Learning to go with the flow: overcoming real and virtual barriers in land and sea enhances connectivity and survival of nearshore reefs, mangroves and seagrass beds.

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Abstract. Coral reefs are under threat from stressors at global, regional and local scales. Nearshore reefs are most at threat from land-based runoff and other human-induced disturbances which may result in 'phase-shift' from coral to another substrate or benthic cover type. Maintaining connectivity between reefs and related ecosystems of mangroves and seagrass enhances reef health via fluxes of nutrient and detritus and the movement of organisms that maintain substrate 'phase'. Three issues were investigated for nearshore reefs within Hervey Bay, an estuarine coastal embayment in the Burnett Mary region of southern Queensland, eastern Australia. (1) Lack of reef mapping was addressed by an integrated field, ecological and remote sensing method. (2) Reef context was characterised in terms of biodiversity and geomorphic values, and regional connectivity between reefs, seagrass and mangroves. (3) The spatial and policy implications of nearshore reef values and connectivity were evaluated in the national and regional context of marine spatial planning. This paper compares natural connectivity of land and sea habitats with current connectivity as it has been affected by man-made barriers introduced since European settlement, including virtual (jurisdictional) barriers; and physical barriers (e.g. estuarine; riparian). Overcoming these barriers to restore and conserve ecosystem values and services requires the development of effective policy and management practice, informed by integrated mapping, assessment and negotiations across all levels of government and sectors of the community. Traditional Owners can enhance reef survival by imparting their understanding of land and sea processes and advocacy through regional NRM groups of connected reef, seagrass and mangrove management (e.g. reducing land-based runoff and re-connecting estuaries with freshwater).

INTRODUCTION

Natural resource management is focussed on the land. Land-based ecosystems are based on plants, which are rooted in the soil – the only way they can move is by dispersion of pollen, seeds, etc. either by biota or through the air. Thus plant communities and ecosystems move slowly but if left undisturbed, may change over time through succession. Disturbances such as fire, flood and drought, modify these systems, but to the planning world, they are spatial units frozen in time – based on land, soil and geology. European regimes of fire, flood and drought are changed, because Europeans partition their environment into sections. Land is cleared, grazing expanded and predation reduced. These disconnected processes alter land-based ecosystems. The community is now aware that capturing sections of land for conservation (National Parks) cannot save all biodiversity or land-based ecosystem processes. Ecosystem-based management across local and regional scales is becoming accepted by government and the community on the land. The Queensland government is designating statutory regional plans, with areas of vegetation AES (Areas of High Ecological Significance) where development should avoid or alternatively offset. The community contributes by developing regional NRM plans, in recognition that that both water quality and biodiversity are impacted by land processes. No such system exists for shoreline, estuarine or marine habitats. Why?

Aquatic ecosystems are very different and in many ways behave in the opposite way to land ecosystems as flux drives these systems. Those anchored in space, e.g. reefs and rocky shores are conspicuous and mappable and thus can be more easily planned for, than mobile soft bottom habitats and biota. Reefs embody and reflect the natural dynamism of marine ecosystems. Disturbances – patchy in time and space (storms, floods, waves, currents; water temperature; salinity)-drive changes in flux of sediment and water and contribute to mosaic and time-varying pattern in benthic biota (Done 2011a). Motile organisms cope with flux by moving across the mosaic. In nearshore environments, motile biota respond to varying regimes of nutrients, sediments and freshwater by moving to the next available patch resembling previous habitat, by widening habitat preferences and/or dispersing young (Sheaves 2009). Soft bottom habitats may be in a state of flux depending on the intensity, regularity, timing and spatial scale of change (Skilleter and Loneragan 2007). Plants and invertebrates colonise soft bottom habitats, anchoring them in space – if left undisturbed, these habitats may become semi-permanent until the next disturbance. The three-dimensional nature of aquatic habitats, and their flux, is a problem for European-Australian governments, planners and managers who like to place boundaries around habitats for containment. For example the Great Barrier Reef has a line around it, separating it from its lagoon in Hervey Bay, within the Burnett-Mary region of southern Queensland, despite the presence of a substantial area of coral reefs within the Bay.

