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Contribution of rivers to the productivity of floodplains and coastal areas of the southern Gulf of Carpentaria

Executive summary

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Front cover photograph: Flinders River estuary (photo: Stephen Faggotter).

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Executive summary

The Queensland State Government has identified three river systems in the south-east Gulf of Carpentaria – the Mitchell, Gilbert and Flinders rivers – where water development for irrigated agriculture is already occurring or likely to occur. Information is needed on the water needs of estuarine ecosystems and their associated fisheries to ensure that any water development occurs in a sustainable way, and that economic and social trade-offs between agriculture, fisheries and the environment are well understood.

This project examined the links between freshwater flow, floodplain productivity, estuarine or coastal productivity and associated fisheries to understand how changes to flows may impact on the floodplains, estuaries and adjacent coastal environments of the Flinders, Gilbert and Mitchell rivers. This project

- quantified end-of-river nutrient concentrations and loads from wet season flows
- measured coastal/estuarine primary productivity *in situ*
- quantified densities and size structure of juvenile banana prawns in the estuaries
- modelled how changes in flow will affect banana prawn catch
- determined how flows affect growth rates of barramundi and their use of the river systems
- quantified the economic impacts of changes to flows on the commercial barramundi fishery and the Northern Prawn Fishery (NPF) in the Gulf of Carpentaria
- identified areas and periods of floodplain inundation using remote sensing, and used this to estimate primary productivity.

Key findings

Estuarine productivity

- There were many similarities in the physical characteristics of the Mitchell, Gilbert and Flinders estuaries. However, the Mitchell River historically has more consistent flow year-to-year and a more extended period of flow each year, compared with the other two rivers (Burford et al. 2020). Conversely, on the other end of the spectrum, the Flinders has the most extreme conditions, with lowest rainfall, highest evaporation and highest year-to-year variability in flow.
- In the wet season, when salinity in the estuaries decreased due to freshwater flows, there were short-term spikes in total nitrogen and phosphorus concentrations. However, for much of the wet season, nutrient concentrations did not increase above dry-season values (Burford and Faggotter 2021). The large volumes of water discharged from the estuaries in the medium-to-large wet seasons during our study resulted in substantial loads of nutrients delivered into the nearshore area, directly and indirectly driving coastal productivity. There were no consistent differences in the nutrient loads between the estuaries, with the scale of the freshwater flow from year to year being the major driver of variability.
- The Flinders estuary was generally the most productive in terms of primary productivity rates (~algal growth rates), compared with the Mitchell and Gilbert estuaries (Burford and Faggotter 2021). Chlorophyll *a* concentrations (algal biomass) in the water and on the intertidal flats across the three systems were comparable to each other and to other tropical estuaries. However, in contrast to other tropical estuaries, respiration rates on

intertidal flats and the organic carbon content of sediments were both low, suggesting limited organic carbon availability from sources other than primary production on the mudflats. This suggests that mangrove detritus is not a major contributor to mudflat productivity. There is little evidence for major organic carbon inputs from freshwater flows in the wet season.

- We tested experimentally whether the input of nutrients to the mudflats was important for stimulating primary production on the mudflats. Primary productivity rates increased in all three estuaries in response to nutrient inputs in both the dry and wet seasons (Burford and Faggotter 2021), indicating that that all three estuaries were chronically nutrient-limited during our study and that wet season inputs of nutrients are critical to maintain primary productivity. This has flow-on effects to food availability for animals within the system.

Banana prawn fishery

- Juvenile banana prawns (*Penaeus merguiensis*) use Gulf estuaries each year for some months as feeding and refuge areas. This study found that the densities and the total number of juvenile banana prawns in each estuary varied substantially between years, with no statistical differences between estuaries (with the exception of the Gilbert estuary in November 2017; Burford et al. 2020). This suggests that all three estuaries are important to the fishery, with the relative importance varying from year to year.
- The study confirmed previous studies in other Gulf rivers showing that during the wet season, most juvenile banana prawns leave the estuaries for offshore areas in response to low salinity and food availability. Adult prawns continued to be captured in lower densities in the nearshore area, highlighting that not all prawns migrated to the offshore fisheries. These nearshore prawns may be an important source of recruitment of postlarvae into estuaries.
- A spatio-temporal Bayesian model was used to quantify the relationship between low, medium and high-level flows and banana prawn catch in the offshore fishery. Three water development scenarios were tested and the effects of this loss of flows were examined. The study predicted a significant decline in banana prawn catch with decreasing flow levels from water extraction (Broadley et al. 2020). Catch was most heavily impacted by water extraction during low-flow years (1 year in 5) for all three rivers. Considerable impacts on catch were also predicted during medium-flow conditions. The greatest impact of water extraction occurred in the scenario with a dam on the Mitchell River, where a 53% reduction in catch was predicted during low-flow years. Overall, these results imply that maintenance of low-level flows is a crucial requirement for sustained fishery yields. Adverse impacts of water extraction are also likely in medium- and high-flow years, depending on the scale of water development.
- Building on the research of Broadley et al. (2020), the impact of irrigation extractions on the financial performance of the banana prawn NPF was assessed. Results suggest that vessel-level business profit could reduce by between 7% and 12% if currently granted entitlements and planned allocations were extracted from Gulf rivers, or by around 22% if major dams are also constructed in the Mitchell River. Fishing effort could be reallocated from the highly productive and economically important south-eastern Gulf to other regions of the NPF, and if that is the case some – but not all – of the revenue shortfall could be recovered. This assumes fishing is not already at capacity in these other regions.

