Report to the Ministry of Environment,

Republic of Maldives

Preliminary site survey of Kulhudhuffushi mangroves

18 May, 2019

Survey team

The survey was conducted by the following team:

1. Professor Joe S.Y. Lee, Director, Simon S F Li Marine Science Laboratory: School of Life Sciences, The Chinese University of Hong Kong; IUCN Mangrove Specialist Group
2. Dr Dan Friess, Associate Professor, Department of Geography, National University of Singapore; IUCN Mangrove Specialist Group
3. Mr. Alfredo Quarto, Founder and International Program Development Director, Mangrove Action Project
4. Mr. Jim Enright, Asia Coordinator, Mangrove Action Project
5. Mr. Ahmed Shan, Senior Environment Analyst, Environment Protection Agency, Republic of Maldives

The survey team was assisted by:

1. Dr Abdulla Naseer, Minister of State, Republic of Maldives
2. Ms. Ilham Atho Mohamed, Assistant Director, Ministry of Environment, Republic of Maldives
3. Mr. Saaif Mohamed Rasheed, Assistant Environment Officer, Ministry of Environment, Republic of Maldives

1. Background and brief

The wetlands of Kulhudhuffushi (1.02 km^2) are the 7th largest in the Maldives (5th National Report to UN CBD, 2015, pg. 21, https://www.cbd.int/doc/world/mv/mv-nr-05-en.pdf). This area likely includes a very small wetland system in the south of the island. The project to develop a domestic airport reclaimed 6.27 ha of land from the sea northwest side and east of Kulhudhuffushi Island. 12.04 ha was reclaimed from the wetland sensitive area of the island. (EIA report for Kulhudhuffushi airport development).

The airport was constructed on Kulhudhuffushi Island as part of an election promise under the previous government and started construction in October 2017. The runway was completed in 2018 but the airport is not yet completed as the terminal building, communications control tower and other facilities have not yet been built.

The Mangrove Action Project (MAP) a USA registered not-for-profit organization, first became involved in 2017 during a campaign initiated by civil society and groups within the Maldives, such as "Save the Maldives", to stop the airport from being developed which involved MAP writing a letter to former president Abdullah Yamin Abdul Gayoom expressing grave concern regarding the impact on the Kulhudhuffushi wetlands and proposing alternative solutions.

On 27 Feb. 2019 Alfredo Quarto, the cofounder of MAP and International Program Development Director via an initial telephone call to the new Minister of Environment H.E. Dr. Hussain Rasheed Hassan, interest was raised in conducting a collaborative investigation between MAP and the Ministry concerning the possibility to restore and conserve the remaining mangroves on the island of Kulhudhuffushi. After Dr. Hassen announced his intent to support such an international investigation into the status of the remaining mangroves on Kulhudhuffushi, Quarto invited Drs Joe Lee and Dan Friese, fellow members of the IUCN Mangrove Specialist Group (MSG), to join him, as well as MAP's Asia Coordinator Jim Enright on this project. Both MAP and MSG are dedicated to the objectives of conserving and restoring our planet's threatened mangroves, and the opportunity to work towards this directive at Kulhudhuffushi was of great interest to both organizations. Preparations were started for the MAP – MSG team to visit the Maldives 11-13 April, 2019 amid local reports that the remaining mangroves were under threat, the water body drying-up and a large fish kill had occurred, at Kulhudhuffushi.

Our brief mission, as communicated to us by the Minister of Environment H.E. Dr. Hussain Rasheed Hassan, at a pre site visit meeting at the MoE on 11th April was to establish the facts surrounding Kulhudhuffushi, and based on this provide suggestions to the range of potential solutions that could be implemented. We note that this visit was conducted over a short period of time with limited

information. We also note that this visit was conducted during the dry season, so we have not seen the full hydrological variability of Kulhudhuffushi across the year or even the monthly tidal lunar cycle.

Another challenge was there was very little base-line data available to understand changes that may have been caused by the airport development. For example, a salinity reading of 60 which we recorded in the southern waterbody may have been fairly normal for that time of year or may have been higher than pre-airport development but this could not be determined as there was no previous comparative salinity data available.