NRM Planning on the land is well-established, but is yet to effectively respond to the continuing decline of aquatic habitats. Why is this so? (i) Possibly because we cannot decide on what is important to monitor in receiving waters; (ii) Water works differently from land as a planning environment, flowing and being more dynamic; (iii) We need to understand how landscape processes influence receiving waters and seascape processes. One way to understand which direction to take is to 'go with the flow' or investigate what connectivity of ecological processes is telling us. Traditional land owners have lived with this flow or flux, and may provide some direction for European Australians whose actions and views currently dominate land and sea science, policy and management.

Connectivity is a term scientists give to movement of materials, water and biota through the landscape and seascape. Traditional owners before European settlement moved in response to the fluxes of the environment, maintaining their resources by 'going with the flow' – moving through their landscape and seascape to use the resources, but then moving on to ensure these biota were not over-used. Moieties ensured that important animals, plants and places had appointed carers to look after them over countless generations. European history since their settlement of Australia documents disturbance over ecological time scales - by storms, cyclones and floods. Traditional owners' oral history embraces geological time – volcanic eruptions, storms removing islands; land or vast lakes where only sea exists today. Surely there are volumes of untapped knowledge about living with landscape/seascape processes, connectivity and disturbance?

The characteristics and values of reefs, and their connected seagrass and mangroves habitats, south of the government line are poorly documented, as are the connectivities of the region's biota, sediment, nutrients and chemicals across this line. What if these subtropical reefs have important values of rarity, diversity, or reef-forming? Have the big disturbance events of the last 40 years, the 2011 and 1992 floods, changed them, or is their present state part of normal variability when viewed within the traditional owners' timescale? Do current pressures threaten the reefs, seagrass beds and mangroves of the Burnett-Mary Region in the GBR lagoon? Do government plans and legislation need to change?

Some of these issues were explored in a reef mapping, ecosystem values, connectivity and policy study in the Burnett-Mary NRM region. The study found significant values: (1) reef-building reefs and communities at their southern range, resembling nearshore reefs of the Great Barrier Reef; (2) high diversity, rarity and high latitude species; and (3) reef-seagrass-mangrove complexes connecting all the way to the GBR. The connectivity and policy study, the topic of this paper, investigated potential regional connectivity between land and sea, comparing reef and connectivity mapping with government policy and plans. It suggests a different approach to scale, mapping, assessment, policy and planning is necessary for regional reefs to survive - involving cooperation between government and community, notably those traditional owners who understand land and sea pathways. To understand why a different solution is needed, first we need to understand the relationship between reef health and connectivity– of biota, sediment, chemicals and water - within and between land and aquatic habitats.

BACKGROUND

Coral reef health and land connectivity. European reef connectivity science is in its early stages, but it is becoming clear that connectivity is very important for coral health. Coral is being killed on nearshore reefs because of threats at multiple scales – the global threat of climate change causes

bleaching; regional threats of land based runoff due to European land use floods the sea with sediment, nutrients and chemicals, smothering and killing coral and seagrass; local stormwater and sewage pollution do likewise. Where disturbances cause coral reefs shift to algal reefs, scientists call it a 'phase shift' (Done 1992a). The key question is the duration of the algal phase, and whether ongoing pressures (human + natural) prevent or retard a reversion to the coral phase.
Connected aquatic ecosystems: Aquatic ecosystems are connected by water, weather and currents. Land ecosystems provide a largely one-way connectivity pathway to aquatic ecosystems (except estuaries). Rain falls in catchments, draining into streams and into the sea, but also filtering into the soil and passing through the land as groundwater to rivers, wetlands, streams, shorelines, estuaries and sand and mud flats. This fresh water may bring sediment and nutrients (predominantly nitrogen and phosphorus). The groundwater passes through the soil or sand into the wetlands and seeps through either dunes or swales to the sea, providing freshwater and nutrients for saltmarsh / saltpan, mangroves and seagrass. Groundwater also seeps through to rivers and streams, providing base flows for rivers in addition to rainfall. Rainfall transports volumes of freshwater with coarse and fine sediment to estuaries. The distance this is transported offshore depends on how much water, how intense and how long is the rainfall event. Freshwater, sediments and nutrients change soft bottom habitats but also reefs, because some corals cannot live under sediment or in freshwater; after they die, algae colonises because nutrients and sediments help it grow (Done 1992a; McCook 1999). How can corals recover and reefs survive?

