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Mangrove proliferation and saltmarsh loss in the Hunter Estuary

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The Hunter Estuary is in a state of ecological crisis. The diverse mosaic of vegetation communities that previously existed in the estuary is rapidly degrading into a mangrove monoculture with a consequent loss of biodiversity. It is concluded that deepening the harbour and harbour channels by dredging, has led to a considerable increase in the tidal range in the estuary. This is considered the main mechanism responsible for the rapid landwards incursion of mangroves into, and displacing, the saltmarsh community. In order to restore the balance between mangrove and saltmarsh communities, it is proposed that existing floodgates be managed adaptively to manipulate tidal inundation. In addition, in areas where critical shorebird habitat is under threat of mangrove encroachment, flow-control structures should be constructed to manage tidal flow into the remaining uncontrolled tidal creeks, downstream of Hexham Bridge.

INTRODUCTION

Mangrove proliferation and the concomitant loss of the saltmarsh community is a phenomenon recognized throughout southeast Australia. This trend is more pronounced in developed estuaries (Saintilan & Rogers 2002). Therefore, it should be no surprise that the Hunter Estuary, the most developed estuary on the New South Wales coast, is experiencing serious ecological changes (**Figure 1**). The process is now so rapid that the estuary is in danger of becoming a monoculture of mangroves within a few years, with all the resulting problems related to loss of biodiversity.

Since the 1950s mangroves have increased in area from about 1300ha to about 1700ha, despite the loss of 240ha to industrial and urban development. At the same time, the original saltmarsh area of 2133ha, was reduced by 67% (1428ha) by 1994 (Williams *et al.* 2000). Since then, this trend has continued and, in some areas, perhaps at a more rapid rate (personal observations). Saltmarsh is now listed as an endangered community. This trend together with the previous loss of saltmarsh and mangroves from the extensive Hexham Swamp and Tomago Wetlands, by the closure of floodgates during the 1970s, has put tremendous pressure on the ecological integrity of the Hunter Estuary that increasingly resembles a canal system. Many people see changes in the estuary as a natural progression. However, the Hunter Estuary, originally a shallow estuarine delta, is being transformed into a deep-water industrial harbour that is now the largest coal-exporting port in the Southern Hemisphere. Myriads of estuarine islands, separated by winding tidal creeks, have been amalgamated into one super-island, Kooragang Island. As a result more than half of the original estuarine shoreline has been lost. Most of the flanking intertidal floodbasins have been closed off by floodgates that have never been opened since installation. The prawn and fish industry has suffered and migratory shorebirds visiting the estuary have declined in numbers from more than 10,000 during the 1970s to about 3,500 as their habitat has degraded. The Hunter Estuary is no longer a pristine wilderness that can be left to “natural processes”. Natural processes have been overwhelmed by “progress”. The estuary is man-modified and must now be managed by man to achieve positive outcomes for the biodiversity that remains.

A number of authors have suggested various reasons for the changes, but have generally concluded that that there is no *single* explanation for *all* estuaries in southeastern Australia. Without a definite explanation there has been no attempt to suggest alternatives for controlling the changes, if indeed that is possible or even desirable. The purpose of this discussion is to briefly review suggested reasons for mangrove proliferation and saltmarsh loss and to discuss the most likely mechanism for these changes as it relates to the Hunter Estuary. Remediation measures are also suggested.

DISCUSSION

Mangrove and saltmarsh communities occur in a restricted, narrow, vertical zone determined by local tidal variations above and below mean sea-level. In the Hunter Estuary this vertical zone measures less than two metres at the mouth and decreases rapidly upstream. Mangrove and saltmarsh communities flourish in sedimentary environments undergoing active deposition. These environments are essentially flat with very low gradients between areas of extremely low relief. Therefore, even slight changes to tidal amplitude and/or relative sea-level have a large effect on the horizontal distribution of these environments.

