東京大学
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Adapting to Sea Level Rise: Real Lessons from Land Subsidence in Japan, Indonesia and the Philippines

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Summary: a peak into the future

- **We can look at cases of land subsidence around the planet to understand how adaptation will actually work**
  - ***Small Islands:***
    - **Case Study in Philippines** **(Jamero et al., 2016, 2017)**
  - ***Cities:***
    - **Case Study of Jakarta** **(Takagi et al., 2014, 2015, 2016)**
    - **Case Study of Tokyo** **(Esteban et al., 2017, Hoshino et al., 2015)**
    - **Phases of Adaptation in cities** **(Esteban et al., 2017)**
    - **The cost of adaptation** **(Hoshino et al., 2016)**
  - ***Ports:***
    - **Case Study of Jakarta** **(More fieldwork needed…)**
    - **Case Study of Tohoku** **(Esteban et al., 2016)**

Sea Level Rise Adaptation: Learning from ~1m “rise” in the Philippines after 2013 Bohol Earthquake

(Think of my presentation as a Time Machine into the Future!)

Coral Islands off Bohol, Philippines

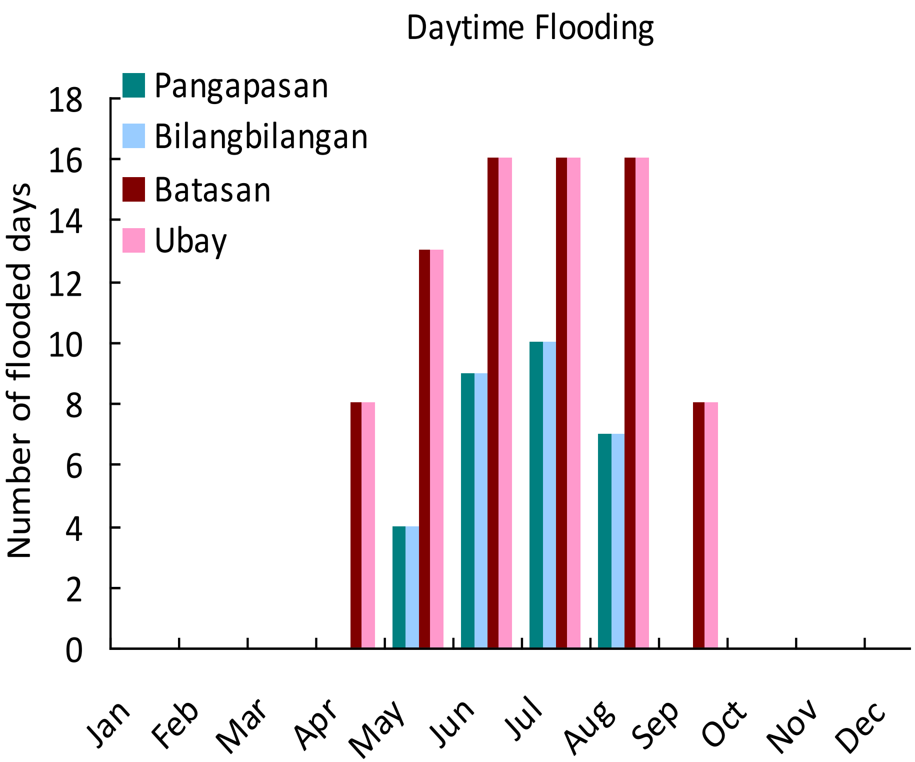
Imagery ©2015 CNES / Astrium, DigitalGlobe, Landsat, Map data ©2015 Google 2 km

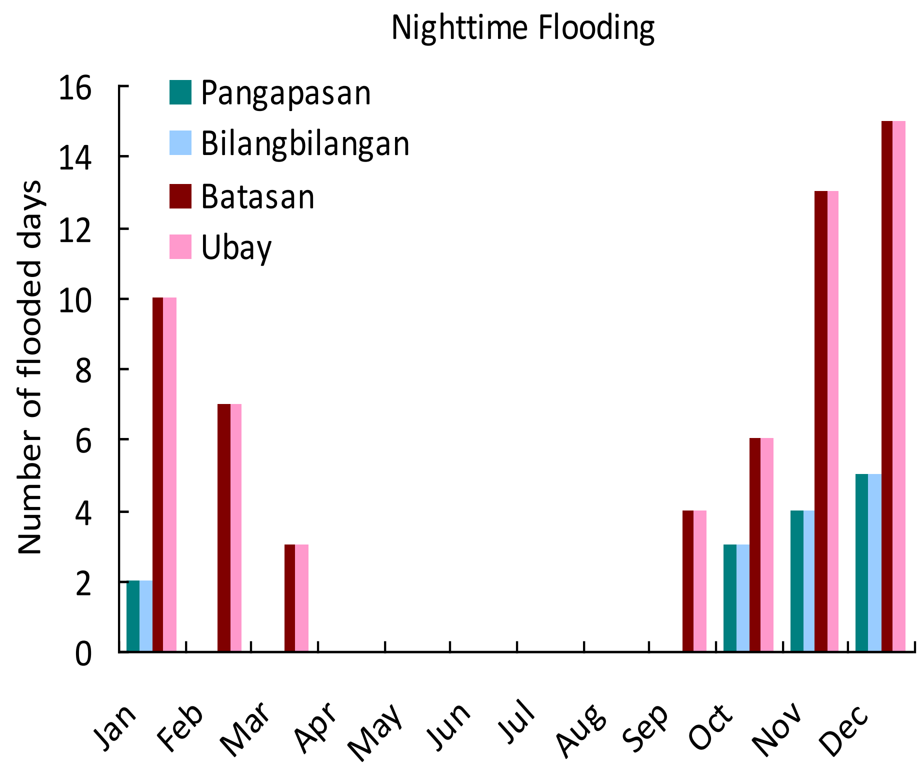
Consequences of ~1m subsidence due to the 2013 Earthquake