Connectivity and reef recovery. Connectivity may provide an environment where coral reefs can recover and re-establish. Grazing animals such as fish (parrotfish, rabbitfish, unicorn fish) and turtles can reduce the algae so that coral larvae have a hard surface upon which to settle and sufficient space in which to grow (Mumby 2006) Currents disperse fish and coral larvae from other reefs, and the coral and fish can settle again; provided the food web is the same as before with predators and grazing animals living together. These animals also live in nearby estuaries, among mangroves / saltpan/ saltmarsh / seagrass, using whatever patches of the environment they encounter in their pathways (Sheaves 2009). Mangroves / saltmarsh / saltpan / seagrass habitats trap the sediment and use the nutrients. Before water gets to the mangroves and rivers, freshwater wetlands and riparian (riverbank) vegetation filters sediment and removes the nitrogen (Hunter *et al* 2006), and provide nurseries for fish; and in floods a pathway to the river. Here is a job that the NRM community can relate to: if we fix the land, the riverbanks and freshwater wetlands, we are fixing the sea.

Barriers to connectivity. Not so simple! Europeans have set up tidal barriers (barrages) and dams and weirs so that biota, water, sediment and nutrients cannot flow normally either in the ground or in rivers; the land is cleared so that rainfall brings up to ten times the amount of nutrients and sediment into the sea; with it come chemicals (e.g. herbicides diuron, atrazine, simazine) designed to kill plants (see Wilkinson and Brodie 2011). Herbicides can kill or affect marine plant reproduction including seagrass, coral (a partnership between a plant and an animal) and mangroves. Fishermen are removing predatory fish so that the balance of reef food webs changes away from one where grazing animals remove algae (McCook 1999). Legislation for land clearing, excavation and development sets up artificial barriers where these ecosystems normally connect by water, sediment and nutrient flux and biota. Urban and rural development releases sewage, chemicals, nutrients and acid sulfate runoff into streams and groundwater; triggering extra nutrient release of iron into waterways so that the balance of ecosystems favours algae over coral or seagrass.

Governments see these problems and are trying to change them by changing farming practices (e.g. ReefPlan) or marine park plans (GBRMPA RAP process – Fernandes *et al.* 2005). Regional NRM groups are promoting voluntary change in land management and restoring riverbank vegetation and wetlands. But after a big cyclone or flood, fluxes pass nutrients, sediment and chemicals through the whole system again, expelled through estuaries to threaten reefs and reef connected habitats of seagrass / mangrove /saltpan / saltmarsh. Scientists term this 'eutrophication' and worry that the southern GBR lagoon may be becoming 'eutrophied'. Surely this is a reason to address NRM planning of land and sea in the Burnett-Mary Region.

METHODS

For my study, a remote sensing and field assessment study of the Burnett-Mary Region provided two datasets, analysed at the regional and local level for context, ecosystem values and connectivity of the region's reefs: (1) a regional (reef boundary) and local (dominant benthic substrate) provided geomorphic units and connectivity data;(Zann *et al.* 2011a) (2) a species field survey provided information about the local geomorphic and biodiversity values.(Zann *et al.* 2011b)

To determine whether the region's reefs were adequately protected by marine protected areas: (1) the connectivity dataset was overlaid by Marine Park zoning plans; (2) a policy review was conducted to determine how effectively the reef mapping was incorporated into policy and planning; and (3) potentially connected ecosystems (dune systems, freshwater wetlands, rivers, mangroves, seagrass meadows, reefs) were mapped and processes (sediment and nutrient flow, groundwater flow, biota movement, currents, and floods) were conceptually overlaid on the map. Lastly a framework for working with connectivity involving mapping, assessment and connectivity processes was outlined in the context of national, state, regional and local policy. In this presentation traditional owners are invited to respond: whether this framework reflects their understanding of the real pathways of land and sea; and how European-Australians and Traditional Owners can work together at the local and regional level.