2. Why is the Kulhudhuffushi wetland important?

Most of the world's mangroves are found in large patches along muddy shorelines such as estuaries and deltas. Low sediment, oceanic yet landlocked mangroves such as Kulhudhuffushi are globally unique and poorly studied. Even though the mangroves of the Maldives are often found in small patches, they can still provide a range of important benefits to local communities and surrounding environment, and as such they should be conserved wherever possible (Curnick et al., 2019). We expect Kulhudhuffushi, as do mangroves in general (Lee et al. 2014), to provide a number of benefits to the neighboring community and Kulhudhuffushi island more broadly:

- Kulhudhuffushi is a key area to help increase **groundwater storage**. Rainwater infiltration into groundwater is less efficient in built up areas with impervious hard surfaces and rapid runoff, and more efficient in natural surfaces such as the mangrove and waterbody where surface water can infiltrate into the ground (Harvey and Odum 1990, Holliday et al. 2007). Increasing groundwater storage is a key priority for communities who heavily rely on water from wells with few other options other than expensive desalination or importing water.
- **Flooding reduction** during the rainy season – runoff from airport: wetlands such as mangrove forests, unlike paved surfaces, act as buffers for floods due to the high permeability of their soil (Deb and Ferreira 2017, van Wesenbeeck et al. 2017). As the mangroves and the adjoining waterbodies are the lowest elevation on the island they act as an important catchment and storage area for rainwater runoff. With more hard surfaces from developments and a reduced water catchment area due to wetland filling for the airport rapid runoff during periods of heavy rain will increase the risk of flooding.
- **Nursery function** and the importance of connectivity: mangrove forests serve as nursery habitats for many species of coral reef fish (Dorenbosch et al. 2004; 2005). Larval and juvenile fish seek shelter from predators and adverse physical conditions from mangrove forests that are hydrologically connected to their adult reef habitat. Preservation of these

forests and their connectivity with the reef will therefore sustain the diversity and productivity of fish beyond the mangroves.

- **Mangrove soils can act as filters and trap sediments**, absorb certain levels of nutrients from sewage and runoff and also lock-up heavy metals, therefore help maintain water quality (Tam and Wong 1994, Wang et al. 2010). The airport will be a new source of pollution and new developments will mean untreated runoff from urban areas.
- **Mangroves are effective in mitigating climate change**, as they are very efficient in soaking up carbon dioxide from the atmosphere and storing it in their biomass and soils. This is important when scaled up to all the small mangrove patches across the Maldives. It is also important in countries such as the Maldives that do not have a lot of other vegetation types that can efficiently sequester carbon from the atmosphere. Other countries with similar small and patchy mangroves have shown that these habitats can contribute substantially to national targets for climate change mitigation; for example, Singapore's patchy mangroves store 1.6 million tonnes of CO_2-e (Friess et al., 2016), and this can contribute to Singapore's Nationally Determined Contributions required under the Paris Agreement.
- **Mangroves provide a range of cultural benefits**, from recreational and educational opportunities, to spiritual and religious benefits. A range of cultural and spiritual benefits of Kulhudhuffushi were described to us during the site visit; for example, we were told how people cover themselves in mangrove mud during Eid.

There are evident local economic benefits towards local livelihood and income from the existing traditional coconut husk coir rope making that provides a flexible hour home-based income for over 400 women. It seems quite significant and provides good incentive to conserve the remaining waterbody and the adjacent mangroves where the coconut husks are soaked and prepared for the coir rope manufacture.

Statistics on coir-rope weaving in Kulhudhuffushi

- • 404 - families' livelihoods depend on it
- • 1,806 - working coconut husk-pits for soaking coconuts in mangrove brackish water
- • 4,848 - bundles of rope produced monthly
- • MVR 726,200 monthly income from rope-weaving
- • MVR 8.7m annual income
- Reference: *Kulhudhuffushi Zuvaanunge Jami*yya (English translation: Kulhudhuffushi Young People's Association)
- NOTE: data was collected before the airport construction occurred

In recognition of their biodiversity and the benefits they provide to Maldivians, Kulhudhuffushi is on the Environment Ministry list of 200 important sites. However, Kulhudhuffushi is not on the Ministry of the Environment's 2019 list of 50 Protected Sites or a Ramsar wetland (the Maldives is not a signatory to the Ramsar Convention).

Local women engaged in coir rope production at Kulhudhuffushi.

3. General observations

During our 2.5-day visit to Kulhudhuffushi we conducted site visits to the waterbodies north and south of the runway. We also visited the small mangrove patches to the south of the island, and the newly protected island of Keylakunu as a reference site where mangroves have been largely preserved. On these site visits we recorded general observations of mangrove health and status, and measured surface water and porewater salinity in various locations.

