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(Cover picture "Mangroves and local fishing boats at Sungai Buloh, Selangor, Malaysia: the mangroves are an important fish breeding ground" (Photo Ian Douglas)

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4. Mangrove harbingers of coastal degradation seen in their responses to global climate change coupled with ever-increasing human pressures

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Preamble

The prospect of dire outcomes for tidal wetlands raises serious and urgent concerns for those currently charged with managing these threatened places. Environmental managers recognise the need to identify and act on pressures and risks faced by such natural ecosystems. An effective monitoring strategy is needed urgently for the description and quantification of habitat condition, their benefits, the threats they face and their survival. Attempts to gain such essential knowledge are however largely thwarted by the popular and insatiable distraction for growth economies instead of seeking alternative sustainable economic practices that account for those all too finite limitations of natural resources, their vulnerabilities and the risks in ignoring expert advice on these matters.

Introduction

We live in a world distinguished by rapid change where natural ecosystems are sorely challenged by human populations demanding ever more land area and resources to feed what appears to be an insatiable and unsustainable appetite for occupation, dominance and control of 'waste' natural spaces. This inevitably untenable situation, with the outdated tag of 'progress', relies on replacement of the world's natural habitats forcibly reducing them into ever diminishing refuges. In the process, their regenerative capabilities have become sorely compromised as their biodiversity and functioning processes progress along a trajectory towards their inevitable collapse. We need to ask, is this what we want? And, can we afford to lose such natural places?

In this essay, I outline the case for preserving natural mangrove ecosystems while briefly acknowledging their unique attributes and values, as well as the threats and pressures they face (Duke et al. 2007). While there is much going on around the world to redress the changes taking place, there is still much more to be done. The recent dramatic mass dieback of mangroves in northern Australia (Duke et al., 2017) provides a cogent case study highlighting key challenges faced by natural ecosystems, and specifically also with changes due to global climate change (Harris et al., 2018). I briefly describe these changes and list what can be done to protect such places.

The case study of unprecedented environmental damage affecting mangroves

In late 2015, an unprecedented climate phenomenon struck drought-weary mangrove stands along the vast and lightly populated, arid coast of the Gulf of Carpentaria in Australia's remote north (Fig. 1; Duke et al. 2017; 2020*).

Over several months, sea levels dropped by 20 cm across the region due to the severe El Nino weather conditions at the time. This was the same weather event responsible for extreme high-water temperatures responsible for the sudden mass bleaching of coral reefs in Great Barrier Reef waters of north-eastern Australia. The unexpected response of Gulf of Carpentaria mangroves, already struggling with prolonged drought conditions, was similarly dramatic and sudden. Along more than 2,000 km of coastline (Fig. 2), up to 8,000 ha of mangrove trees died of thirst and heat stress in the latter months of 2015 due to this previously unrecognised phenomenon.

Because of the region's remoteness, and the novelty of the phenomenon, the incident remained undetected and out of public attention for 3-6 months following the event. Those to have noticed the damage and who finally got word out were community members including local fishermen and environmental consultants who interrupted their own activities to do so – so much was their concern. The delay in raising the alarm, and the role of those making such a significant discovery has led to renewed calls for Australian and State government agencies to develop more effective monitoring of the national shoreline for an improved rapid response capability in future instances of such dramatic impact. This could be applied to all potentially damaging events like severe tropical cyclones, large oil spills, large tsunami waves, as well as unknown phenomena like the mass dieback of mangroves in Australia's Gulf of Carpentaria.

Fig. 1. *In late 2015 mass dieback of mangrove forests occurred in Australia's Gulf of Carpentaria. These photographs show the dead shoreline three and four years after (Limmen Bight, Northern Territory). Note the loss of standing dead trees in 2019 scoured by Tropical Cyclone Owen (a cat. 3 cyclone) six months earlier. The inset shows the extent of shoreline impacted by the mass dieback and the image location. Images: N.C. Duke.*

Fig. 2. *Aerial views of seaward mangrove fringes showing foreshore sections of minor damage (left photo) and extreme dieback (right photo) observed in June 2016 between Limmen Bight River and McArthur River, Northern Territory. These could easily represent before and after scenarios, but infact shows how some shoreline sections were left exposed and vulnerable while others were left intact with relatively minor damage at the back of the fringe. Images: N.C. Duke.*

Knowledge of individual mangrove plant distributions and the physical factors influencing them