DISCUSSION OF RESULTS

Overlaying the reef mapping on the Marine park zoning plans showed that, while three reef-seagrass-mangrove networks featured in the Burnett-Mary Region, protected areas (green zones) did not coincide with these networks. This may be a legacy of the dearth of nearshore reef mapping and inappropriate scale for nearshore reefs; and the lack of habitat mapping as a foundation layer for zoning plans. However, the values and connectivity study found an almost unbroken chain of reefs, seagrass and mangroves links the Burnett-Mary Region with the GBR. Key reef-seagrass-mangrove networks requiring re-examination of their zoning plans link the Burnett-Mary Region with the GBR, notably: (1) Hummock Hill Island to Bustard Bay; (2) Fingers reef-Baffle Creek; (3) Burnett-Woongarra-Elliott River; and (4) Hervey Bay – Great Sandy Strait Ramsar area. Gaps in seagrass-mangrove networks between these complexes were minimal. To address these disconnects, the region's marine ecosystems require mapping, assessment and management in their context with the GBR and subtropics.

The policy review found very few policies and plans able to incorporate the reef mapping data in their context with connected ecosystems (seagrass/mangroves). A diagram was shown representing the plethora of policies and plans that dissect these connected ecosystems.

By contrast, my analysis of the potential for regional and local connection of ecosystems and ecosystem processes did not display these discontinuities. Significantly, the extent of the region's dunes and wetland systems demonstrate important connectivity processes which should be protected (groundwater and nutrient/sediment filtration) and their proximity to estuaries, mangroves, saltpan/saltmarsh(fish nurseries) is also significant for biota movement. These areas are in turn linked to seagrass beds and nearshore reefs, providing potential for reef and seagrass recovery from the substantial flooding (shown as plumes on Figure 1). Fishing marks representing deepwater reefs punctuate the paleo Mary River valley (when sea level was > 100 m lower some 20,000 years ago), all the way to offshore reefs, providing staging posts for maturing fish to move offshore from shallow nurseries and nearshore reefs. However today, cleared riparian vegetation and catchments are allowing significant slugs of chemical-laden sediment and turbid, nutrient-rich water to extend offshore north and eastward toward the Captricorn-Bunker Group of the GBR. Superimposed over this are regional current flows which propel heavier nutrient-rich, anoxic saline water into the depths off Fraser Island (Ribbe 2006), possibly re-circulated back onto the GBR shelf by upwelling from the depths by the Capricorn Eddy (Weeks *et al.* 2010).

How can Marine Ecosystem-Based planning processes (Foley *et al.* 2010) capture such connectivity? Firstly, the author suggests an integrated process of mapping and assessment of the values and connectivity of terrestrial, aquatic and estuarine-marine ecosystems; but importantly