The following discussion reviews various mechanisms proposed to explain the proliferation of mangrove and the simultaneous loss of saltmarsh as they relate to the Hunter Estuary and compares them with the views expressed here that tidal range increase is the main causal mechanism for the ecological problems now manifest in the estuary.

Several possible mechanisms for mangrove incursion into former saltmarsh habitat have been discussed in the past:

- Precipitation;
- Agricultural practices;
- Sedimentation and nutrients;
- Subsidence;
- Global sea-level change and
- Altered tidal regime.

These points are used for the following discussion concerning the Hunter Estuary.

Precipitation

In southeast Australia average annual precipitation has increased since 1945 (Pittock 1988, in Saintilan & Williams 1999). It was suggested that hypersaline conditions within saltmarsh soil could be diluted sufficiently to allow mangrove colonization. In an area of mangrove expansion in the Hunter Estuary, Buckney (1987) noted a loss of vigour following an *El Nino* drought period in 1982, leading him to believe that increased rainfall may have contributed to initial mangrove expansion. If this is so then there should be a noticeable decline in the health of mangroves that have developed since then in relation to the present prolonged drought that is now regarded as the most severe in the last 100 years. Contrary to this expectation mangroves are vigorously expanding their range at what appears to be an increasing rate (personal observations). In addition, a large area of saltmarsh on Area E, Ash Island (western part of Kooragang Island, **Figure 1**), suffered no mangrove incursions during this period. However, during the late 1990s mangroves did rapidly encroach and displace saltmarsh within only a few years, but only after creek culverts were removed allowing increased tidal flushing. This effectively decreased the hypersalinity of the saltmarsh soil, as additional rainfall was predicted to do. But over the very short period of only a few years, the reduced salinity was much more likely to have been the direct result of opening the area up to full local tidal amplitude (especially as this ongoing process was taking place during a prolonged drought).

It is considered that increased rainfall has had no significant effect on mangrove proliferation and saltmarsh loss in the Hunter Estuary.

Agricultural Practices

It has been suggested that mangroves may have recolonised areas previously cleared of mangroves in the past in Moreton Bay (Morton 1994). This may well be the case for parts of Ash Island that were cleared for dairy farming in the late 1800s. It has also been observed in those areas that grazing cattle prevented mangrove propagules from establishing into mature plants. Continuous cattle grazing would then keep these areas free of mangroves. On the other hand, withdrawal of cattle from areas on Ash Island, particularly Area E and Milhams Pond, has seen the sudden proliferation of mangroves over wide areas of saltmarsh that previously never supported mangroves. Thus, it is considered that grazing by cattle has merely served to delay the spread of mangroves until recently, in contrast to areas where mangrove proliferation has been occurring for the past 30 years or more in areas that have never been grazed (e.g. Kooragang Nature Reserve).

In the past mangrove branches have been utilized to construct racks for oyster farming and may also have been used as fuel for burning shells for lime manufacture. The extent of these activities has not been investigated here, but they were probably more commonly carried out in the North Arm of the Hunter River from Fern Bay to Sandy Island where oyster leases are still present and where dredging of oyster banks for shells was practiced.

