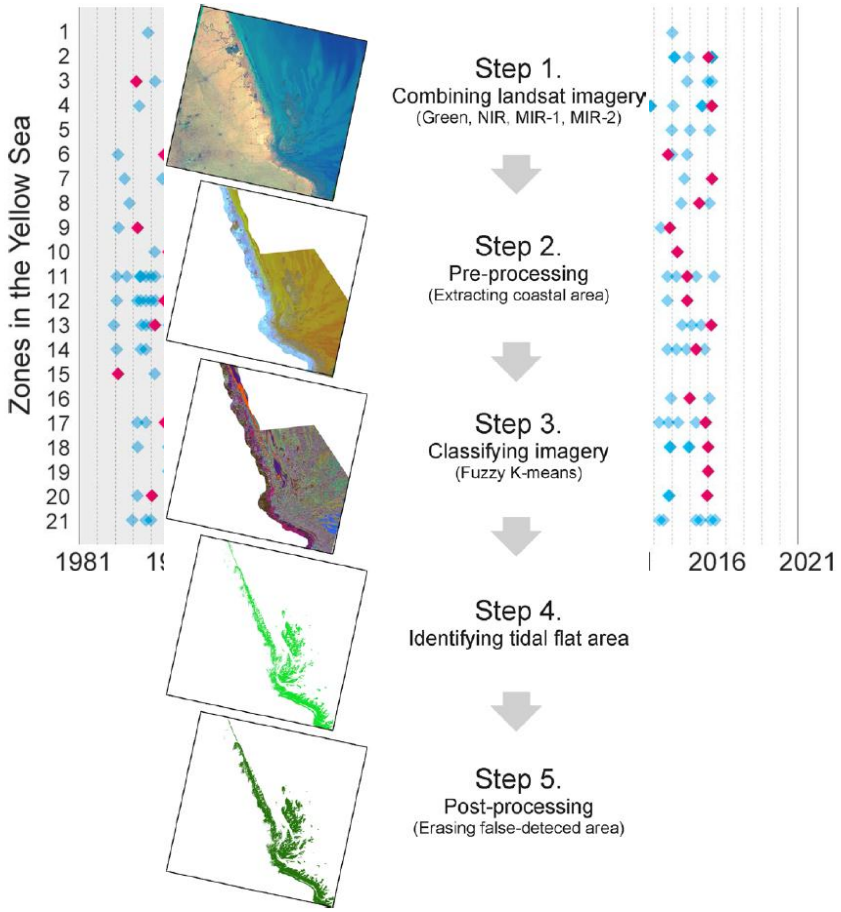
Lake Shihwa reclamation projects
One of the worst cases for ecosystem deterioration due to reclamation

before embanked	after dike constructed	after seawater exchanged	after built tidal power station
1990 →	1995 →	1998 →	2011 →
natural tidal condition healthy & productive	tidal current blocked totally destroyed	water partly circulated slowly recovering	water fully circulated but still contaminated?

2. Materials and Methods

► Study area & reclamation info.