Barramundi fishery

- A historical collection of barramundi otoliths (ear bones) was examined from the Flinders, Gilbert and Mitchell regions to quantify the relationship between river discharge volumes and otolith increment widths, which serve as a proxy for growth. Across all three regions, total river discharges from January to March each year had a strong positive effect on otolith increment widths (growth rate) of barramundi up to three years old (Leahy and Robins 2021). This relationship was particularly strong in the Gilbert and Flinders regions which experience intermittent, highly seasonal flows. River discharge from October to June positively affected juvenile growth rates in the Mitchell region which experiences perennial flow.
- Juvenile barramundi growth rates were modelled under a hypothetical severe water extraction scenario for the Mitchell region. Models predicted a 19% reduction in juvenile barramundi growth rates from birth to the formation of the third otolith increment (age 2+; Leahy and Robins 2021). This translates into smaller fish available for the commercial and recreational fisheries, as well as fewer fish, given that smaller fish are more vulnerable to predation.
- The barramundi increment-width models were adapted to use atmospheric indices such as the Southern Oscillation Index (SOI) and the Madden-Julian Oscillation (MJO) to replace river discharge data when adequate flow data is not available (Leahy and Robins 2021). The intensity of positive wet-season MJO pulses, as well as SOI values corresponding to La Niña events, had strong positive effects on juvenile barramundi growth rates.
- Analysis of barramundi catch and age data identified that the highly variable recruitment of Gulf of Carpentaria barramundi across rivers of the Gulf is significantly related to river flow. Patterns in catch-at-age highlighted the importance of the sequential pattern of river flows over multiple years on barramundi population dynamics i.e. not just in their first year of life. As a long-lived species (22 years, in the Gulf), with female maturity occurring on average at seven years, barramundi are a long-term measure of ecosystem health that integrates inter-annual patterns in the relationship between estuarine production (in the broadest sense) and river flows in Gulf catchments.
- Analysis of strontium$^{87/86}$ isotope ratios from otoliths of barramundi indicated variable use of freshwater habitats by individuals in the Mitchell, Gilbert and Flinders rivers. The Mitchell River had the highest freshwater residency (~60% of sampled individuals, with residency defined as the type of aquatic habitat inhabited over the dry season). The Flinders River had the highest estuarine residency (~67%), while the Gilbert River had the highest 'intermediate' residency (i.e. brackish, 66%). These results indicate that differences in the geomorphology and inter-annual river flow patterns between the Mitchell, Gilbert and Flinders rivers affect spatial and temporal connectivity of aquatic habitats (including seasonal floodplains) used by barramundi. Water-resource development should aim to minimise disruption to the frequency and duration of floodplain inundation and connectivity along the river system to maintain the natural productivity of barramundi in Gulf of Carpentaria catchments.
- Currently, the long-established Gulf of Carpentaria Inshore Fin Fish Fishery harvests barramundi and other species (e.g. king threadfin and mud crabs) that rely on estuarine productivity. This is supported by the patchwork of river flows in time and space. This concurs with the finding on juvenile banana prawns – the Mitchell, Gilbert and Flinders

rivers all contribute to the production of estuarine fisheries, although variably between years.

- Barramundi are well adapted to the variable climate of northern Australia, being highly fecund (i.e. producing millions of eggs) and capable of very fast growth and relatively high survival when conditions are optimal. However, the Gulf of Carpentaria and associated catchments are vulnerable to extremes in climate, as evidenced by successive poor wet seasons (e.g. 2013 to 2015). Successive poor wet seasons reduced the spatial extent of aquatic habitats, negatively affecting barramundi recruitment, growth and survival. We suggest barramundi population dynamics are most sensitive to altered patterns of river flow during and immediately after successive years of below-median flow. Water resource development in the Mitchell, Gilbert and Flinders rivers should aim to avoid exacerbating or prolonging the impacts of climate variability on Gulf of Carpentaria barramundi populations.
- The relationship between monthly barramundi commercial catch, effort and river flow in each catchment was determined over the 1990–2010 period to estimate the economic cost to the barramundi fishery from water extraction. The most likely water development scenarios in each catchment were tested. The net present value (NPV) of the average commercial barramundi licence under baseline conditions was shown to range from approximately $146,000 in the Flinders River catch zone to approximately $451,000 in the Mitchell River catch zone (McMahon et al. 2020). Water extraction reduced NPV by 6%, 9% and 6% for the Flinders, Gilbert and Mitchell catch zones respectively.
- The modelling indicates that water extraction scenarios would reduce NPV for each fishery catch zone by 6%–9%. For irrigated agriculture, obtaining an NPV sufficient to deliver an acceptable return on investment would only be possible under a limited set of circumstances, i.e. optimal growing conditions for agricultural crops and major local processing facilities funded by a third party (McMahon et al. 2020).