Mr. Shan of the EPA conducted a drone survey of the mangrove and waterbody area to collect true color aerial photography and create a Digital Elevation Model (DEM) of the area. This information was key to allow us to understand elevations at different locations around the study site, which are required in order to understand where different options can take place. To create the DEM the drone survey was supplemented with elevation measurements from an RTK GPS. However, this data is still unavailable at the time of preparation of this report so the options suggested are made without this knowledge.

To understand community viewpoints, we held several meetings with various groups during our visit. These included meeting with the Island Council President, representatives from the community (20 participants) at the Island Council office, and a group of women coconut coir rope makers (45 participants) one evening at a MI college. A BBQ hosted by the local environmental youth group, BeLeaf, provided an opportunity to chat with members about their efforts to protect the mangroves on Kulhudhuffushi and nearby islands in the Atoll.

The team meeting with the Island Council president (left) and conducting on-site measurements at the lagoon (right)

Regarding our general observations on ecology, the dominant species at Kulhudhuffushi was *Lumnitzera racemosa.* There was also evidence of healthy *L. racemosa* colonizing on the dredged spoil for the runway that ended up flowing adjacent to the existing stand on the south side. The mangrove generally were in good health, with little leaf discoloration (reflecting stress in some mangrove species) and a moderate amount of insect damage to leaves; some individuals were flowering. This was encouraging, as our earlier communications suggested that the mangrove vegetation was at risk due to the altered hydrological conditions.

Lumnitzera racemosa *in flower at Kulhudhuffushi.*

Our general observations on hydrology indicated that water flows within the southern part of Kulhudhuffushi have been fundamentally and irreversibly altered by the construction of the runway. This has led to several issues, most important of which is that the water level in the higher elevation southern waterbody is now substantially lower during the dry season. This leads to bad odors and increased availability of mosquito habitat. It also leads to fish kills: fish would have previously moved to the deeper water of what is now the northern waterbody, but this route has been blocked by the runway. Our site visit suggested that the hydrology in the deeper northern waterbody is currently OK, so our recommendations below to fix hydrology refer to **the southern waterbody only.**

Our general observations on community and socio-economic aspects during informal exchanges as well as organized public meetings with various stakeholders suggested diverged views on the wetland's future. This difference in views is not surprising for a community that comprises many walks of life, with their livelihoods contingent on the various management options for the wetland. We can, however, conclude from the community meetings that there is no one overwhelming view on the future of the wetland.

4. Summary of issues currently facing Kulhudhuffushi

Many of these issues are not caused by the mangrove wetland itself but exacerbated by the construction of the runway. **These are not natural issues inherently associated with the mangrove wetland.** The runway has fundamentally changed the hydrology of the area and has caused or exacerbated the following issues:

All year round

- Dumping of waste is a very serious issue
- Illegal cutting: recent as well as historical cutting of mature *Lumnitzera racemosa* trees was evident in the forest (Fig. Y). While it is not clear who felled the trees and for what purpose, continued cutting would pose a strong threat to the long-term viability of the forest

During the dry season

- Bad odors from the lagoon due to poor water quality and fish kills
- Low water levels leading to fish kills due to high temperatures, higher salinity and resulting low dissolved oxygen levels
- As the water level drops, birds causing danger to aircraft landing or taking off from the airport (particularly to migratory birds present December to March)
- Loss of coconut husk soaking area
- Poor tasting groundwater and groundwater with strong hydrogen sulfide odor

A mature Lumnitzera racemosa *tree found cut down very recently before our field visit*

There was evidence of significant past cutting of trees in the mangrove forest

At the beginning of the rainy season

- Mosquitoes (but **not** the dengue mosquito *Aedes aegypti*, which prefers stagnant freshwater for breeding): the solid waste dumped within and near the mangrove including plastic bottles, cans and containers provide freshwater breeding sites for mosquitoes
- Fish kill due to heating and low water level resulting in low dissolved oxygen levels in the dry season would promote mosquito breeding during the subsequent wet season. A healthy fish population would normally help reduce mosquito larvae abundance

During the rainy season

- Increased risk of flooding: with the connectivity with the ocean blocked, any rain exceeding the buffering capacity of the lagoon will spill over to areas around the site