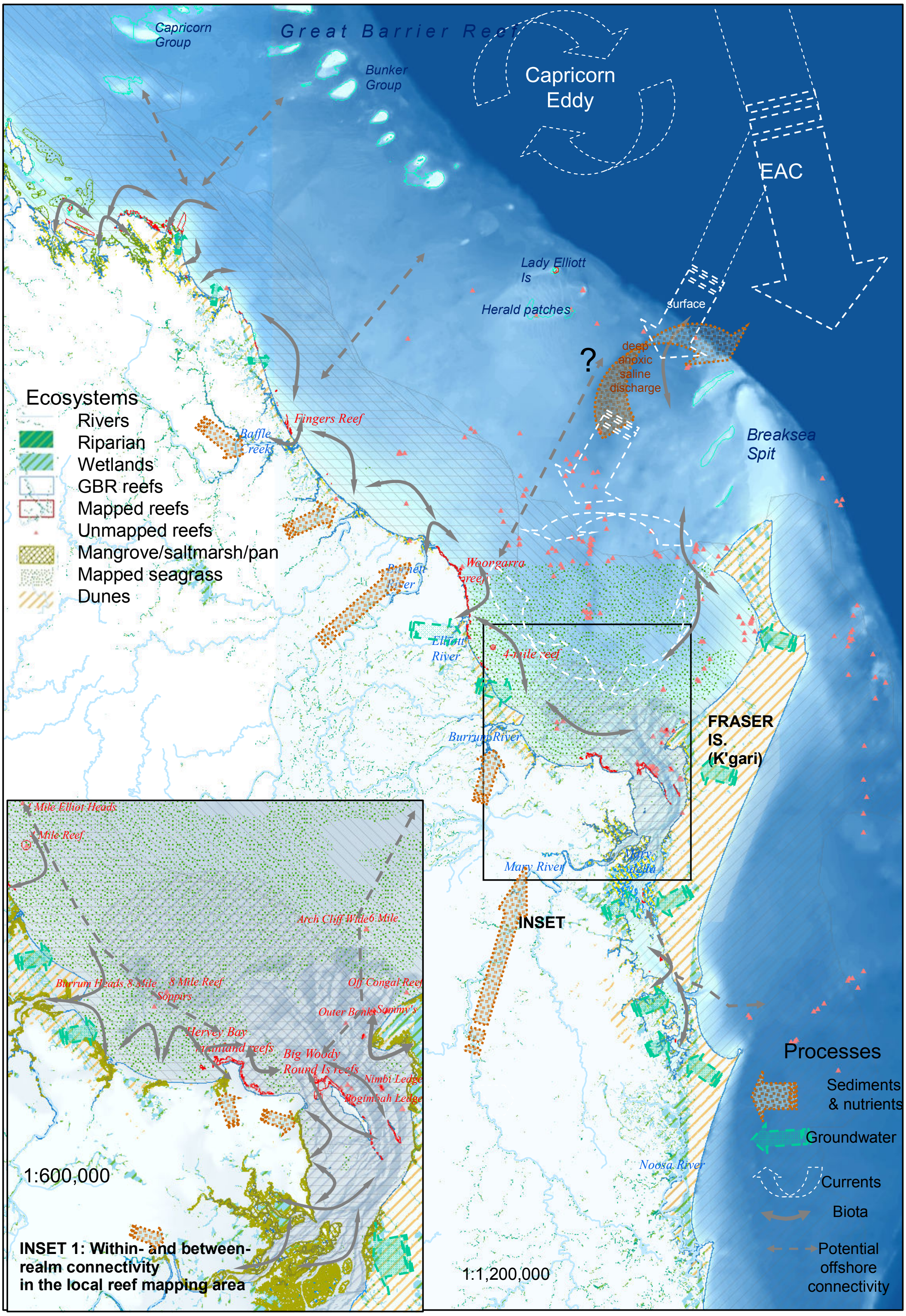

Figure 1 shows the Burnett Mary Region's mapped reefs and reef-connected ecosystems with connectivity processes superimposed (arrows), grey hatching denotes flood plumes.

also mapping and assessing the connectivity processes that link all three ecosystems, and passing across important flow parameters triggering biota recruitment, reproduction and oceanographic processes. This means capturing knowledge of change in ecosystems over time – what processes are important for biota reproduction, recruitment, movement and migration at local and regional scales and above. For this to happen, we need to understand the extent of important events (e.g. estuarine flows, flood plumes, cyclone effects) in space but also over time. Traditional owner knowledge can extend further in space and time than European knowledge, so we need to capture this knowledge.

Secondly, these datasets need to be the foundation layers upon which all management and planning decisions are made. This involves breaking down many of the barriers between levels of government, State government departments and local authority sections; and government working in partnership with the community. Regional NRM groups are the ideal institutions to broker this process, as they bring together community members – notably Traditional Owners, local government and land owners and community organisations (catchment care and conservation interests). It is at this level that Traditional Owners can make their voices heard.

Thirdly, action is required on the land, in the sea and at the land-water interface to enable connectivity to be maintained or restored. This must be done at all levels: locally by the community and local government; regionally, by NRM groups and government working together; and regionally by neighbouring NRM regions coordinating work and research to identify connectivity in the sea that crosses imaginary boundaries drawn by governments.

Traditional owners have three roles: (1) Locally look after your sea country by not overfishing, picking up any rubbish, and telling us your local knowledge about land and sea pathways (2) Regionally, join your NRM group's traditional owner working group and influence government decisions; teach us how to 'go with the flow' of our land and sea country pathways; tell us dreaming stories about real geological time and places that show us how to care for land and sea country (3) Nationally, help integrate whitefella science with blackfella wisdom.

TAKE HOME MESSAGE. A different planning system is needed to manage sea country to ensure coral reefs survive local, regional and global human threats. This involves connectivity, or 'going with the flow' of water and biota between the land and sea. This connectivity between reefs, seagrass and mangroves exists locally and regionally in the Burnett-Mary sea country, linking it to the GBR. The region's marine ecosystems require mapping, assessment and management in their context with the GBR and subtropics. Biota travels these sea country pathways linking mangroves, seagrass meadows and reefs, keeping the reefs healthy. Traditional owners understand these pathways in space and time, and by pooling their knowledge with that from conventional science, can work through regional NRM groups to look after sea country at the local level as they have always done

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