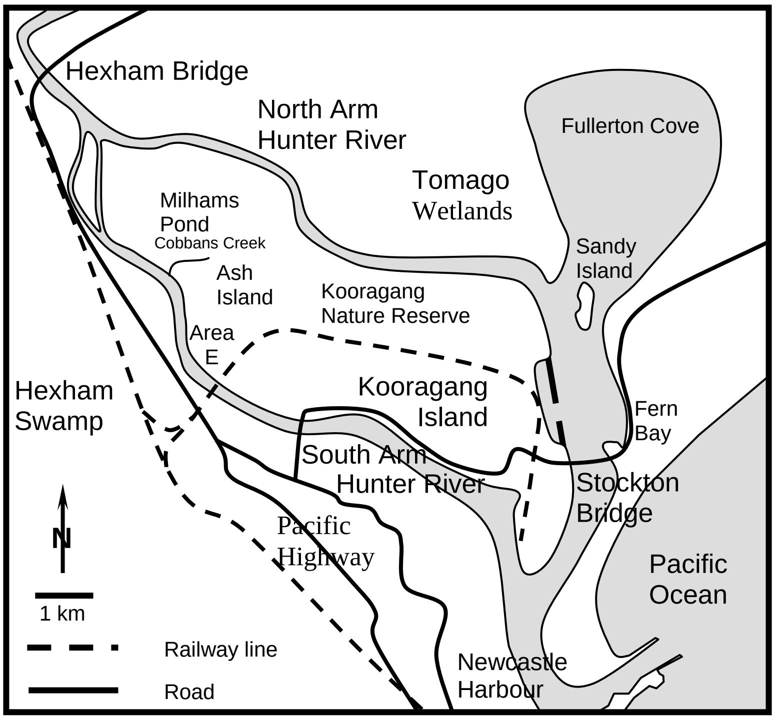

Figure 1. In the lower part of the Hunter Estuary a maze of former estuarine islands has been amalgamated into one super-island called Kooragang Island. Dredging has converted the shallow estuarine delta into a deep-water port by deepening the seaward end of the South Arm, Newcastle Harbour and the entrance channel.

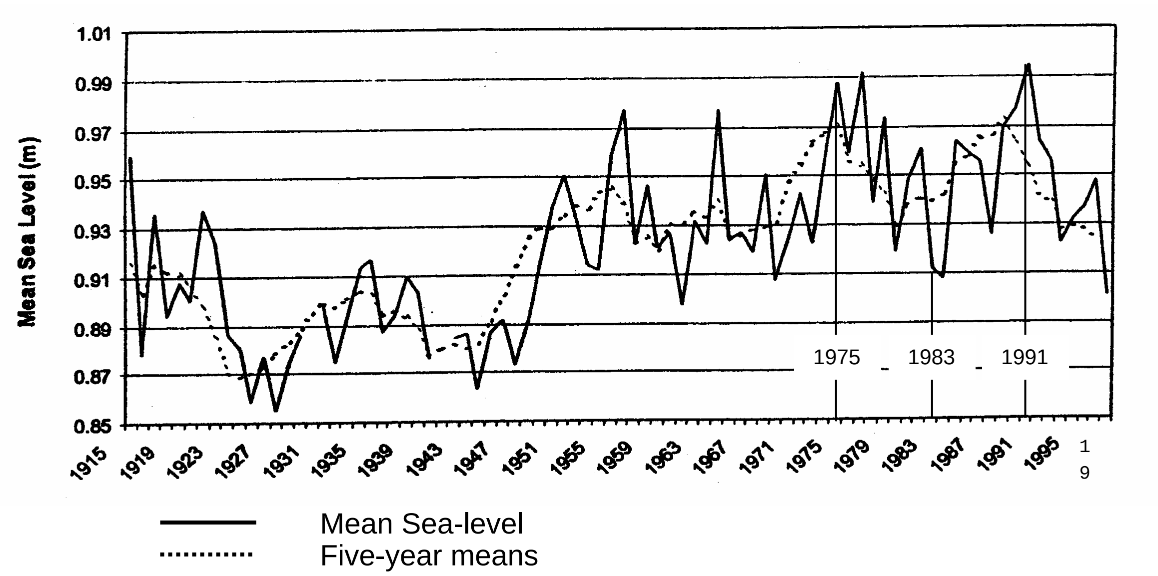

Figure 2. Sea-level trends at Fort Denison, 1915-1998 (modified from Saintilan & Wilton 2000). The five-year means sea-level curve, if smoothed even more, appears to be a sinusoidal curve with a periodicity of about 80 years.

Other areas where mangrove destruction probably took place in the lower part of the estuary are now covered by industrial development or housing.

It is evident that agricultural practices, where cattle grazing is continuing, have *prevented* mangrove expansion. The sudden expansion of mangroves in areas of saltmarsh where cattle have been removed merely indicates that grazing has delayed the ongoing proliferation of mangroves compared to areas never grazed. In fact these areas have probably experienced an accelerated growth of mangroves that has tended to catch up with the steadier proliferation of mangroves elsewhere.