Island	Highest elevation (m)	Area (m^2)	Cross-section (m)	Built environment	Flooding situation	Severity
Batasan	**2.28**	**58,296**	**47.4**	From the start, ground raised using coral stones; houses built up to the sea	• **Before earthquake:** **Flooded during strong typhoons** • **After earthquake:** **Completely flooded during spring tides (e.g. 1 hour daily floods for 1 week around new and full moon)**	**2**
Ubay	**2.15**	**14,638**	**84.8**			**1**
Pangapasan	1.91	20,694	71.1			**3**
Bilangbilangan	1.99	16,668	100.3	Ground not raised; Has beach, with some areas lined with seawall; houses built well within grounds		**4**
Mocaboc	2.06	29,674	118.1		• Before and after earthquake: Houses near waterline occasionally flooded during very high tides (i.e. +2.0m) and typhoons. No perceived changes in flood levels before and after earthquake	**5**
Bagonbanwa	2.5	60,839	187.4		• Before and after earthquake: Not flooded	**6**

Ubay: attempted using sea walls (note also problem of planting mangrove in high energy environment)

Flooding Severity





By 2100 global mean sea level will rise by 0.28m-0.98m, or higher, as numerous presenters have explained

(IPCC 5AR, 2013)

Jamero, L., Esteban., M. and Onuki, M. (2016) *"Small island communities in the Philippines prefer local measures to relocation in response to sea-level rise",* Nature Climate Change (should be online any day now…)

Current situation (Ubay Island, typical water levels) Coping?

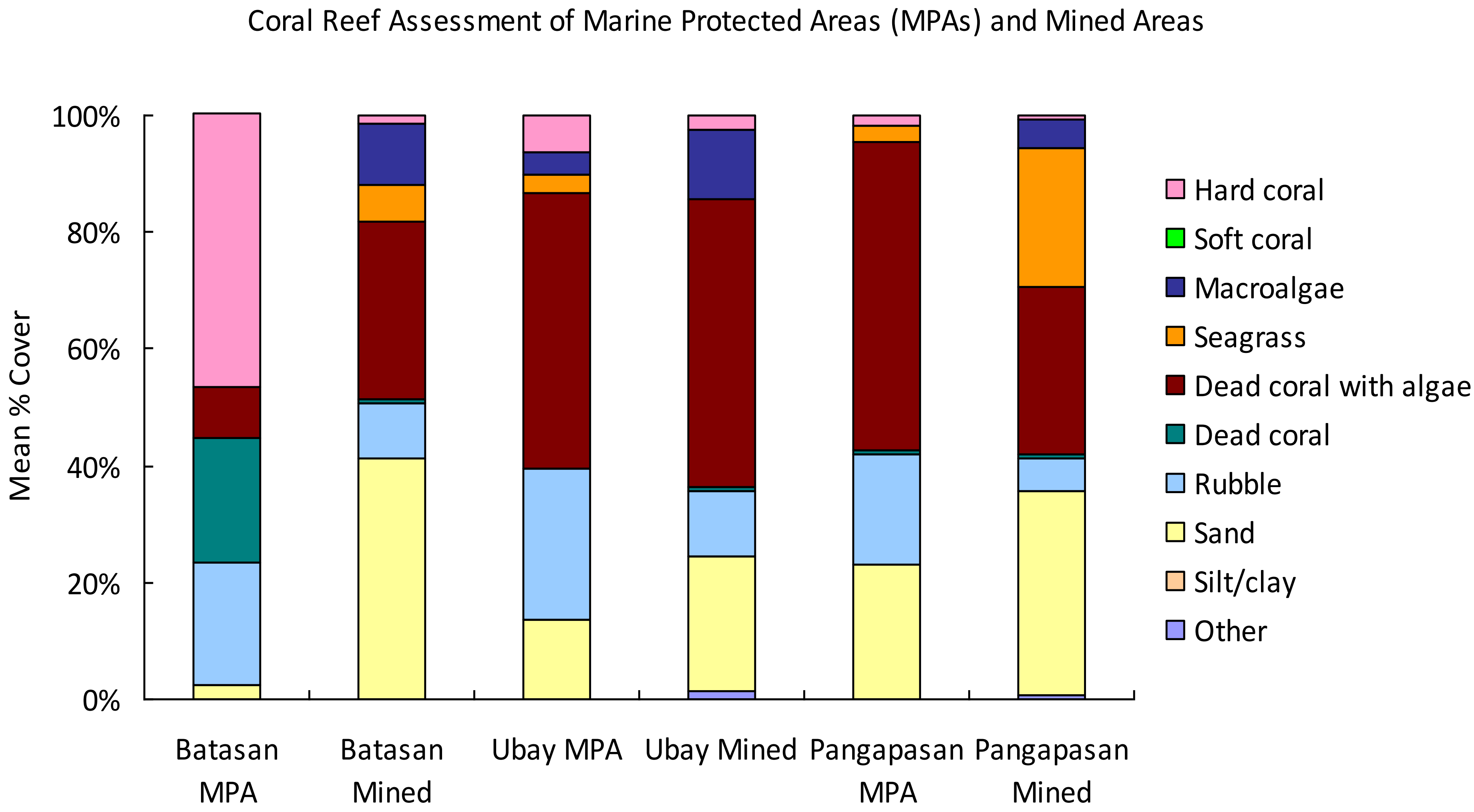
Adaptation: Bio-adaptation vs Engineering