Issue	Potential solution (including short-term remedies)	Option
All year round		
Dumping of waste	Improved awareness/ signage/ management/enforcement	1
Illegal mangrove cutting	Improved awareness / signage management/enforcement	1
During the dry season		
Bad odor from the lagoon	Restore hydrologic connectivity/ management?	1,2,3
Low water levels leading to fish kills	Temporary placing diesel or electric powered mechanical aerator(s) paddle wheels to increase dissolved oxygen levels; Permanent solution may include excavating a small deeper pool within the southern waterbody where fish can shelter in cooler water	2,3
Birds and the airport (particularly December to March)	Requires in-depth study by ornithologist familiar with airport requirements; steeper waterbody shore edge to reduce waders; air canon to scare birds; trained falcon to scare birds from runway area are all possible partial solutions	1,2,3
Loss of coconut husk soaking sites	Island council could create a special area by the government constructing soaking pits which would eliminate the need to cut mangroves for pit marker posts and mangrove branches for weights to keep husks submerged for 3-4 months	1,2,3
Bad tasting groundwater	Maximize fresh groundwater recharge areas; Use building roofs for rainwater harvesting; Use water filtration system including activated carbon to improve drinking water quality	1
At the beginning of the rainy season		
Mosquitoes	Increase awareness of removing mosquito breeding sites which includes removal of solid waste and litter; restore hydrologic connectivity; restock water bodies with suitable fish species to reduce mosquito larvae abundance	1,2,3
During the rainy season		
Increased risk of flooding	Hydrologic connectivity with the ocean through a sluice gate	2,3

Table summarizing the major management issues concerning Kulhudhuffushi and how these may be addressed by the three suggested management options (see section on options below)

5. Objectives

The objective of our recommendations is to achieve sustainable management while optimizing the beneficial services that are potentially supported by the Kulhudhuffushi wetland, given the airport development. The following options are proposed to fix issues caused by the existing runway as well as to mitigate future impacts of a completed airport.

6. Options for Kulhudhuffushi

Option #1 – improved management of the remaining mangrove and the lagoon waterbody area

The mangrove trees in Kulhudhuffushi are in generally good condition, as was reflected by flower production and natural recruitment occurring after runway construction. The trees did not show significant signs of physiological stress, e.g. yellowing of leaves, wilting. Given that our survey was conducted towards the end of the dry period, these observations suggest that the mangroves likely had access to low-salinity groundwater for alleviating salinity stress. This hypothesis is supported by the relatively low salinity values (30-32) recorded in the porewater inside the mangrove forest.

The local resident group and the coconut husk coir rope group both raised the issue of people dumping rubbish in and near the mangroves due to a lack of a proper waste management collection system in place.

Water quality, breeding sites for mosquitoes are the issues of most concern to local people.

There were cut stems and stumps from previous mangrove cutting, especially within the southern portion of the mangrove forest, as well as evidence of recent cutting of large healthy *Lumnitzera racemosa* with the chopped tree laying on the ground awaiting removal. Other mangrove species, including *Rhizophora mucronata* (this species could have been misidentified in previous studies – probably *R. stylosa*) and *Bruguiera cylindrica*.

Trash management and enforcement is needed.

The Council should take the lead in this but mentioned they require help from MoE to establish the waste transfer site on the island. The Council President also said he needed information to persuade the community to participate in a waste recycling and collection program.

<u>Education</u>

Introduce and adapt MAP's Marvelous Mangrove Curriculum to the public schools there, thus raising children's awareness so they can become better mangrove stewards.

Reasons for the recommendation:

Raising awareness via education and public is essential, if effective mangrove wetland management is to succeed. There are many misconceptions that promote reclamation of the remaining mangroves and waterbodies. Mosquito-borne disease threats, for instance, are not substantiated by fact, as salt-water mosquitoes are not the ones responsible for dengue fever, and are relatively less significant as a vector for malaria, whereas freshwater mosquitoes do pose such threats.

Expected environmental impacts:

Increased wild fish production, more stable soil with less erosion, increased carbon sequestration and long-term storage, a counter force to rising sea levels, vital water recharge and some flooding protection.

Expected impacts to people:

Less smelly water, fewer fish die-offs, sustain such local traditional industries as coir rope manufacture, keep traditional livelihoods alive, better organized local participation in future such challenges.

Issues to consider:

- While this option will reduce odors and mosquitoes, it will not completely eliminate them, as these issues are part and parcel to tidal wetlands. The current issues of smell and mosquitoes have been exacerbated by the modified hydrology.
- Making sure seawater does not seep into the groundwater is important, which can be caused by over-pumping the groundwater source beyond the natural recharge capacity. Implementing an island-wide water use conservation program will help extend the groundwater capacity and help improve future water security. This needs to include use of low flush toilets, showers, faucets and a restriction on non-essential uses such as garden irrigation.