Sedimentation and nutrients

Saintilan & Williams (1999) suggested that fresh nutrient-rich sediment promotes the establishment of mangrove propagules in the upper intertidal environment. This is certainly a possibility for the Hunter Estuary, which has a largely cleared, agriculturally developed catchment. However, most of the clearing and subsequent sediment mobilization would have taken place in the late 1800s and early 1900s, not during the later part of the 1900s when the most significant mangrove proliferation commenced. In addition, it would be expected that mangrove proliferation should have been rapid following the 1955 floods with the accompanying sedimentation. But, it was not until the 1970s that mangroves were noticeably increasing their range. While it is possible that sedimentation and nutrients would assist the spread of mangroves the mismatch in timing is not convincing for this to be a major cause. In addition, Saintilan (2003) suggested that nutrient addition may only contribute by increasing luxuriance of the mangrove seedlings and does not contribute to mangrove establishment.

Subsidence

In an active depositional estuary subsidence is usually offset by vertical aggradation (sediment deposition). If the rate of sedimentation exceeds the subsidence rate the estuarine delta advances seawards. If the rate of sedimentation is lower than the subsidence rate the estuarine delta retreats as it is increasingly inundated. In the latter case, net subsidence of the estuarine surface has the effect of a relative sea-level rise and may therefore contribute to mangrove transgression (landward encroachment). Conversely, if the estuarine surface increases in elevation mangroves should retreat.

Rogers *et al.* (2006) found that on Kooragang Island the rate of sediment accretion was about twice the rate of subsidence caused by sediment compaction in areas of mangroves, and mixed mangroves and saltmarsh, resulting in a net increase in surface elevation. In saltmarsh, increased surface elevation mostly resulted from sediment accretion and was little affected by subsidence caused by compaction.

These findings indicate that surface elevation had increased and that mangroves should not, therefore, find conditions suitable for proliferation. Indeed they should be in retreat in that area. The area studied was described as an area of "… minimal mangrove expansion …" which is not surprising. In order to provide a clearer picture of the role of subsidence and sediment accretion in relation to mangrove expansion in the Hunter Estuary it is necessary to sample areas of rapid mangrove expansion, not areas of minimal expansion. In fact, other areas studied by Rogers *et al.* (2006) in estuaries with rapid mangrove encroachment into saltmarsh had sediment accretion rates that did not translate to a net increase in surface elevation (equivalent to a relative sea-level fall).

In view of the above discussion, the role of subsidence contributing to mangrove proliferation is not supported in the Hunter Estuary. However, the few locations studied may not be representative of areas of rapid mangrove proliferation.

Global sea-level change

Saintilan & Williams (1999) noted that eustatic (global) sea-level rose during the last century and that small increments in sea-level translate … *"into substantial alterations in the frequency of [tidal] inundation over wide areas, and this may be one factor contributing to mangrove incursion upon saltmarsh"*.

From Fort Denison sea-level data, Saintilan & Wilton (2001) suggested that mean sea level had been 4cm higher for the period 1950-2000 than for the first half of the century (**Figure 2**). Saintilan & Williams (1999) implied that eustatic (global) sea-level rose by about 5cm during the 1900s and Saintilan & Rogers (2002) stated that it had risen by 7cm. MHL (2004) states that there has been 4.5cm rise in sea-level since the 1950s. However, whatever the real sea-level rise has been, the full rise would be experienced only at the mouth of the Hunter Estuary and would decrease progressively upstream to perhaps only a couple of centimetres between Stockton and Hexham Bridges.