Islands with mangroves are facing far less problems that those that have attempted to build seawalls

However, not so easy to plant mangroves!

But, generally it seems to be the way to go…

Long-term sustainability of adaptation strategies: importance of sediment budgets



Jamero, L., Esteban., M. and Onuki, M. (2016) *"Small island communities in the Philippines prefer local measures to relocation in response to sea-level rise",* Nature Climate Change (should be online any day now…)

Adaptation strategies (Batasan Island)

-Rising floors (using coral stones or rubbish)

-Building seawalls (using coral stones)

-Houses on stilts

-Learning to live with flooding

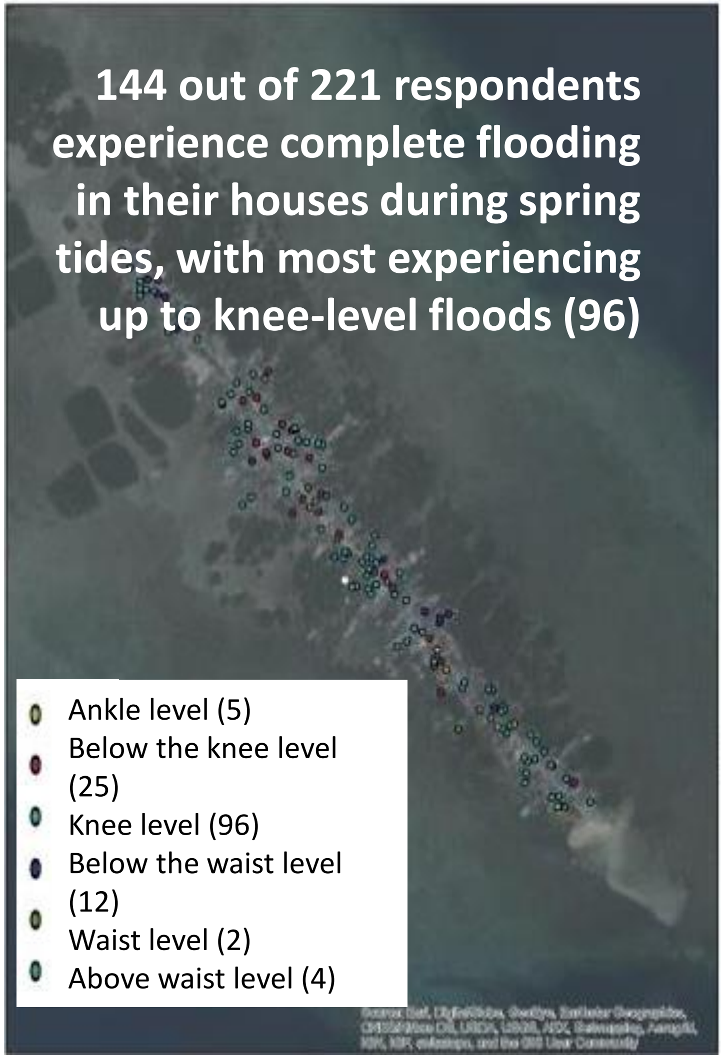
Adaptation strategies: Effectiveness

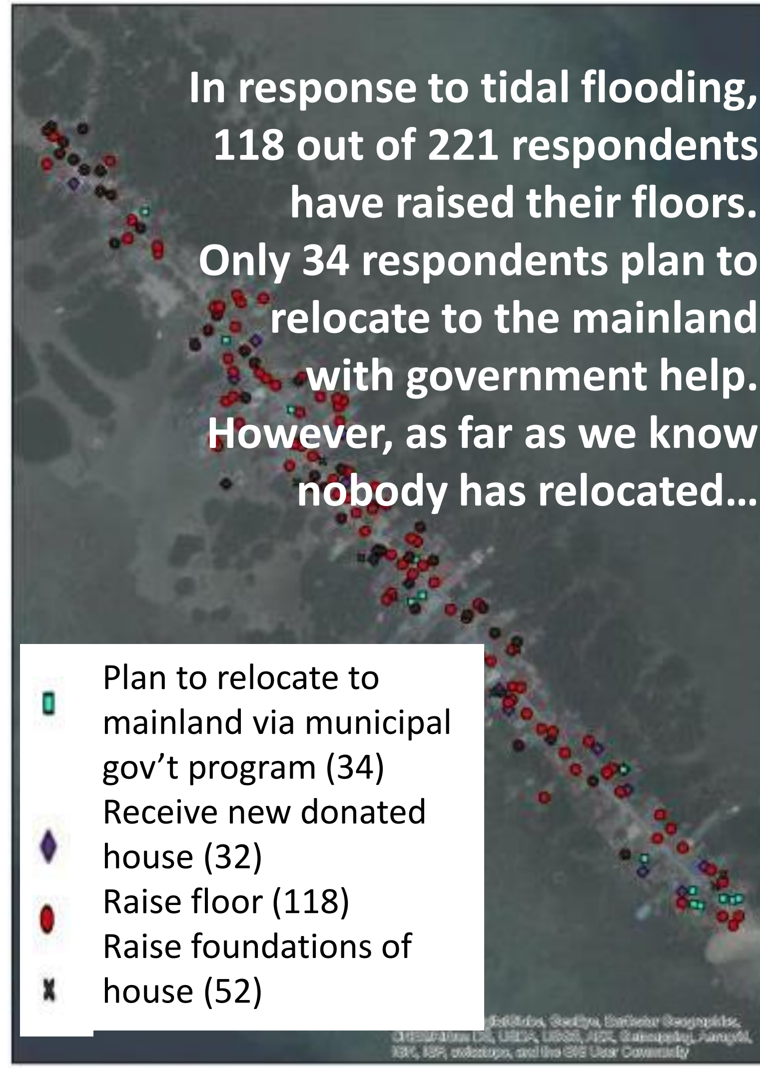
		Flood height	Hard Measures			
			Stilted House		Raised Floor	
Flooding Severity	Island	Median (cm)	Median (cm)	Households Not Flooded	Median (cm)	Households Not Flooded
Low	**Pangapasan**	20.5	87	100%	29	73%
	Bilangbilangan	24.5	79	100%	27.5	67%
Medium	**Batasan**	36	100	100%	44	22%
	Ubay	43	120.5	100%	67.25	46%

✓ **STILTED HOUSES** *have great allowances for flooding, and even for high waves during typhoon and monsoon seasons. However, they also need to be properly engineered against strong winds*

Jamero, L., Esteban., M. and Onuki, M. (2016) *"Small island communities in the Philippines prefer local measures to relocation in response to sea-level rise",* Nature Climate Change (should be online any day now…)