Option #2 – channel to connect the southern lagoon to the sea

A new channel connecting the southern lagoon to the ocean may help restored tidal connectivity and help rehabilitate the mangroves into a functional wetland. A rough estimation suggested that a channel of at least ~300 m will be necessary. Given that the tidal range is only ~1 m, and the lagoon's elevation is considerably higher than that of the beach, any channel constructed will need a sluice gate (see option 3) to enable water level and flushing control. The team has conducted a quick survey of the forest area between the southern lagoon and the beach. The forest is a mixture of mangrove and beach forest species. If this option is taken, the channel should be constructed along the road, not

through the existing mangrove area, for easier construction and less damage to the mangrove forest. This option was also suggested by the Island Council.

Reasons for the recommendation:

- This option will be relatively less costly and provide direct solutions to many issues, such as mosquitoes, fish die-off, flooding and tree damage
- Although some hydroperiod management will still be necessary to avoid or minimize the above issues while enhancing the beneficial services of the wetland, the level of management will still be less intensive compared to that required for option 1

Expected environmental impacts:

- Some damage to the forest will result from channel construction
- Improved water level and hydroperiod control of the southern lagoon
- Water quality will be maintained to reduce issues of mosquito infestation, fish kill or odor r
- A reasonable level of biodiversity (e.g. fish, crustaceans) will be supported by the lagoon, albeit at a lower level compared to the beach area
- Long-term sustenance of the mangrove wetland
- Water level management through initial site and channel design as well as sluice gate operation will be necessary to maximize benefits and reduce potential problems, e.g. attraction to birds

Expected impacts to people:

- Reduced concerns about odor, mosquitoes and fish kills
- Potential site for recreational, e.g. kayaking, fishing, or educational activities
- Allow use of the lagoon for traditional activities such as soaking of coconut husks for coir rope manufacture

Issues to consider

- We considered a long underground culvert but it would be difficult to maintain it due to siltation and breakage due to soft soil causing shifts.
- Someone needs to determine the max. water body level as the channel needs to be constructed to that precise elevation and cannot be easily adjusted lower once constructed
- The gradient between the high elevation mangrove/lagoon and the lower elevation beach presents an engineering challenge for water inflow into the site.
- Harbor on the west coast may also expand north.

A channel of ~300m (yellow arrow in photo above – exact position to be determined) connecting the ocean and the lagoon could help restore some hydrologic connectivity and reduce many of the management concerns at Kulhudhuffushi

Option #3 – sluice gate in the south

There is an example of this on Fuvahmulh (‘fourmalah’). The ~300 m distance is similar. The sluice gate would enable water flow and level control to achieve many of the beneficial uses of the wetland, such as flood and bird control and habitat for fish.

Reasons for the recommendation:

One-way drainage system would prevent flooding and keep the water body at a desired level to reduce problems with birds at airport.

Expected environmental impacts:

Less odor, less fish die-offs, mangrove health sustained

Expected impacts to people:

Less chance of flooding, continuation of local livelihoods options such as coir rope manufacture, more stable fresh water recharge

Issues to consider

- Maintenance and operation – who will do this?

- Water level and hydroperiod management requires some training to get it right, e.g. prolonged flooding could kill mangroves

Other options were discussed, including future economic uses of the area, but the presence of an airport precludes this.

7. Other considerations

There are several other considerations that must be investigated regardless of the final option chosen.

- We need to know the groundwater dynamics that are supporting the mangrove. We still do not know the location of the groundwater reservoir and its connection with the lagoon. But maybe that could be enough to tide it over during the dry season.
- May want to consider deepening part of the waterbody. The Island Council suggested this as a way to reduce fish kills. While potentially desirable, this would generate a large amount of spoil. However, considering what can be done with the dredge spoil is outside the scope of this report.
- Need a better understanding of the bird dynamics, suggest consulting with knowledgeable ornithologists.
- Some of these issues could have been mitigated earlier if the EIA statement had been followed. There is also the requirement that the developer would be required to perform ex-situ compensation, i.e. protect another patch as required by the EIA statement.
- Any major works resulting from these recommendations should have an associated EIA or similar.
- Decision could be delayed until at least the end of the next wet season because the problems that have surfaced in the past few months mainly arose because of the falling water level. This would give sufficient time for all stakeholders to consider all possible options
- Decision should involve the community. Greater and more representative public consultation (including women). Additional small group/individual perception surveys should be conducted so that people feel comfortable giving their opinion without community pressure. The community also needs sufficient notice of any planned works. For example, the coconut coir rope makers need at least three months' notice to remove their husks from the waterbody if major works are planned.