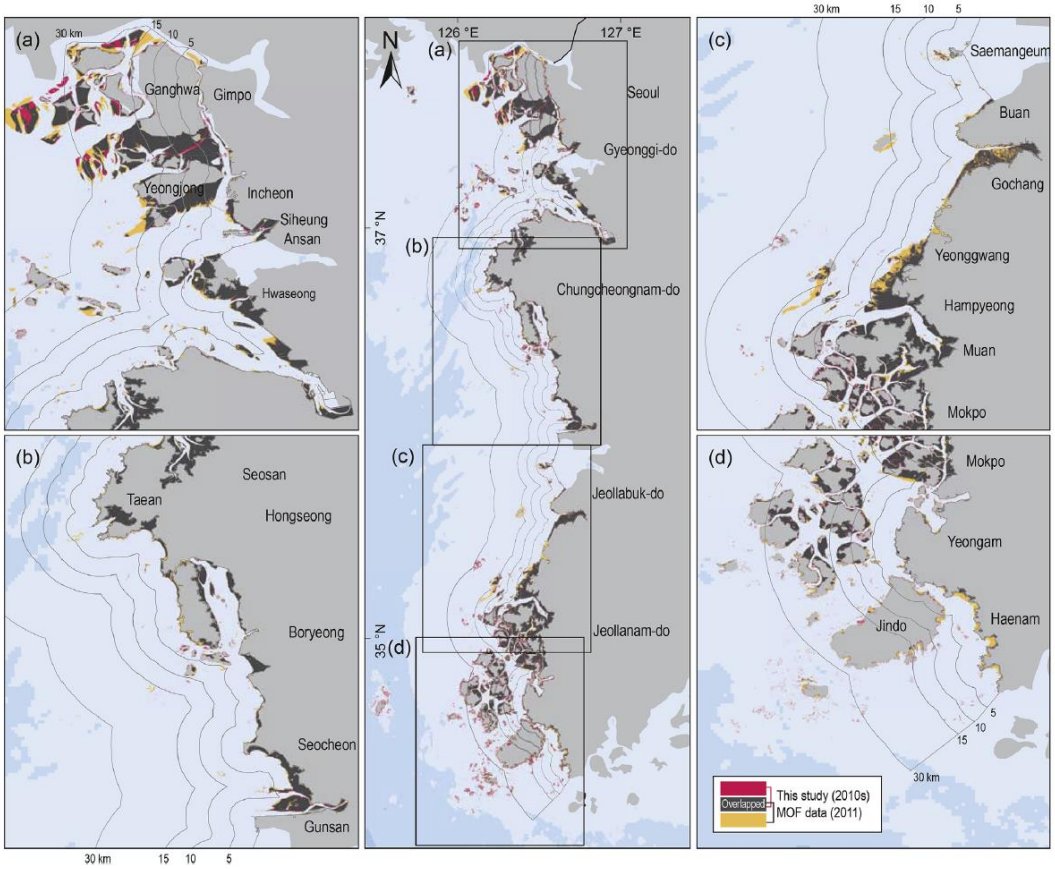




- Map showing satellite images analyzed along the coasts of China and North/South Korea
- Coastal reclamation in the three neighboring countries of CHN & N/S KOR along the coasts of the Yellow Sea from the 1980s to the 2010s → Accumulated area given in parenthesis

3. Results and discussions

► Delination of tidal flats (1/2)

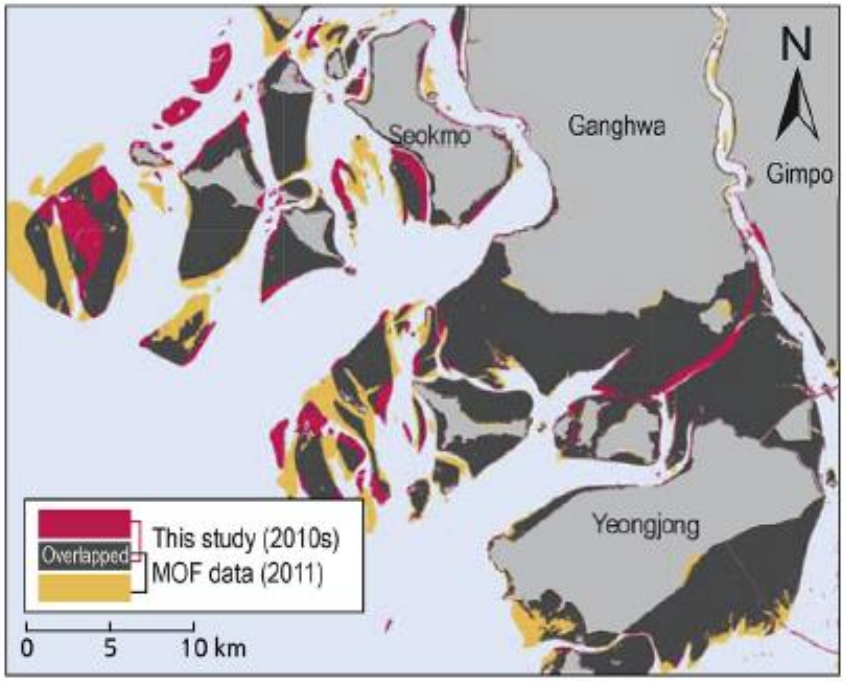


- The comparison of the delineation between the present study (data of the 2010s) and the Ministry of Oceans and Fisheries (MOF), Korea (data of 2013)
- Overall, the accuracy between two data sets was ~ 86%, reasonable ranges considering the short-term spatial variations in tide-dominated areas

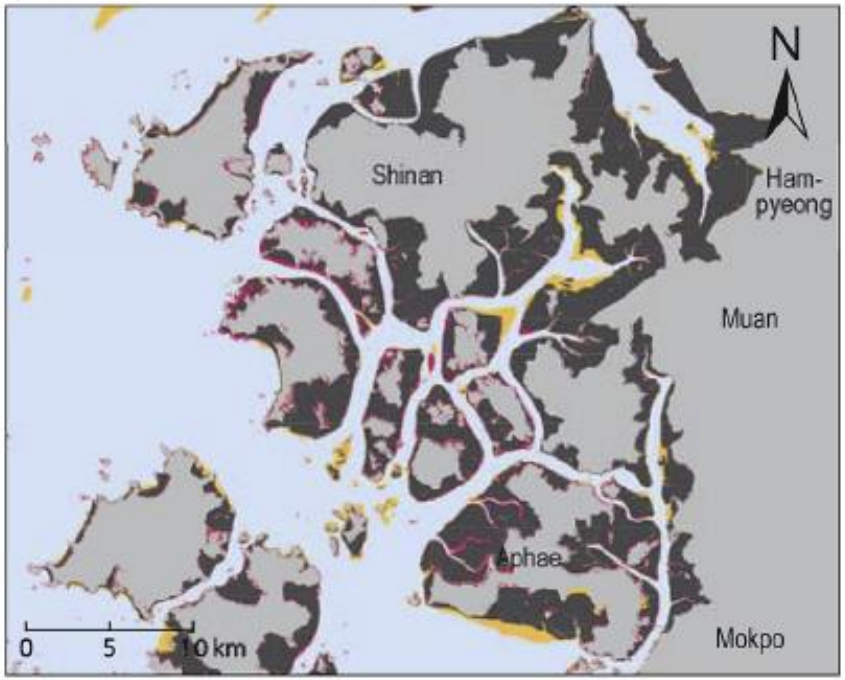
3. Results and discussions

► Delination of tidal flats (2/2)