Willingness to Relocate

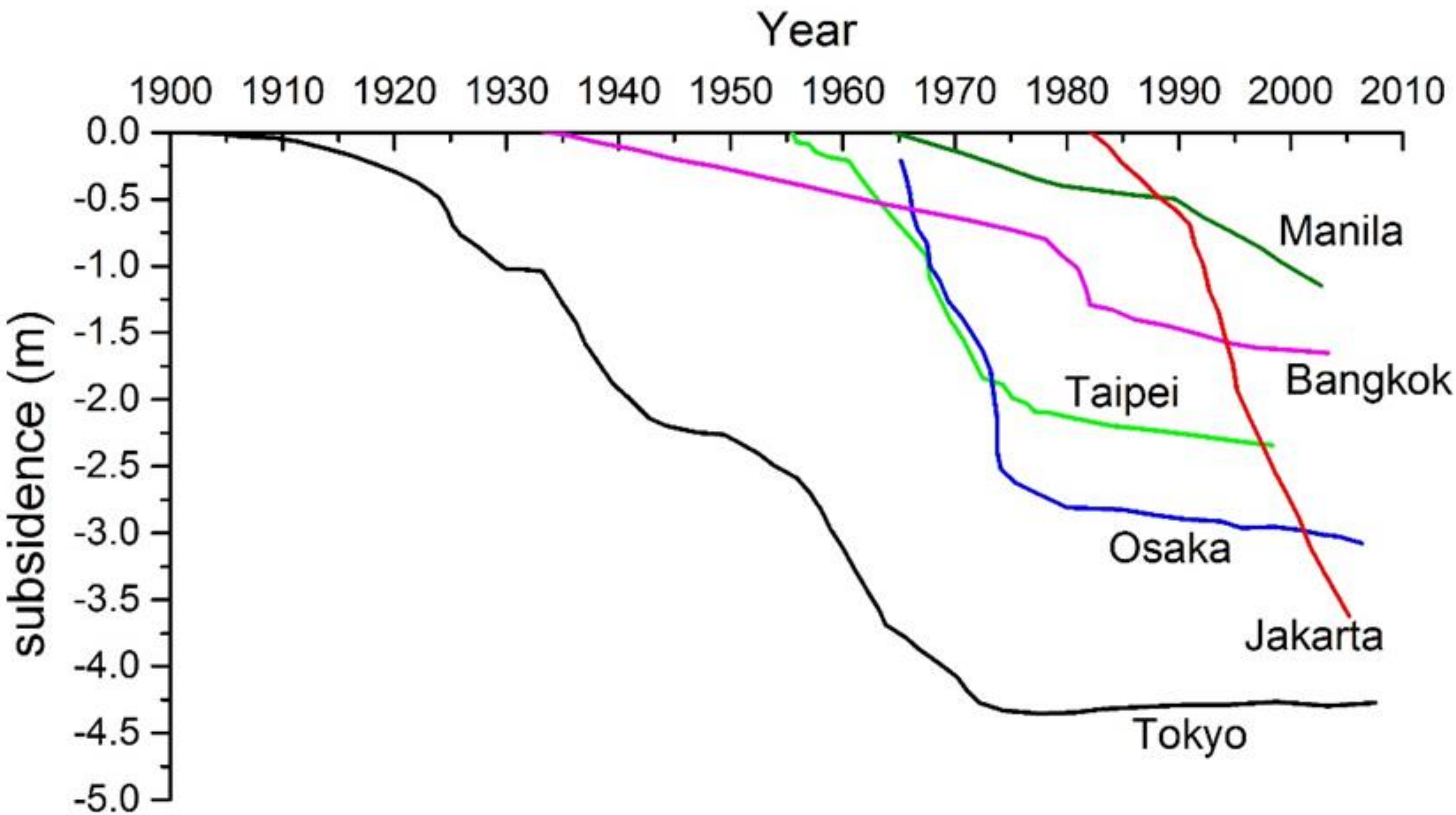




Jamero, L., **Esteban., M.** and Onuki, M. (2016) *"Potential In-Situ Adaptation Strategies for Climate-Related Sea-Level Rise: Insights from a