It is interesting to note that the sea-level curve in **Figure 2**, if smoothed even more than the dotted five-year means, is actually a sinusoidal curve with a periodicity of about 80 years, virtually coincident with the period chosen for the chart from 1915 to 1998. This observation has several implications in attempting to relate global sea-level to mangrove proliferation. Although, according to the chart, five-year-mean sea-level was 4cm higher during the late 1900s, the five-year-mean sea-level in 1998 was only about 1cm higher than it was in 1915. Furthermore, the *mean* sea-level was, in fact, about 6cm lower in 1998 than it was in 1915! Also sea-level during the latter 1900s was, for most of the time, less than the sea-level in 1915. In addition, if the sinusoidal curve is projected back in time, to before 1915, it implies that sea-level during the latter part of the 1800s was similar to the elevated levels during the late 1900s. However, there is no evidence to suggest that mangroves were proliferating during the late 1800s in response to the implied higher sea-levels as inferred from the sea-level chart. Also, the considerable 9cm-fall in sea-level during the 1990s (1991 to1998) has not been reflected in a decreased rate in the proliferation of mangroves. On the contrary, this has been a period where even casual observations have noted the continuing very rapid rate of mangrove expansion. However, Buckney (1987) showed that on Kooragang Island there was actually a decrease in the expansion of mangroves from 1975 to 1982. Williams *et al*. (2000), when comparing their longer-term data with Buckney's, suggested two possible explanations for a discrepancy between their results; either "one or other of the analyses is wrong, or the dynamics of mangrove change need to [be] mapped at less than 10 year intervals". In support of the latter statement, this short term reversal in the prevailing trend of mangrove proliferation could be explained by a period of falling sea-level that took place between 1975 and 1983 (**Figure 2**). Thus, it appears that global sea-level does have some influence on the distribution of mangrove and saltmarsh communities but the amount of rise and fall does not appear to be enough to explain the overall magnitude of the ecological changes observed. Saintilan & Wilton (2001) found that this was the case in Currambene Creek, Jervis Bay, where the 30cm vertical increase in the range of mangroves was much greater than the small amount of global sea-level rise could account for. However, Saintilan & Rogers (2002) indicated that "the consistency of the trend between estuaries … suggests at least some component of saltmarsh loss is related to sea-level trends".

Saintilan & Wilton (2001) noted that in Jervis Bay saltmarsh overlies strata with mangrove remains dated to about 2000 years before present, implying that the vegetation succession from mangroves to saltmarsh has been stable for the last 2000 years. Therefore, it is only recently that we have seen the reverse situation where mangroves have been replacing and overlying saltmarsh. It appears from the above discussion that global sea-level has been oscillating with a periodicity of about 80 years and that the magnitude of this oscillation has not had an overall controlling influence on mangrove expansion. Another process with greater influence on the ecology of the estuary must be implicated.

Altered tidal regime

Morton (1994) attributes the landward incursion of mangroves with altered tidal range (presumably an increase) in Moreton Bay. This concept is supported by Saintilan & Williams (1999) who noted that the construction of tidal barrages and modification of entrance conditions could be contributing factors that altered (presumably increased) the tidal range significantly, promoting the landward colonization of mangroves, as discussed by Druery & Curedale (1979) for the Tweed and Brunswick Rivers.

During the last 50 years, the solstice tidal range in the Hunter Estuary increased by 100mm at Stockton Bridge and by as much as 250mm at Hexham Bridge (Umwelt 2002). Smaller tidal range increases were noted for spring, mean and neap tidal cycles.

"These recorded increases in tidal range indicate that a greater volume of water now passes through the entrance channel on each tidal cycle with estimates indicating approximately a 5% increase in tidal exchange volume.

Analysis of channel cross-sectional information … indicates that since 1950 the controlling cross-sectional area of the entrance channel has *increased [by dredging] from approximately 3400m^2 in the 1950s to approximately 5780m^2 in 2000 with a corresponding increase in depth from approximately 10 metres to approximately 17 metres. This equates to approximately a 1.7 times increase in entrance channel cross-sectional area."* (Umwelt 2002).