(a) Incheon, Korea



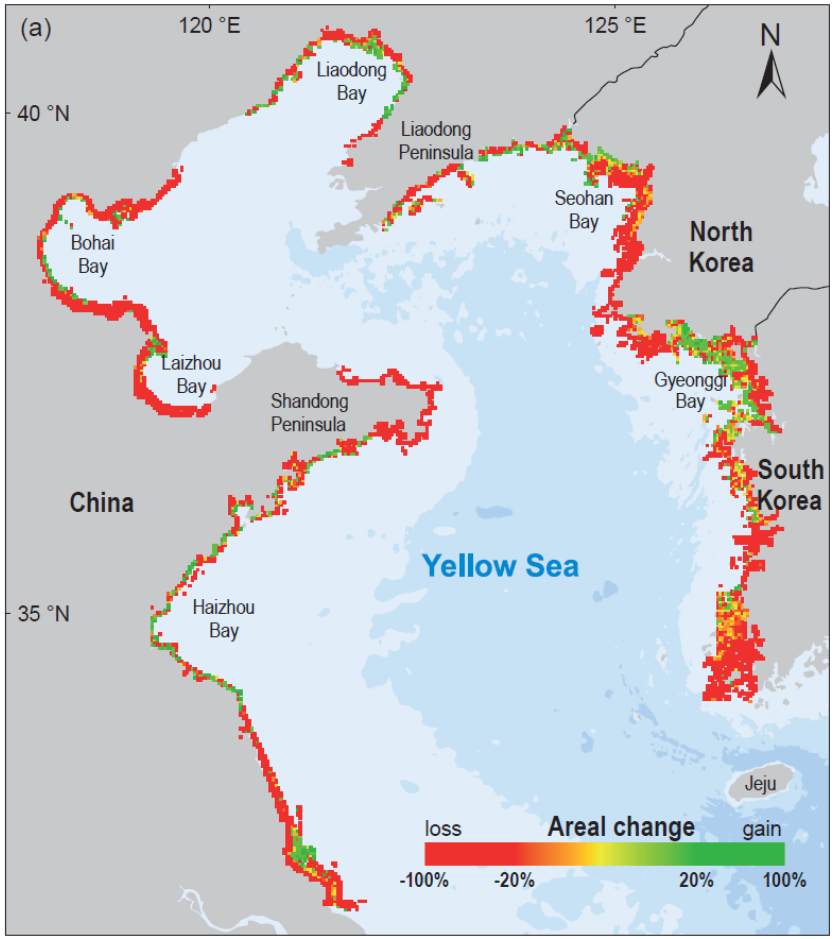
(b) Jeollanam-do, Korea

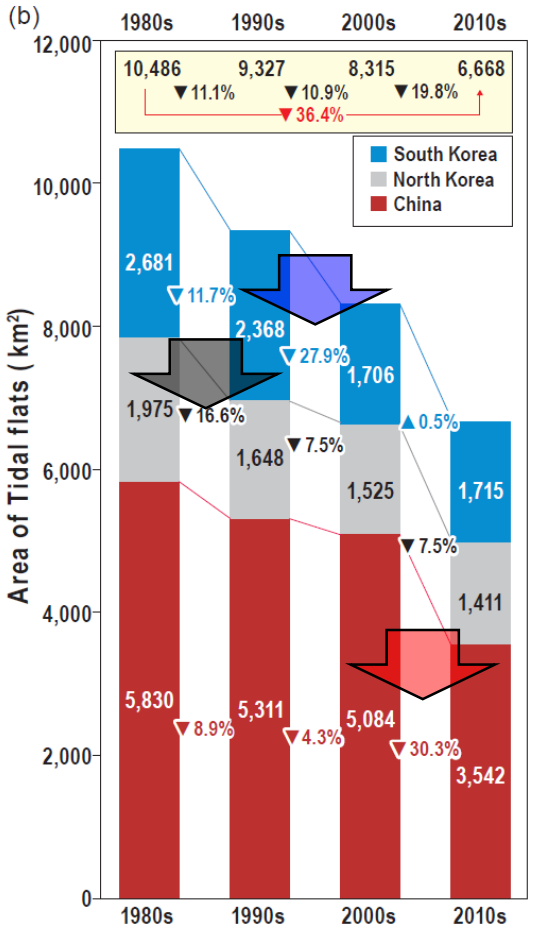


- Noticeable difference prevailed in Incheon due to dynamic sedimentological and morphological changes in an open-coast macrotidal (~9m) environment
- Up to 98% accuracy in Jeonnam, even a macrotidal (~5m) environment with many islands, pronounced the embayment tidal flat, lesser influenced by offshore tide- or wave effects