Small Island in The Philippines Experiencing Earthquake-Induced Land Subsidence",* J-SustaiN 4 (2) pp 44-53.

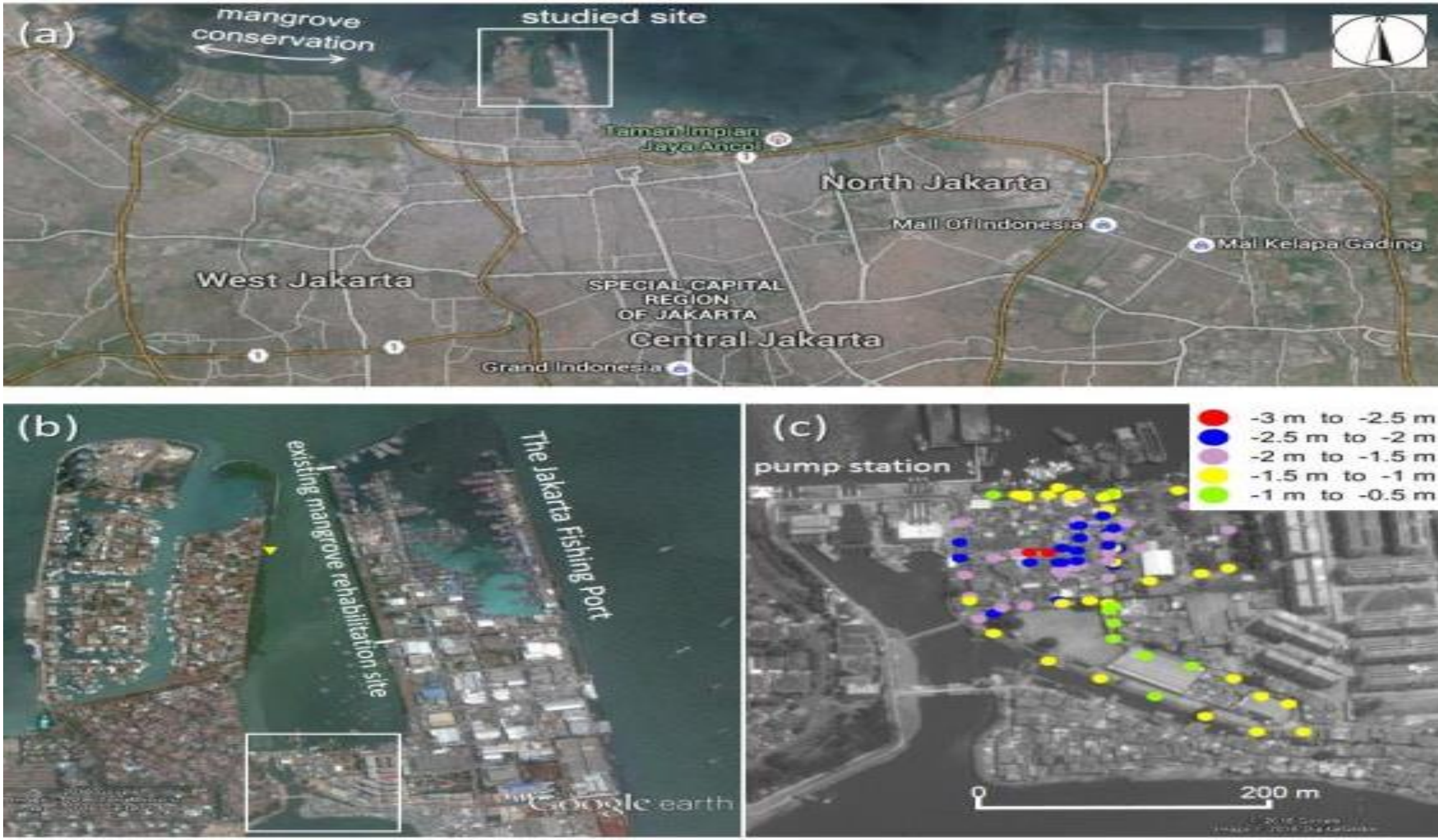
Sea Level Rise Adaptation: Learning from >5.0m "rise" in Jakarta

