Catchment2Coast

a systems approach to coupled river-coastal ecosystem science and management

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Executive summary

Introduction

Catchment2Coast was an interdisciplinary research and modelling project involving nine partner organisations from three European and three southern African countries. It aimed to provide an ecosystem-scale understanding of the linkages between economically important tropical coastal resources and their associated river catchments (Monteiro & Matthews, 2003; Marchand, 2003). Maputo Bay, a large, shallow bay on the coast of Mozambique sustained by three transboundary river catchments, served as the study site.

The core hypothesis of the project was that the most important biophysical interactions between freshwater catchments and coastal domains occur at the sub-seasonal event scale (days). Without a full understanding of the mechanism of these event-scale interactions, their economic consequences cannot be adequately assessed. The project therefore used a number of numerical models (coastal, river basin and ground water) with the required dynamical capability to implement a system-scale approach to the functional dependence of coastal systems on river basin drivers. Resource economics models then allowed these results to be translated into impacts on urban and rural livelihoods.

The project focused on a single coastal resource, the shrimp (*Penaeus indicus*), which was used as an indicator of the ecosystem productivity response to catchment forcing. Shrimp is Mozambique's most economically important living resource, and catch per unit effort (CPUE) data provide the best proxy for long-term trends in coastal ecosystem productivity (although it is recognized that CPUE may not represent the true status of shrimp biomass). This approach was also generic enough to allow other recognized impacts of catchment-based human activities, such as mining effluents, pathogens, eutrophication, erosion and silting, to be addressed in a holistic way in the future.

The biophysical component of the research was guided by a number of hypotheses, which were articulated by the leadership team at the first and second project steering committee meetings.

Scales of forcing hypothesis:

1) The overarching hypothesis across all process domains is that the key linkages between river fluxes and coastal responses occur at the event scale and not at the aggregated seasonal or annual scale.

Physical forcing hypotheses:

2) Density-driven circulation: the impact of the river inputs on shrimp production is through the stratification and circulation characteristics driven by density gradients that develop as a result of the mixing of river and sea water. This is the ROFI (region of freshwater influence) hypothesis.
3) Salinity hypothesis: the impact of local rain, river-derived freshwater and ground water is key to maintaining the required salinity ranges for the early life stages in the mangrove habitats.
4) Temperature hypothesis: temperature variability is an important factor in defining habitat suitability for the early life stages of the shrimp (shade).

Biogeochemical forcing hypothesis:

5) The impact of river inputs is through the input of suspended sediments, organic matter and nutrients into the mangrove biogeochemical remineralization – production system. Variability in this biogeochemical forcing regulates the space and time scales of energy input into the food web that supports the shrimp.

Findings

Given that the physical forcing hypothesis was initially the preferred one, there was a strong focus on understanding the nature of stratification and density flows linked to freshwater inputs. Maputo Bay is a tidally energetic embayment with a highly variable seasonal freshwater input (up to 3000 $m^3 \cdot s^{-1}$ in extreme conditions). There is an unusually large spring to neap tide ratio (~6), so tidal currents and the associated circulation are modulated on a fortnightly cycle. Although tidal range rises and falls periodically and continuously changes the amount of energy available for bottom mixing, the water column remains vertically mixed throughout the dry season.

During the wet season, freshwater input creates density-driven currents, which also appear to be modulated by the tides. However, the sudden episodes of intense discharge result in density-dependent stratification of the water column. An interesting inference from the model runs is that the density-driven flows evident at neap tides are largely suppressed by the increased vertical mixing at spring tides. The observations confirmed that stratification occurs at neap tides and there is some evidence of periodic stratification at spring tides. They also indicated that significant stratification is only induced by freshwater input, and even during the period of maximum surface heating, persistent thermal stratification does not develop.

These variations in vertical and horizontal density gradients control the flushing patterns of the bay. During neap tides, low tidal energy input allows the development of stratification and density-driven currents, which tend to flush the bay efficiently. During spring tides, however, enhanced vertical mixing arrests the estuarine plume for most of the tidal cycle and hence allows baroclinic circulation only near low-water slack.