3. Results and discussions

► Loss or gain of tidal flats along Yellow Sea





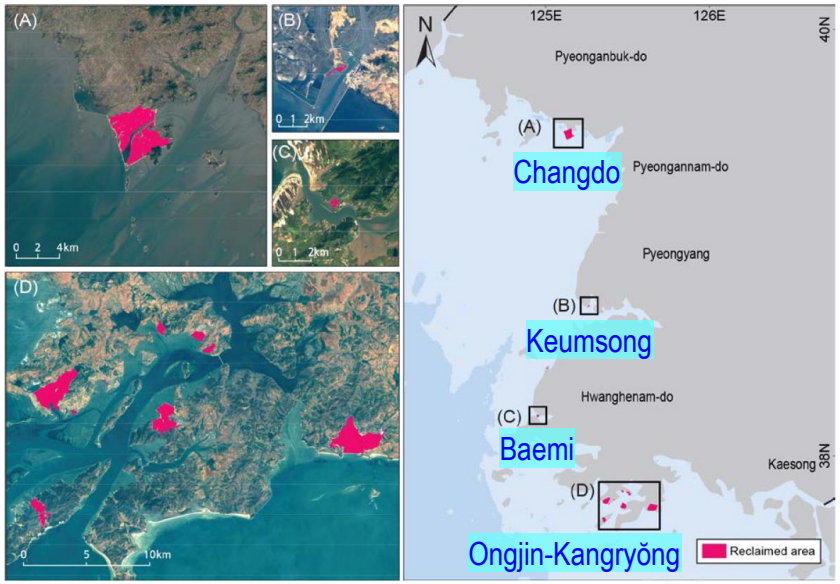
- (a) areal loss or gain of the natural tidal flats & (b) historical change of the natural tidal flats
- 1% annual loss of tidal flats; ~9,700 km² loss expected in the 2020s

3. Results and discussions

▶ Coastal Reclamation (Review)

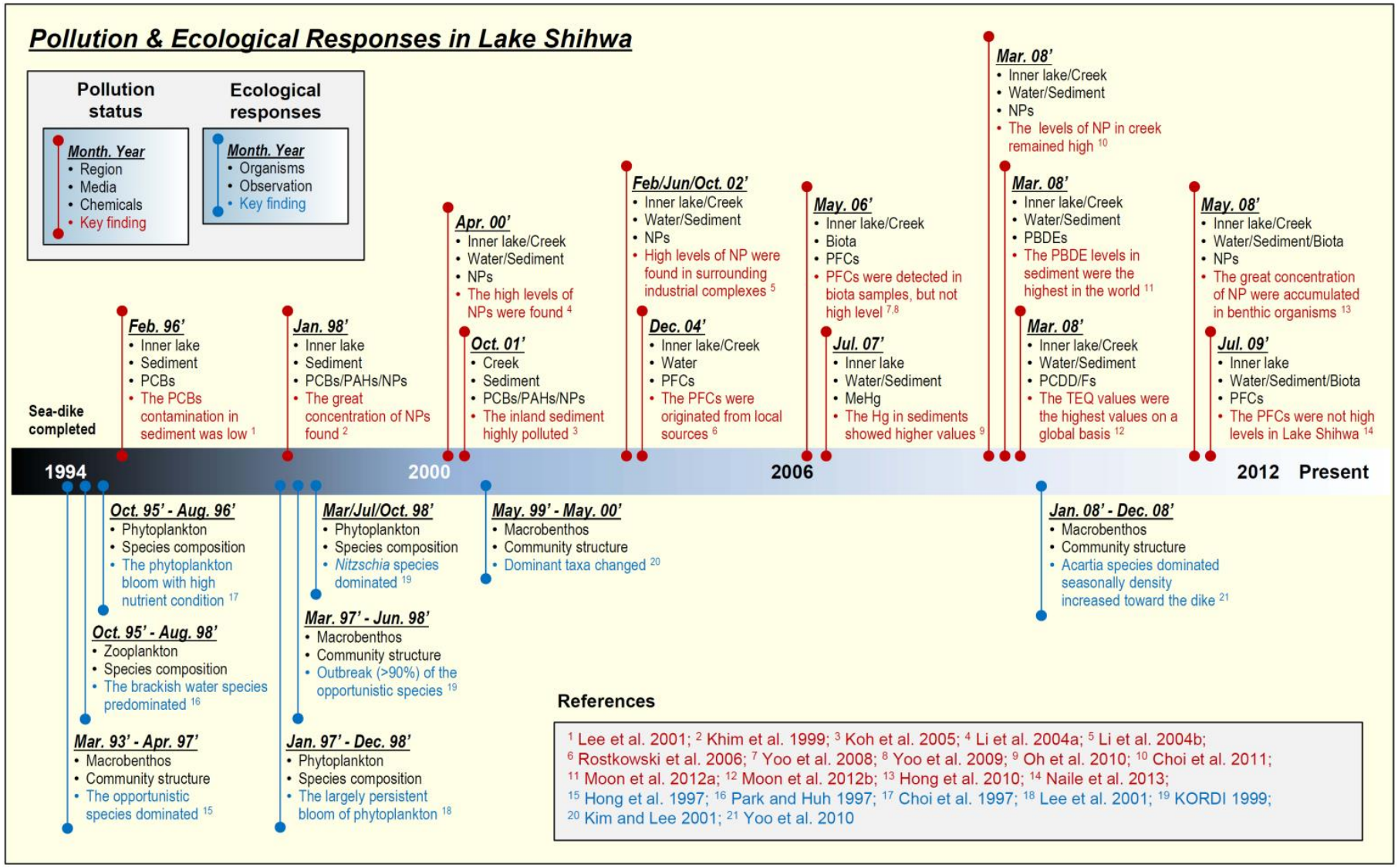
Region	Area of coastal reclamation (km^2)						
	1980s	1990s		2000s		2010s	
China	[a]2361	[b]1178	(3539)	[b]2723	(6262)	[c,*]1105	(7367)
Liaoning	573	235	(808)	656	(1464)	253	(1717)
Hebei	170	86	(256)	431	(687)	150	(837)
Tianjin	19	17	(36)	272	(308)	92	(400)
Shandong	1284	231	(1515)	797	(2312)	345	(2657)
Jiangsu	315	609	(924)	567	(1491)	265	(1756)
South Korea	[d]368	[d]539	(907)	[d]523	(1430)	[e, **]150	(1580)
Incheon	–	46	(46)	–	(46)	–	(46)
Gyeonggi	–	211	(211)	62	(273)	–	(273)
Chungnam	230	56	(286)	14	(300)	–	(390)
Jeonbuk	–	–		401	(401)	–	(461)
Jeonnam	138	226	(364)	46	(410)	–	(410)
North Korea	[f]155	[f]218	(373)	[g]376	(749)	[***]31	(780)
Yellow Sea	2884	1935	(4819)	3622	(8441)	1286	(9727)