Thus, Umwelt (2002) suggested that harbour dredging has been the major cause of tidal range increase in the estuary. A study by Manly Hydraulics Laboratory (MHL 2002) on Hunter Estuary processes also concluded that tidal range had increased in the estuary and suggested three possible mechanisms: dredging and deepening of channels; construction of levees; and construction of floodgates [the latter two mechanisms confining the tidal prism to the main channels instead of allowing the tide to dissipate into flanking estuarine wetlands].

Thus, channel, river mouth and harbour deepening by dredging has substantially increased tidal inflow into the estuary, resulting in a greater tidal prism penetrating upstream and directly contributing to tidal range increases in the upstream reaches of the estuary. Increased tidal amplitude has caused a considerable increase in *relative* sea-level in the Hunter Estuary, which is well in excess of *global* sea-level rise.

The boundary between saltmarsh and mangroves is related to small differences in elevation and soil salinity. An increase in tidal range increases the rate of tidal inundation that can, in turn, reduce the hypersalinity of the saltmarsh environment allowing mangroves to invade. It is suggested that the relatively huge increase in tidal range recorded between Stockton Bridge and Hexham Bridge is the most significant factor leading to mangrove proliferation and saltmarsh loss. In support of this conclusion, the timing of the rapid mangrove expansion correlates with the most significant period of dredging that took place in the early 1980s. Williams *et al.* (2000) also suggested that increased tidal range caused by harbour dredging is one of the main factors related to mangrove expansion and specifically identified tidal range increase as the reason for rapid mangrove expansion following culvert collapse at the mouth of Cobbans Creek.

Contributing factors for tidal range increase

Although it is considered that harbour and channel deepening is the main process for increasing the tidal range in the Hunter Estuary there are additional estuary modifications that contribute to this effect. These modifications all tend to increase the tidal range, exacerbating the effects of dredging.

Since the 1800s about half the estuarine shoreline has been lost by the construction of rock training walls. Reclamation of saltmarsh and mangroves by infilling behind the training walls completed the transformation of these areas for industrial purposes. The straightening and smoothing of the estuary banks effectively increase the efficiency of tides moving in and out of the estuary by reducing bed friction thereby assisting the penetration of the larger tidal prism. Rising tides that would normally flow into the saltmarsh and mangrove are now prevented from dissipating into the area behind the training wall. The effect of assisting tidal inflow, but at the same time, preventing the lateral dissipation of the resulting inflow translates to vertically increased tidal range.

The removal of even greater areas of estuarine floodplain, where tidal inflow was previously dissipated, such as Hexham Swamp, Tomago Wetlands and many additional areas upstream of Hexham Bridge, have also contributed to increased tidal range. All these areas have been cut off from the estuary by the construction of flood-gates that have mostly been kept closed. As mentioned above, MHL (2002) also implicates the construction of levees and floodgates as contributing to tidal range increase.

Increasing the tidal prism entering the estuary has the effect of moving the limit of tidal influence upstream. However, in many places this is not possible because weirs have been constructed inhibiting saltwater penetration into the upper reaches of the estuary (e.g. Seaham Weir on the Williams River). Siltation and subsequent shallowing of the upper reaches of the Hunter, Williams and Paterson Rivers also inhibit upstream movement of the tidal limit. All these upstream effects contribute to tidal range increase in the downstream areas of the estuary.

All the factors discussed above effectively restrict lateral movement of tidal flow. But progressive deepening of the harbour entrance and channels forces more tidal inflow into the estuary. Thus, the estuary has experienced modifications that have progressively decreased its capacity to laterally dissipate this increased tidal inflow. The increased volume of water entering the estuary as a result of harbour and entrance deepening can no longer be accommodated laterally, therefore it can only go upwards by increasing the tidal range.

CONCLUSIONS

Although there may be several factors exacerbating the expansion of mangroves and the concomitant loss of saltmarsh in southeastern Australia, it appears that, within the Hunter Estuary, increased tidal range is the most important factor. The magnitude of the change is such that it outweighs all other factors combined. This is effectively a local relative sea-level rise that has had an enormous physical effect on the lateral distribution of ecological communities throughout the estuary.