Reason: Groundwater Extraction (currently ~0.2m* subsidence/year)



**No, this is not a typo, it really is 20cm per year!*

Study site: Coastal Jakarta (-0.5 to -3m below sea level)



Takagi, HJ., Fujii, D., Esteban, M., Yi, X. (2017) "Effectiveness and Limitation of Coastal Dykes in Jakarta: the Need for Prioritising Actions against Land Subsidence". Sustainability 9, 619

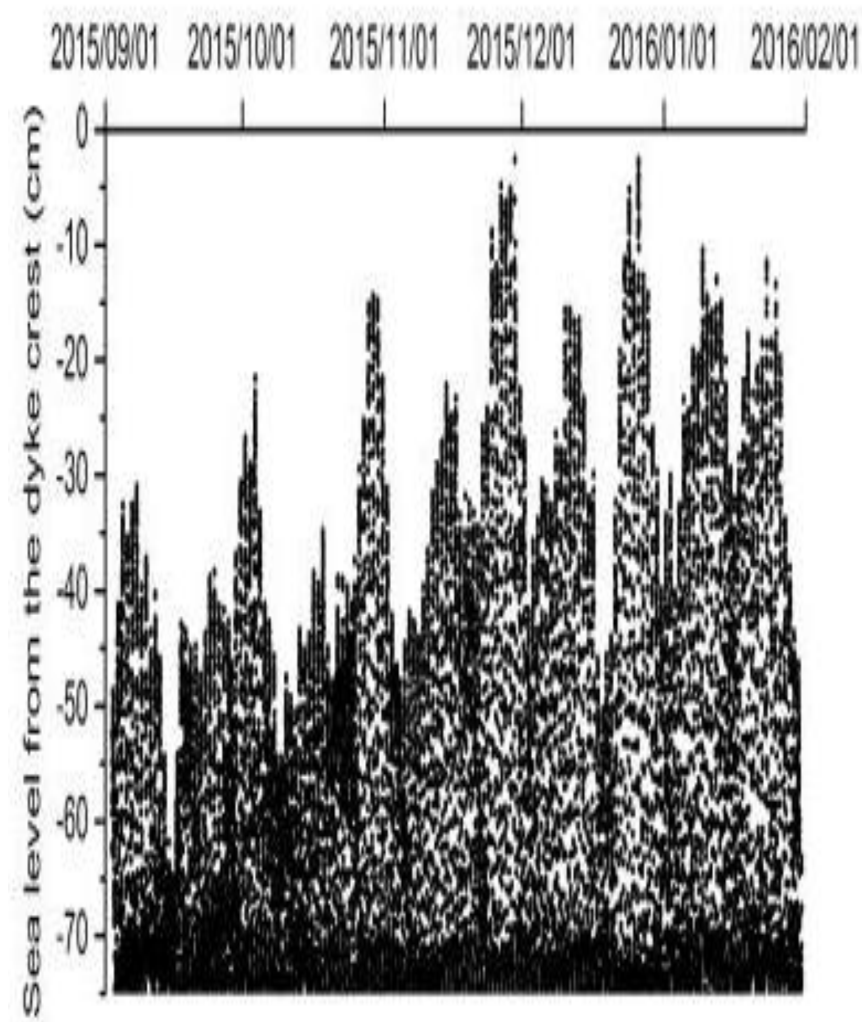
Adaptation (coping?): Building of Sea Dykes

2007 Flooding and Raising of Dyke

Pluit District suffered extensive inundation during a high tide on November 26, 2007

The thin dyke protecting the settlement was raised by about a meter after the 2007 event by the local government

However, sea levels almost reach the top of the dyke on a monthly basis (dike is being raised almost on a yearly basis…)



Takagi, H., Fujii, D., Mikami, T. and Esteban, M. (2016) “Mangrove Forest against Dyke-break induced Tsunami in Rapidly Subsiding Coasts”, Natural Hazards and Earth System Science, 16, 1629-1638.

Adaptation Counter-Measures

Pluit has one of the main pumps for Jakarta (needed to pump the water out of the city, as it no longer flows out!)

Dykes are being built around all waterways, which anyway are below MWL.

Esteban, M., Takagi, H., Mikami, T., Aprilia, A., Fujii, D., Kurobe, S. and Utama, N. A. (2017) *"Awareness of coastal Floods in Impoverished Subsiding Coastal Communities in Jakarta: Tsunamis, Typhoon Storm Surges and Dyke-Induced Tsunamis"*, International Journal of Disaster Risk Reduction 23, 70-79

Problems for Ports (I)

Problems for Ports (II)

The case of Tokyo

Also due to groundwater extraction in the 20th century

Some wards would be completely flooded if dykes were breached

Adaptation sequence. Stage 1: Construction of thin concrete walls

Construction of thin concrete dykes to protect against flooding

(**Left,** memorial remains of the seawall built to protect Edogawa ward after Typhoon Kitty in 1949, and before reclamation for the Kasai Seaside Park project started). **Right**, concrete wall defending Pluit in Jakarta. Photo taken in May 2016, the wall has since been heightened in 2017)

Stage 2: Construction of pumps to remove excess water

As the height of the seawater outside of the dykes increases, water inside the cities (either in canals or flood storage basics) cannot be removed, especially during heavy rain.