[a] Meng et al., 2017, [b] Tian et al., 2016, [c] Wang et al., 2014, [d] MAFRA, 2015, [e] Koh and Khim, 2014, [f] Noh et al., 2001, [g] MLIT and NGII, 2014.
[*]Ongoing projects.
[**]Planned but not on the construction.
[***]Newly analyzed in this study.

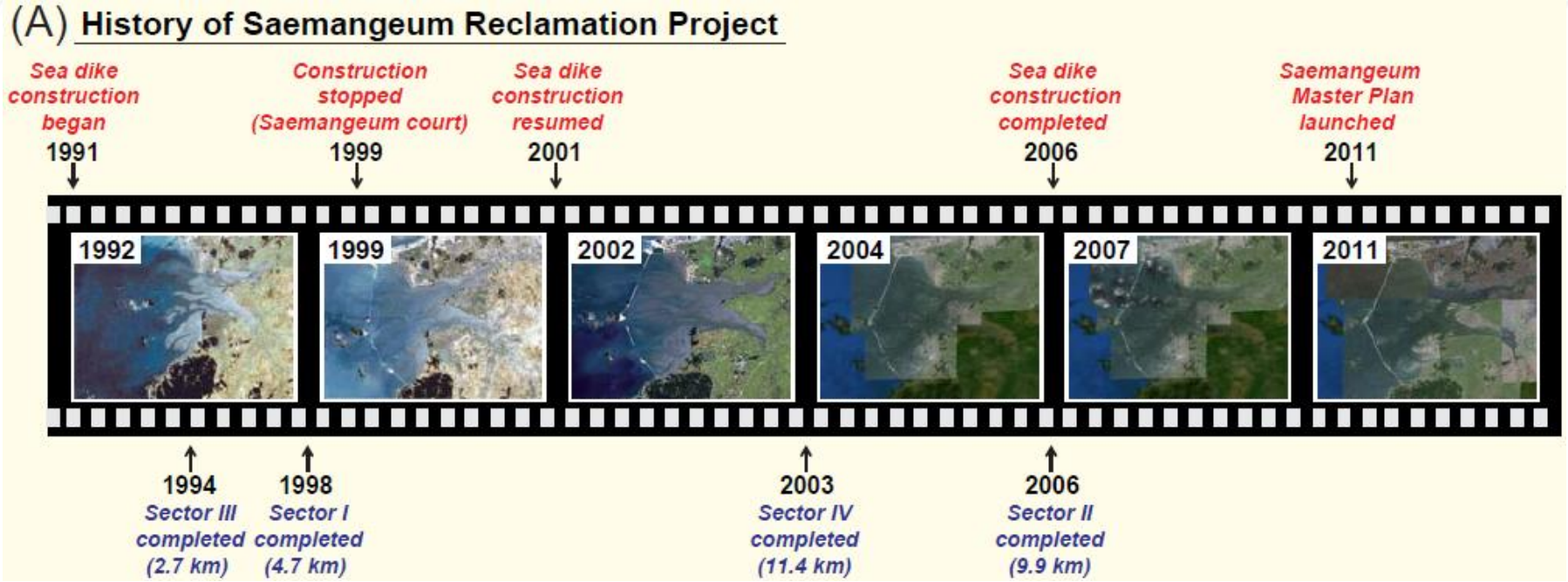


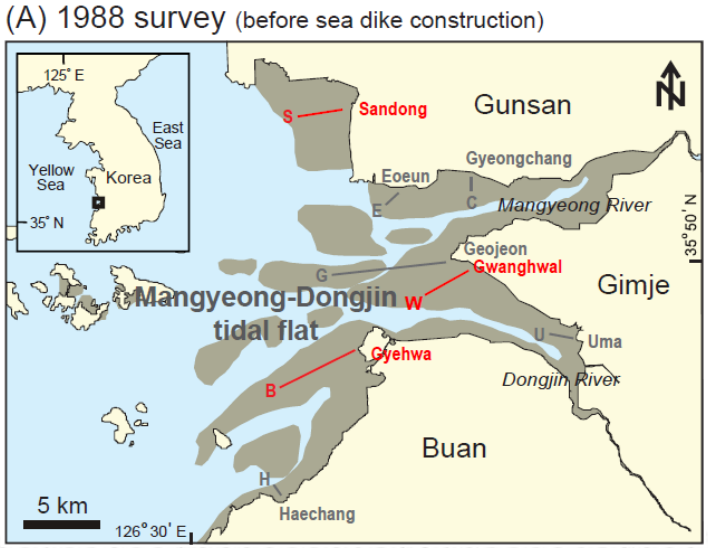
- The greatest reclamation area in China, with total reclaimed area of 7367 km^2
- Reclamations reduced in recent years in CHN, N/S Korea
- Newly updated for North Korea: ~30 km^2 reclaimed in the 2010s

3. Results and discussions

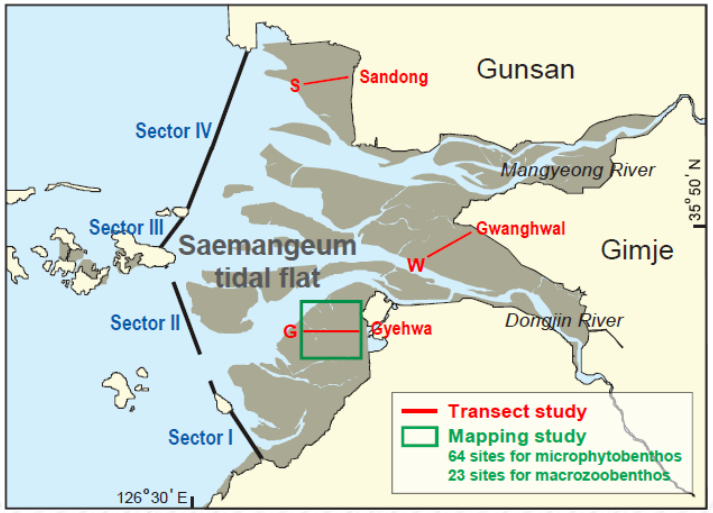


3. Results and discussions





1988 vs. 2000s



3. Results and discussions

(B) Changes in Environmental Conditions

Study area
- *Tidal flat (Intertidal area)*
- *Subtidal area*

1999 - 2000
- *Saemangeum area showed relatively low organic matter distribution* [1]
- *More than 95% reduction in land-based nutrient loadings could meet water quality criteria* [2]

2002 - 2003
- *Organophosphorus pesticides in seawater from riverine sources remained to be constant in tidal cycles* [3]
- *Nutrients came from two rivers, controlled by physical mixing of seawater* [4]
- *Heavy metals remained to be natural level* [4]
- *Organochlorine pesticides from two rivers widely distributed in seawater and sediments* [5]

2004 - 2006
- *River inputs enforced formation of stratification in waters inside sea-dike* [6]
- *Dike construction triggered active sinks of nearshore sediments* [7]
- *After Sector IV completed, sedimentation increased near tidal flats by change of current direction and velocity* [8]
- *Dike construction induced vigorous erosion near the dike openings owing to fast tidal currents* [9]

2007 - present
- *Seawater turbidity greatly reduced after completion of the construction* [10]
- *Dike construction weakened the pressure gradient and tidal amplitude, resulting less momentum and friction* [11]

(C) Changes in Ecological Responses

Study area
- *Tidal flat (Intertidal area)*
- *Subtidal area*

1999 - 2000
- *Shellfish catch sharply decreased from 1991 to 1998* [12]
- *High concentration of lead and cadmium found in tissues of shorebirds* [13]

2002 - 2003
- *Fine sediments severely deposited on tidal flats near Sector IV, resulting species diversity decrease and opportunistic species increase* [14]
- *A total of 44 species of decapods found* [15]

2004 - 2006
- *Three benthic faunal assemblages identified in intertidal areas* [16]
- *Shorebird composition significantly changed before and after dike completion* [17]
- *Abrupt tidal damping induced great decrease of species number and density* [18]