Where mangroves are known to defend erosion-prone shorelines (Fig. 3), it is critical to know something about these unique plants. Mangroves have been around for more than 50 million years (Duke 2017) – along with their unique combination of capabilities for dealing with salty water and regularly inundated soils (Duke 2006). These defining features evolved long ago independently in up to 20 different plant families. This makes it tricky to define exactly what specific plants can be called mangroves, and what are not. Each family re-invented the capabilities needed to achieve the necessary ecosystem functions in sometimes quite different ways. While mangrove plants sometimes share a number of features, like the bearing of live young (vivipary), the ability to excrete salt from specially adapted pores on leaves, special exposed air breathing root structures either emergent from sub-soil roots or as aerial roots coming down from high branches, and as notably buoyant propagules, they each have their own unique combination of this assortment of specialised features and more. For example, the mangrove palm *Nypa* is a rare and unusual palm with a uniquely buried rhizome-like trunk that grows under the mud. Another mangrove, called the keeled pod mangrove *Heritiera*, has a large buoyant seed capsule shaped like a small boat complete with sail for effective dispersal. Other mangroves, the stilt root mangrove *Rhizophora*, have long bean-shaped buoyant propagules germinated on the parent tree and ready for long distance dispersal with plenty of provided food for the journey.

The combination of these amazing but sometimes unrelated and very different plants adds to some confusion with the definition. So, the defining features largely come down to whether the specific plants are dedicated inhabitants of the upper tidal wetland niche between mean sea level and highest tide levels. But this creates another challenge with the definition since

Fig. 3. View of seaward mangrove fringe damaged by Tropical Cyclone Trevor (a cat. 4 cyclone) in early 2019 showing uprooted trees, trees stripped of foliage and severely eroded shoreline near the Robinson River, Northern Territory. It is doubtful this shoreline will recover insitu but instead erode and retreat inland with the rapidly rising sea levels. Image: N.C. Duke.

other species called saltmarsh plants share this physical niche with mangroves. Fortunately, these latter plant types are not as tall and tend mostly to be succulents and sedges unlike mangroves being mostly shrubs and trees taller than 0.5 m. In addition, mangroves tend to prefer warmer and wetter conditions so saltmarsh dominate in colder and drier locations. The differences in types of mangrove plants are understandably also reflected in their ecophysiological preferences where different species grow in different places across the tidal profile, upstream in estuaries with some preferring open sea conditions while others only grow upstream in certain riverine settings, still others grow only in wetter climatic zones while others dominate more arid regions (Duke et al., 2019). Key physical factors influencing mangrove distributions are largely framed and defined by these three factors, sea level, temperature (with latitude) and rainfall (Duke et al., 1998).

Mangrove habitats respond and re-locate where they are able to do so as constraining physical factors change

One of the most limiting factors constraining mangrove habitat is sea level. So, as sea levels rise plants must re-locate higher up the tidal profile in order to re-establish the niche and maintain their position between mean sea level and highest tide levels (Duke et al. 1998). Mangroves do this in two independent natural processes. While trees are eroded at the seashore edge, at the other extreme of the tidal range seedling recruitment occurs at the landward margin. Changes with sea level rise are characteristically incremental with only small changes detectable in any one year. The most sensitive and vulnerable of these processes is recruitment at the landward margin. The presence of any disruptive activities along the landward edge will have significant consequences to the maintenance of mangrove habitat in the area. These disruptive factors include construction of man-made structures like rock walls, digging up of young mangrove plants by wild feral pigs, land fires scorch and kill mangrove plants, and exotic weeds like rubber vine smother and also kill mangrove plants.

In the Gulf of Carpentaria case study, while the rates of sea level rise have been exceptionally high over the last 30 years, the mass dieback was instead caused by a temporary drop of 20 cm in sea level. The mass dieback was distinguished from changes caused by rising sea levels (Duke et al. 2020*) where: 1) the dieback in this case affected a very large area in a relatively short period of time, and 2) the location of the dieback was most evident at mid to higher intertidal positions rather than at either the sea edge or the land edge. Vegetation at the latter upper edge in this incident was likely preserved by groundwater influences since few if any changes were observed there. However, after the El Nino event had passed, ambient sea levels were restored and the pressure of rising sea levels on mangrove shorelines was resumed.

Fig. 4. Aerial view of the landward dense green edge of mangroves notably covered in piled dead wood dumped there by the storm surge and severe winds from Tropical Cyclone Trevor (a cat. 4 cyclone) in early 2019 near the Robinson River, Northern Territory. The adjacent bare area marks a patch of the mass dieback in 2015 being the likely main source of the dead wood given its proximity, the remaining stumps and that sediments have been notably scoured. Image: N.C. Duke.