(**Left**, Edogawa ward, Tokyo. **Right,** Pluit, Jakarta)

Stage 3: Reinforcing levees and construction of storm surge gates

Reinforcing river levees, construction of storm surge gates and other hydraulic measures.

(**Left:** storm surge gate in Koto ward, Tokyo. **Right:** Improvements of levee system in Pluit, Jakarta)

Stage 4: Land Reclamation and Conservation Projects

Tokyo: many islands (Odaiba, Haneda airport), or coastal areas have been reclaimed from the sea (such as the Kasai Rinkai Park, where large areas that were lost to the sea were once again recovered, **left** figure above).

Jakarta:, several islands have been reclaimed to make room for expensive apartment blocks, such as those in Pelangi Island (**right**). Also, “Great Garuda” Project…

Stage 5: Super-levees and elevation of entire districts

Tokyo began working on super levees, wide embankments that are built in cooperation with various urban redevelopment projects. Large areas with old housing or industries are demolished, and then land is elevated throughout the area, with new buildings constructed directly on top of the levee (**left**).

Jakarta, no work yet, but I'm sure they'll reach this phase eventually

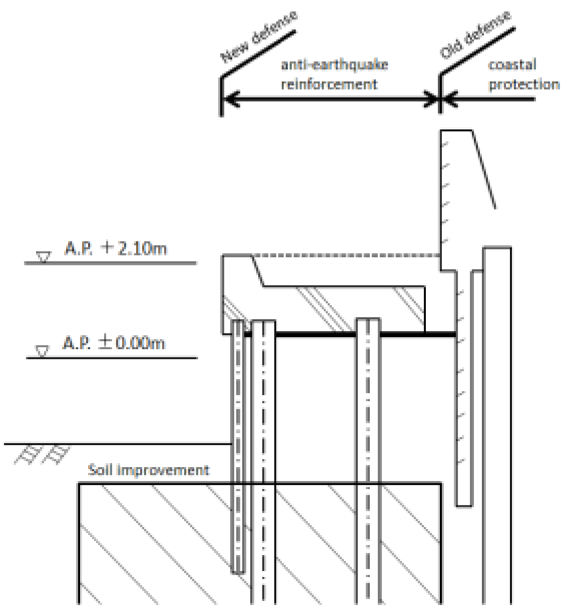
The cost of adaptation to SLR and more intense tropical cyclones

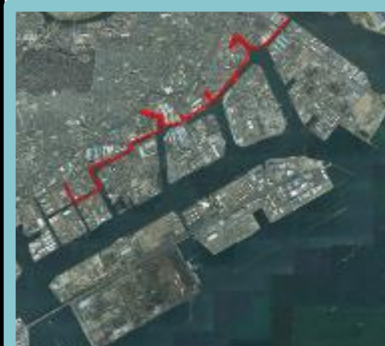
Calculating the Cost of Adaptation (I): Rising and reinforcement of levees to cope with SLR

Order program of Naka-river protection works (2012)

Levee protection works of Naka-river (at Katsushika)	**Length**	**159.4 m**
	Total Cost	**7.06 (100 million yen)**

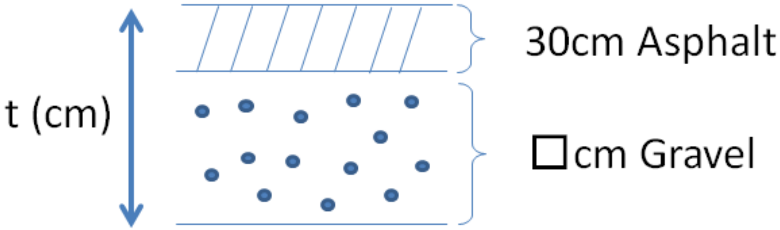
includes the indirect cost





	Tokyo	Kawasaki	Yokohama
Length	22.0 km	13.5 km	21.4 km
Cost (Unit: 億円)	974.3	597.9	947.8

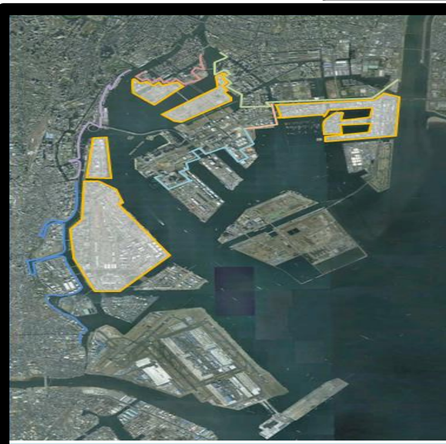
Calculating the Cost of Adaptation (I): Raising the ground level outside the levees



Unit cost Ministry of Land, Infrastructure, Transport and Tourism (2008)

Asphalt (30cm height)	**5,194 yen/m²**
Gravel (30cm height)	**296 yen/m²**

The areas that are selected according to the year of construction (before 1975)