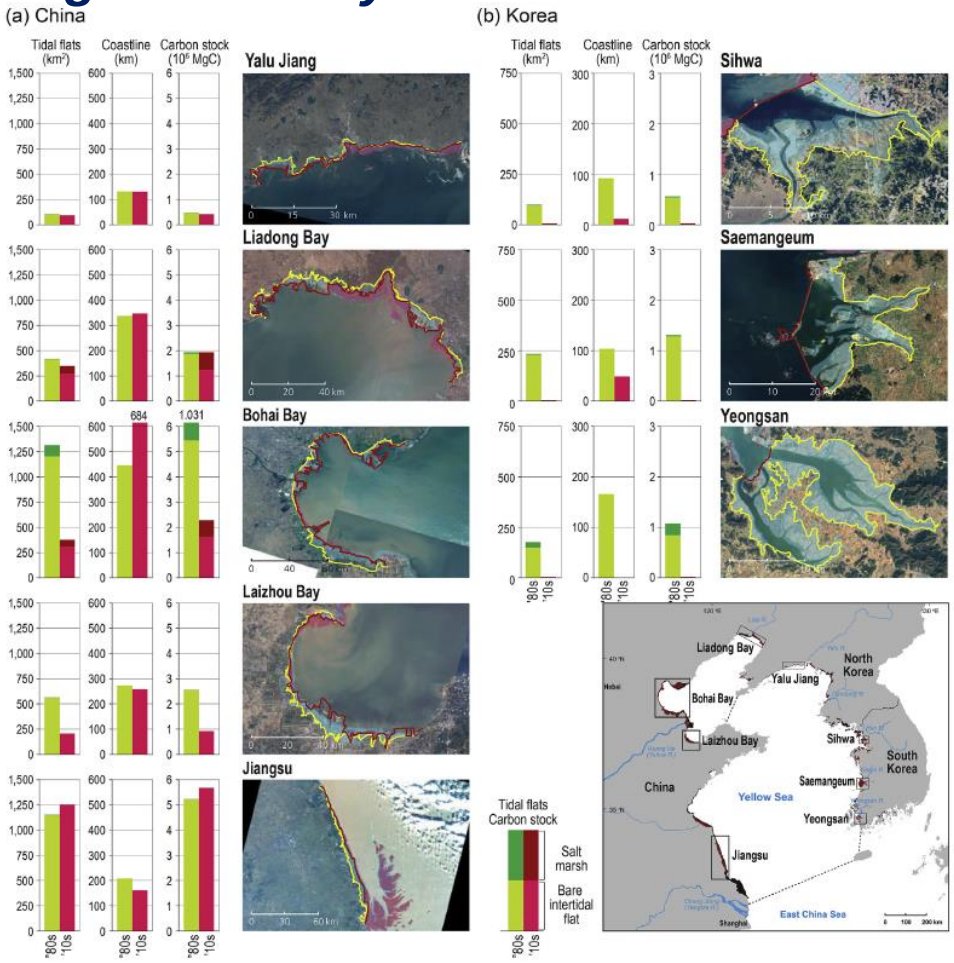
2007 - present
- *Water level change by water gate control significantly affected Halophyte community* [19]
- *Hyper eutrophic bacterial abundance and production found inside of dike* [20]
- *Zooplankton community significantly impacted by whether the sluice gates are closed or open* [21]
- *Five species of halophytes dominant in salt marshes* [22]
- *Dominant species of waterfowls changed due to the dike construction* [23]
- *A total of 58 algal species identified would be affected by effluents of lake water through the water sluices* [24]

References

[1] You et al., 2003; [2] Kim et al., 2002; [3] Li et al., 2006; [4] Kim et al., 2009; [5] Hong et al., 2006; [6] Kim et al., 2006; [7] Lee and Ryu, 2007; [8] Woo et al., 2006; [9] Lee and Ryu, 2008; [10] Min et al., 2012; [11] Park et al., 2014; [12] Kim and Hwang, 2003; [13] Lee et al., 2008; [14] Koo et al., 2008c; [15] Rho et al., 2004; [16] Ryu et al., 2011a; [17] Jin et al., 2010; [18] Koo et al., 2008b; [19] Sin and Kim, 2010; [20] Choi and Noh, 2008; [21] Lee et al., 2009; [22] Kim, 2009; [23] Kang et al., 2011; [24] Kim et al., 2011.