Although the physical forcing hypothesis was later rejected, these insights were key to understanding the mechanisms of freshwater retention, which are an essential part of the biogeochemical hypothesis.

The physical forcing hypothesis was rejected mainly because an observational programme undertaken at the mangroves revealed that the early life stages of shrimp (post-larvae) arrived at the mangrove nursery areas prior to the onset of the wet season river flows and floods. The data showed that the recruitment of early life stages into the nursery areas was completed by December, and therefore largely independent of the physical oceanography resulting from freshwater inflows during the wet season.

Following the rejection of the physical forcing hypothesis, the science focus shifted to the biogeochemical forcing hypothesis. The original formulation of this hypothesis was also rejected, because modelling and observations showed that the river was not the supplier of nitrogen to the coastal – estuarine system, and could not support the productivity needs in the mangrove nursery. In the absence of any oceanic or other land sources, the biogeochemical hypothesis was reformulated to account for an autochthonous source of nitrogen in the form of nitrogen fixation (N-fixation). Ravikumar *et al.* (2004), working in Indian mangroves, showed that N-fixation was driven by salinity dependence, which was sensitive to the spatial and temporal character of the 20 – 30psu range. The re-designed field work, focussing on sediment water production and remineralization fluxes, showed that the *Avicennia* mangroves, where most N-fixation occurs, were indeed the areas where the greatest salinity dependence on new production was found. Hindcasting ecosystem productivity (shrimp CPUE) for the period 1996 – 2004 showed that the modelled productivity was able to “predict” the trends in 8 of the 9 years.

The study was therefore able to show that salinity-dependent mangrove production during the nursery phase of the shrimp life cycle was the critical factor governing interannual ecosystem production in Maputo Bay.

The linkages between river flow, salinity, mangrove production and shrimp grow-out results in a two to three month lag between wet season river flows and shrimp recruitment into the fishery. This supports local traditional knowledge of a two month lag between good rains and high shrimp catches.

Advances

The most important scientific contributions that this work made towards increasing understanding of tropical river – coastal ecosystem linkages were:

1. Identifying salinity variability - N-fixation coupling as the key linkage that governs the dependency of coastal ecosystem productivity on river flows in low-nutrient systems

2. Highlighting the underestimated role of N-fixation in driving critical new production that governs overall ecosystem productivity, rather than the much larger regenerated production fluxes generated by the mangrove forests themselves

3. Clarifying the extent to which physics governs ecosystem productivity, as the retention character of the estuarine – coastal water body physics governs the magnitude and temporal scale of the freshwater pulse (flood) that sustains wet season new production in the nursery zones

4. Showing that nitrogen losses from the mangroves (outwelling) were limited to the spring tidal periods in the wet season, when physical transport rates exceeded uptake rates by microphytobenthos in the mangroves.

5. Demonstrating the importance of a system approach in both formulating the hypothesis and understanding the critical linkages, including the ecological role played by the freshwater and estuarine wetland systems.

Recommendations

Based on the findings of Catchment2Coast, it is recommended that:

- Harvesting of mature mangrove trees (particularly *Avicennia*) is suspended immediately, and protected areas are established to protect ecosystem processes in the mangroves
- Operation of the four largest dams in the Incomati and Maputo basins are coordinated to ensure a minimum wet season (Jan – Apr) water flux of 500 Mm^3 for the Incomati River and 250 Mm^3 for the Maputo River
- Catchment management and water allocation plans in the Incomati and Maputo River basins are coordinated to increase resilience of the system to natural fluctuations in runoff
- Conservation areas in the Xinavane and Maputo wetlands are declared
- Annual estimates of prawn biomass are initiated, and the January experimental CPUE is used to forecast the seasonal average
- The main sources of uncertainty are investigated further:
    a. Maputo River flow data
    b. New production hypothesis: N-fixation – salinity relationship
    c. Mangrove food web and resource competition
    d. Salinity variability in the bay and mangrove domains.

- Awareness should be raised about the dependence of coastal resources and ecosystem health on the integrity of adjacent river systems. It is not feasible to develop coastal conservation strategies without including the modifications of ecosystem services provided by river systems through changes in land use and water allocation.