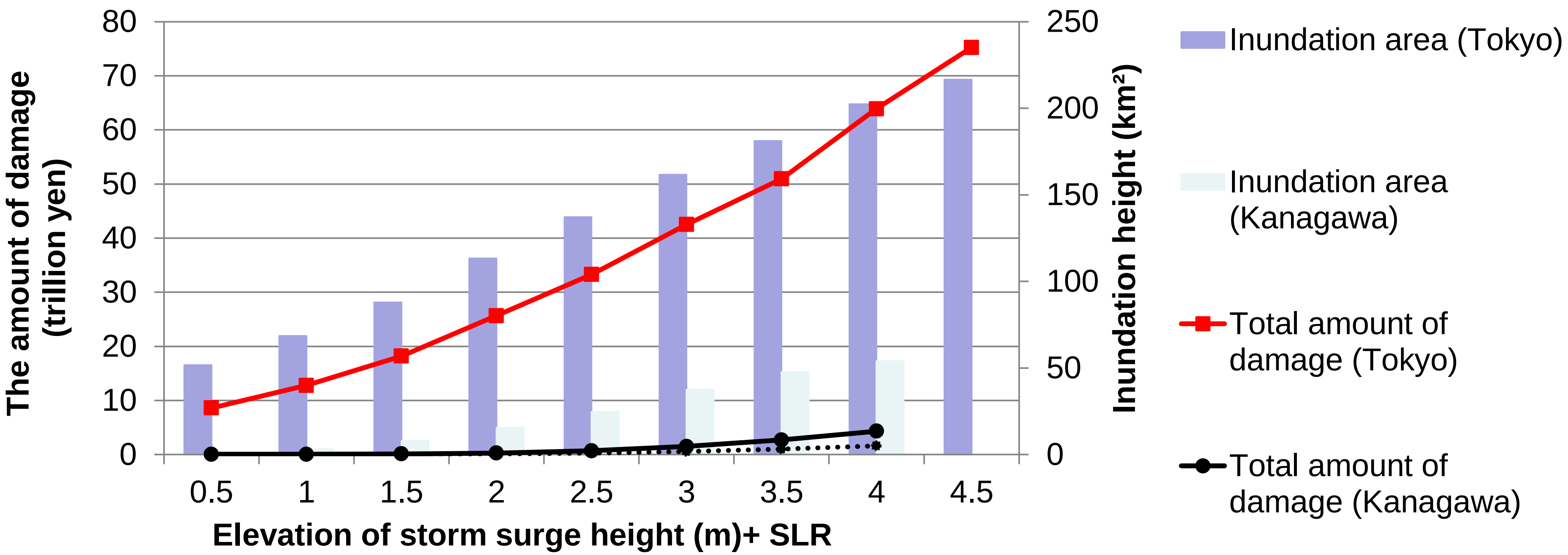


	Tokyo	Kawasaki	Yokohama
Area	11.9 km²	17.6 km²	8.5 km²
Height (T.P.)	4.5 m	4.0 m	3.9 m
Cost (Unit: 億円)	195.11	677.37	345.24

Risks and costs

Depending on SLR and storm surge scenarios, potentially between ~15-80 trillion yen of property could be affected in Tokyo and Kanagawa (~3-17% of GDP)

Cost of raising levees and land areas would be over 123 bn for Tokyo and 263 bn for Kanagawa (3.4bn USD, only including cost of materials, **NOT** cost of rebuilding all the buildings)



Hoshino, S., Esteban, M., Mikami, T., Takagi, H. and Shibayama, T. (2016) "Estimation of Increase in Storm Surge Damage Due to Climate Change and Sea Level Rise in the Greater Tokyo Area", Natural Hazards, Vol. 80 (1), pp. 539-565.

Tohoku and Land Subsidence (0.5 to 1m subsidence due to 2011 Earthquake)

Raising of Port Levels

Raising of Port Levels

Adaptation on a pharaonic scale? (Tsunami Layer 2 Measures)

Esteban, M., Onuki, M., Ikeda, I and Akiyama, T. (2015) *"Reconstruction Following the 2011 Tohoku Earthquake Tsunami: Case Study of Otsuchi Town in Iwate Prefecture, Japan"* in Handbook of Coastal Disaster Mitigation for Engineers and Planners. Esteban, M., Takagi, H. and Shibayama, T. (eds.). Butterworth-Heinemann (Elsevier), Oxford, UK

Shallow Breakwaters and Climate Change

Huge investments are being made to elevate the level of towns and villages along **<u>hundreds</u>** of kilometres of coastline

Elevation depends on town and the results of tsunami inundation models

In some cases towns are being elevated by 15m

It is thus possible to get around problems of sea level rise by elevating land, provided that you have enough money!

Conclusions

- **People WILL NOT MIGRATE just because they get their feet wet (contrary to what most people hypothesize)**
- **We ARE NOT GOING TO RETREAT from coastal areas (at least not those that are densely populated)**
- **If anything, we will probably *ADVANCE* on the sea!**
- **This is all VERY EXPENSIVE!**
- **However, all this will have a disproportionate effect on the POOR, who often inhabit areas most at risk**
- **Questions: esteban.fagan@gmail.com**