3. Results and discussions

► Historical changes in Ecosystem Services Values (ESV)



- Total loss of ~ 34% carbon stocks in five reclaimed regions of China
- Carbon stocks in Sihwa, Saemangeum, and Yeongsan were 2.8x10^6 MgC in the 1980s but dramatically reduced to 0.024x10^6 MgC in the 2010s

3. Results and discussions

► Historical changes in Ecosystem Services Values (ESV)

Region	Total ecosystem services			Provisioning		Regulating		Supporting		Cultural	
	1980s	2010s		1980s	2010s	1980s	2010s	1980s	2010s	1980s	2010s
China	12416	7543	(▼39)	3104	1886	7419	4507	395	240	1498	910
South Korea	5156	3298	(▼36)	1475	943	2697	1725	652	417	332	212
North Korea	3798	2713	(▼29)	1086	776	1987	1419	480	343	245	175
Total	21370	13554	(▼37)	5665	3605	12103	7651	1527	1000	2075	1297

KOREA vs. CHINA

Location	Total ESV	Provisioning services				Regulating services						Supporting services		Cultural services	Reference
		FP	WP	RM	GE	GR	CR	MD	WR	WT	SF	HS	BD		
Jeonnam	1.95	1.07								0.85		0.03			Choi (2000)
Jeonnam	1.47	0.72								0.74					KSEE (2000)
Jeonnam	1.4									1.4					Pyo et al. (2001)
Jeonnam	1.18	0.48								0.7					MOF (2000b)
Jeonnam	0.32	0.32													Park (2000)
Jeonnam	0.23	0.13								0.05				0.05	MAF (1998)
Jeonbuk	1.39	0.15								1		0.23			Jang (1997)
Jeonbuk	0.44	0.44													Choi (1998)
Incheon	2.04									2.04					MOF (2000a)
Incheon	1.36	1.36													Lee and Youn (1997)
Incheon	0.66									0.66					MOF (2001)
Incheon	0.53									0.53					Lee (1999)
Incheon	0.16													0.16	Yoo (1998)
Korea*	1.1	0.3				0.02		0.18		0.02		0.41		0.16	RDC (1999a)
Jeonnam	0.79	0.79													Kang and Nam (2003)
Korea*	0.59	0.29										0.3			RDC (1999b)
	Mean	0.55				0.02		0.18		0.8		0.24		0.12	

FP, Food; WP, Water; RM, Raw materials; GE, Genetic resources; GR, Gas regulation; CR, Climate regulation; MD, Moderation of disturbance; WR, Water flow regulation; WT, Waste treatment; SF, Soil fertility maintenance; HS, Habitat; BD, Biodiversity

* Typical tidal flats in South Korea

Location	Total ESV	Provisioning services				Regulating services						Supporting services		Cultural services	Reference
		FP	WP	RM	GE	GR	CR	MD	WR	WT	SF	HS	BD		
Zhejiang	1.26	0.01		0.01		0.06	0.31		0.31	0.33	0.05		0.08	0.11	Shao et al. (2017)
Liaoning	3.35	0.62	0.03	0.15	0.2	0.03	0.21	0.25	0.8					1.06	Ye et al. (2016)
Liaoning	1.15	0.01		0.01		0.05	0.28		0.28	0.3	0.04		0.08	0.1	Li et al. (2017)
Jiangsu	1.45	0.01		0		0.04	0.39		0.36	0.42	0.04		0.06	0.13	Xu et al. (2016)
Jiangsu	1.43	0.01	0.35	0.01		0.06	0.35			0.38	0.05		0.1	0.12	Chuai et al. (2016)
China*	0.33	0.002		0.001		0.01	0.08		0.08	0.09	0.01		0.02	0.03	Xie et al. (2008)
	Mean	0.11	0.19	0.03	0.2	0.04	0.27	0.25	0.37	0.3	0.04		0.07	0.26	

FP, Food; WP, Water; RM, Raw materials; GE, Genetic resources; GR, Gas regulation; CR, Climate regulation; MD, Moderation of disturbance; WR, Water flow regulation; WT, Waste treatment; SF, Soil fertility maintenance; HS, Habitat; BD, Biodiversity

* Typical tidal flats in China

- ESV decreased from 21 billion USD yr^{-1} in the 1980s to14 billion USD yr^{-1} in the 2010s
- Huge losses in ecosystem services being provided by the Yellow Sea natural tidal flats need immediate action to prevent or at least alleviate accelerating

4. Conclusions

- ✓ Tidal flats in the Yellow Sea has been drastically reduced by 36% as of the 2010s compared to the 1980s, from ~10,500 to 6670 km^2, say **annual decrease of 1%**
- ✓ Net loss of Yellow Sea tidal flats during the same period was ~3800 km^2, accordingly the **loss of estimated ESV** of Yellow Sea tidal flats was **7.8 billion USD yr^{-1}**.
- ✓ To minimize coastal vulnerability and loss of ES, **science-based policy design** toward coastal conservation should be strengthened in the near future.

Reclaimed mudflat in Saemangeum, KOR

5. Remarks

Environmental Pollution 241 (2018) 74–84

Contents lists available at ScienceDirect

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Analysis of forty years long changes in coastal land use and land cover of the Yellow Sea: The gains or losses in ecosystem services

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Yim, Kwon et al, 2018, Environmental Pollution 241: 74-84

THANK YOU
for your attention

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Acknowledgement

This work was supported by the project entitle
"Marine ecosystem-based analysis and decision-making support system development for marine spatial planning (20170325)"
funded by the *Ministry of Oceans and Fisheries of Korea*