In the past, there has been ***no*** recognition of the upstream ecological problems caused by dredging and harbour deepening. The proposed dredging of the South Arm of the Hunter River for new coal loading facilities on Kooragang Island will add to the problem of tidal range increase and accelerate the incursion of mangroves into the small amount of remaining saltmarsh. In the EIS for the proposed dredging there was no consideration of upstream effects as a consequence of channel deepening (other than the statement that tidal range ***will*** increase). Also, in a report concerning the environmental risks of dredging the North Arm, it was indicated that a tidal range increase of 50mm should be expected as far upstream as the Hexham Bridge. However, there was still very little comment regarding the drastic ***effects*** of this expected tidal range increase on the total ecology of the estuary.

It is interesting to note in the Hunter Estuary Processes Study, that although alteration to the natural flow regime is listed as a threatening process, tidal range increase is not specifically discussed (MHL 2004). However, they do suggest that the identification of processes affecting the balance between mangroves and saltmarsh requires further study. Although increased tidal range in the estuary is recognized, the study does not specifically identify it as the main mechanism for mangrove proliferation and saltmarsh loss. It is ironic that MHL’s main concern is the *restriction* of tidal inundation to estuarine wetlands where floodgates have been installed, such as Hexham Swamp, rather than the main concern expressed here regarding *excessive* inundation of estuarine wetlands in areas *not* protected by flow-control structures or where mangroves have rapidly invaded saltmarsh after culvert removal (Howe 2005).

Planned and future industrial development will require additional harbour and channel deepening with further consequent tidal range increases. This will exacerbate the continuing ecological crisis. It has to be accepted that economically and politically this situation will persist. The question is, should we and can we take steps to halt, or at least ameliorate, the effects of tidal range increase. Given the impossibility of allowing environments to expand landwards “naturally”, because of the limitations of surrounding development, we have to consider managing the estuary. The author fully endorses the statement by Saintilan & Rogers (2002) that “… if the expansion of mangroves at the expense of other habitats is the result of human modifications of the estuary, then the issue must be addressed within the overall framework of estuary management”. In support of reinstating ecological balance to the Hunter Estuary “… data suggest that the diversity of habitat types is of more significance in supporting healthy fish stocks than mangroves alone” (Saintilan & Rogers 2002). If we decide to halt the effects of tidal range increase and to restore, or at least be able to manipulate, the balance between mangrove and saltmarsh communities there *are* measures that can be taken. “Hard engineering works have a role to play in maintaining preferred estuarine wetland habitat in areas where landward migration is constrained by topography or land use” (Howe 2005).

Weirs and culverts with flow control structures, preferably with mangrove seed exclusion facilities, can be installed at the mouth of every tidal creek in the estuary downstream of Hexham Bridge. These structures can be adaptively managed to adjust the amount of tidal inflow in order to achieve the inundation and salinity balance required for mangroves and saltmarsh development. The number of flow-control structures required should not be a daunting task as all tidal creeks in the estuary upstream of Hexham Bridge already have floodgates installed (about 200) and many others have been installed downstream (e.g. Hexham Swamp and Tomago Wetlands). There are 59 culverts in the estuary, mainly downstream of Hexham Bridge that could be modified. Floodgates are in the process of being progressively opened to reintroduce controlled tidal inundation to both Hexham Swamp and the Tomago Wetlands. The same should be considered for all tidal creeks in the estuary that have floodgates already installed. The expense of installing the existing floodgates was apparently justified for flood-control alone following the 1955 Maitland flood. It is not too much to expect that the installation of additional flow-control structures, on the remaining uncontrolled tidal creeks, in order to halt the ecological degradation of the entire estuary would be well justified. The expense would be a small proportion of the expenditure on port development that is considered the main cause for the present state of ecological imbalance in the Hunter Estuary. Flow-control structures would also be useful to manage the expected future sea-level rise that is attributable to climate change.

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