8. Options that should not be pursued

We do not recommend the following options:

Reclaiming Kulhudhuffushi

With the runway already in place, it may be a tempting option to reclaim whole wetland. This decision will have profound environmental and socio-economic implications for the lagoon as well as the island, and could result in reduced groundwater recharge, more flooding, and poor building quality due to subsidence.

Connecting the north and south lagoons under the runway

We considered options that would connect the two remaining parts of the lagoon to replicate how it used to be. Options could include culverts under the runway. However, we do not see this as feasible as we assume there are load bearing regulations for the runway. This connection of the two waterbodies should have occurred during the construction of the runway and should have been an EIA requirement.

9. Next steps

As the digital elevation data are not available during the preparation of this report, the feasibility of options 2 and 3 cannot be established. It is imperative that the final decision will benefit from a digital elevation model built on the survey data. In the meantime, we recommend the following actions:

- Enforcement on clamping down illegal dumping and cutting activities should be implemented straight away to avoid further deterioration of the wetland. If left uncontrolled, these illegal activities will degrade the wetland and make excuse for its eventual destruction.
- When the digital elevation data are available, consult a hydrological/ civil engineer for options #2 and #3 for the technical construction requirements which will then determine the costs involved.

Wider consultation involving all stakeholders should be conducted to match engineering options with environmental as well as socio-economic objectives. The support of the local community is of important concern, as their active participation in the management of the lagoon will strongly influence its chance of success.

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References

Curnick D, Pettorelli N, Amir A, Balke T, Barbier EB, Crooks S, Dahdouh-Guebas F, Duncan C, Endsor C, Friess D, Quarto A, Zimmer M, Lee SY. (2019). The value of small mangrove patches. *Science* 363, 239.

Deb M, Ferreira CM (2017) Potential impacts of the Sunderban mangrove degradation on future coastal flooding in Bangladesh. *Journal of Hydro-Environment Research* 17:30-46.

Dorenbosch M, van Riel MC, Nagelkerken I, van der Velde G. (2004). The relationship of reef fish densities to the proximity of mangrove and seagrass nurseries. *Estuarine Coastal and Shelf Science* 60:37-48

Dorenbosch M, Grol MGG, Christianen MJA, Nagelkerken I, van der Velde G. (2005). Indo-Pacific seagrass beds and mangroves contribute to fish density coral and diversity on adjacent reefs. *Marine Ecology Progress* Ecology :63-76

Friess DA, Richards DR, Phang VXH (2016). Mangrove forests store high densities of carbon across the tropical urban landscape of Singapore. *Urban Ecosystems* 19, 795-810.

Harvey JW, Odum WE (1990). The influence of tidal marshes on upland groundwater discharge to estuaries. *Biogeochemistry* 10:217-236.

Holliday D, Stieglitz TC, Ridd PV, Read WW (2007). Geological controls and tidal forcing of submarine groundwater discharge from a confined aquifer in a coastal sand dune system. *Journal of Geophysical Research-Oceans* 112:-.

Lee SY, Primavera JH, Dahdouh-Guebas F, McKee K, Bosire JO, Cannicci S, Diele K, Fromard F, Koedam N, Marchand C, Mendelssohn I, Mukherjee N, Record S (2014) Ecological role and services of tropical mangrove ecosystems: a reassessment. *Global Ecology and Biogeography* 23:726-743.

Tam NFY, Wong YS (1994) Nutrient and heavy-metal retention in mangrove sediment receiving waste-water. *Water Science and Technology* 29:193-200.

van Wesenbeeck BK, de Boer W, Narayan S, van der Star WRL, de Vries MB (2017) Coastal and riverine ecosystems as adaptive flood defenses under a changing climate. *Mitigation and Adaptation Strategies for Global Change* 22:1087-1094.

Wang M, Zhang J, Tu Z, Gao X and Wang W (2010) Maintenance of estuarine water quality by mangroves occurs during flood periods: A case study of a subtropical mangrove wetland. *Marine Pollution Bulletin* 60:2154-2160.