The legacy of the severe damage to mangrove stands however remained. So, despite recovery since the mass dieback incident, the subsequent direct hit of two severe tropical cyclones in the summer of 2018-2019 caused significant sections of previously impacted shoreline to be scoured clear of dead wood, re-sprouting stumps and seedlings (Figs. 1 & 4). The damaging effects of each cyclone extended along approximately 200 km of shoreline either side of the point where the cyclone's path crossed the coast.

Within these areas, piles of dead wood from the scouring of 2015 incident areas were swept across and scoured prior surviving areas (Fig. 4). There are serious concerns about the longer term recovery in view of the accumulated damage caused. But these sites are also under the constant pressure of rapidly rising sea levels. The threat of further severe tropical cyclones is all too real. The damage to shorelines brought on by such accumulated destructive impacts have caused the on-going disruption of natural recovery processes of mangroves by preventing their normal re-establishment and their role in building living shoreline defences. There is an urgent need to slow down and reduce the destruction of such mangroves.

Actions needed for building greater resilience in natural shoreline defences of mangroves

A national shoreline strategy involving monitoring by local communities and science specialists would be very useful indeed. This strategy might also benefit greatly by recording changes to mangrove stands as targeted indicators of specific change. In adopting such a strategy however, there are three alternate considerations to be appraised as the foundations for an effective way forward:

a) to **reduce the risk**, if possible, of the occurrence or repetition of environmentally damaging events;

b) to **facilitate recovery** of damaged stands where the threat no longer poses an imminent risk; or

c) to **facilitate the transition** of any relevant affected habitat into its alternate environmental state, notably where recovery into its prior state is no longer feasible.

In view of these considerations regards an appropriate mitigation response to the 2015 mass dieback event, large scale replanting to replace dead trees is considered costly and unhelpful. In this regard, consider the damage to seedlings caused by those subsequent cyclones. In full consideration of all the available information, the best response in the circumstances has been to establish a monitoring and evaluation program that draws strongly on the quantification of habitat indicators. Then this needs to be followed up by linking each indicator with its respective driver of change in an encompassing monitoring and evaluation strategy. In establishing such a program, it has been important to firstly establish a baseline as a key reference point. The baseline status is best defined by key parameters of the ecosystem including its biodiversity, structure, function, threats, values and condition. Once established, these baseline features would continue to provide measures of on-going change.

Such a national shoreline monitoring strategy (Duke et al. 2020*) would desirably include some if not all of the following components (some of which may already be enacted depending upon the relevant region of application). A summary of the key elements of this strategy are listed.

1) **Manage threats** where alternatively they might require separate local (like control of feral animals) or national management intervention actions (like international climate change abatement programs).
2) **Develop an inventory of natural resource** using maps to define spatial extent and context (like those based ion maps of vegetation types) making sure to include both mangrove, saltpans and tidal saltmarsh as framed between mean sea level (MSL) and the highest tide level (HAT). This should then be repeated regularly to identify sites of change for the respective vegetation units.
3) **Determine habitat condition and habitat responses** linking each with its particular driver of the change. This is best achieved working with community groups, indigenous rangers and habitat specialists using either or both oblique aerial shoreline surveys and boat-based shoreline video assessments to extend and compliment the resource mapping (per element 2). working with the specialists, community members can help score each indicator (Fig. 5) to define the severity and extent of changes taking place like shoreline erosion, damage by feral pigs, and the dieback of mangroves.
4) **Derive models to describe the functional changes** in the tidal wetland habitat observed in previous elements where the expansion of mangroves was associated with the dieback and loss of saltmarsh. One model already described (Duke et al. 2019) used this strategy to develop a predictable dynamic relationship between the proportion of mangrove vegetation compared to saltmarsh depended on longer term rainfall. As such, the model explained why in wet tropical areas there are more mangroves than saltmarsh and saltpans while in drier areas the opposite is true.
5) **Conduct rehabilitation trials** to test and evaluate specific mitigation strategies and methods. With an understanding of the findings from the above elements of the strategy, this approach has already contributed to a number of successful rehabilitation trials. The general tenants followed include substrate stabilisation and shoreline reshaping to fully create and define the mangrove 'sweet spot' before planting was undertaken. And, in order to validate these construction and planting efforts accompanied by on-going maintenance, it has been critical to continue monitoring the rehabilitation site for many years, even decades afterwards.

Fig. 5. Local aboriginal land and sea rangers are keen to monitor the shoreline health in their respective countries throughout the Gulf region as with this group of Numburindi Rangers surveying the Rose River near Numbulwar, Northern Territory. Image: N.C. Duke.

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