Floodplain productivity

- The large-scale assessment of the productivity of the Flinders and Gilbert floodplains used a framework that integrated remote-sensing biophysical indicators (vegetation and inundation) with hydrological data (rainfall and river discharge; Ndehedehe et al. 2020a, 2020b). The same approach was used for the Mitchell floodplain in NESP Project 1.3.1 (Ndehedehe et al. 2021).
- In the Flinders, long-term (10–30 years) modelling showed that area of the catchment inundated in the wet season ranged from less than 50 km^2 up to 2,500 km^2, although in most wet seasons the area inundated was less than 500 km^2. Areas ranging from less than 50 km^2 up to 1,000+ km^2 were inundated in the Gilbert, and estimated average inundation in the Mitchell ranged from 50 to 500 km^2, with most years less than 200 km^2. Overall, the Gilbert and Mitchell catchments had similar inundation in the wet season over the long term. However, the Mitchell catchment had longer periods of inundation compared to the other two catchments, providing more time each year for aquatic vegetation to become established and productivity to increase.

Implications

These new and important findings have implications for water planning.

- Maintaining flows in low- and medium-flow years is critical for sustaining estuarine productivity. These flows deliver essential nutrients that fuel primary productivity. This has flow-on effects to the whole food web that relies on the primary producers (i.e. algae). Additionally, first-flush flows at the start of the wet season are crucial for delivering nutrients which stimulate productivity, providing food for fisheries species, as well as other species such as migratory shorebirds. The first flush is also important in reducing estuarine salinity, which is typically hypersaline in the late dry season and stressful for the plants and animals living in the estuaries. The Flinders estuary is likely the most in need of first-flush flows due to the longer period of no-flow each year, compared with the Gilbert and Mitchell estuaries, making it the most vulnerable to loss of these flows.
- In low- to medium-flow years, reduction of flows from water extraction will keep salinities high, making prawns less likely to move from the estuaries into the offshore fishery. Prawns are short-lived and face heavy predation within the estuaries, so prawns that do not move out of estuaries are unlikely to contribute to the next generation and fisheries catch will be affected in both the short and long term. The scale of impact in the short term has been quantified via a model of flow and fisheries catch, with implications for catch and profits.
- Water extraction in a year following multiple years of low-to-medium flow will have major impacts. This scenario is not unusual, particularly for the Flinders which has the highest interannual variability in flow of the three rivers and can have multiple consecutive years of no to low flow. Both banana prawn and barramundi (and other species using the estuary) will be highly vulnerable to additional years of no or little flow. It is not clear what impact climate change and resulting changes of weather patterns will have as there is considerable uncertainty in current models for this area of Australia.
- Modelling suggests that reductions in flow will affect commercial prawn and barramundi catch, with the potential that significant infrastructure projects, such as dams, will have major impacts on these fisheries. Economic analysis showed that substantial reductions in profits could result in the commercial prawn and barramundi fisheries in the short term. The potential adverse long-term cost implications to the fisheries are as-yet unquantified. Additionally, the commercial fishery harvests reflect only one source of value delivered by water resources in these catchments – other economic values include tourism revenue from recreational fishing, and Indigenous harvesting for fish and other species. Additionally, species and habitats are of environmental value. Water-resource development could put this full suite of values at risk.
- Gulf rivers do not have discrete catchments. During the wet season, these rivers sometimes interconnect to become one large floodplain, e.g. the Norman, Gilbert and Flinders rivers. Nutrients, sediments and animals move between river systems when they are connected and upstream activities may impact more than one river. The cumulative impacts of water-resource development should be considered across multiple river systems, not by individual catchments.
- Given the variability in flow from year to year and from river to river within a year, all rivers in this study and in other areas of the Gulf are important to sustaining downstream fisheries and estuarine species in general, as the network of rivers flowing into the Gulf of Carpentaria buffer one another in low-flow years.

- It may take some years to determine the impacts of water development on productivity in the estuaries, given the natural variability of the Gulf systems. Water allocation should occur on a cautionary basis.
- Inundated floodplains are crucial habitats for many species, including barramundi, as well as providing a nutrient source for rivers and estuaries as floodwaters drain. This study has provided important information on the scale and duration of flooding and how it differed from year to year between the three river systems. The longer periods of inundation of the Mitchell River floodplains (research undertaken in Project 1.3.1) mean that floodplains play a more important role for barramundi in the Mitchell than in the other two rivers. Water development needs to ensure that floodplain inundation is maintained.
- The modelling capacity developed in this project has the potential to be i) used by management agencies to evaluate future water-resource development scenarios and ii) provide a platform which can be enhanced over time as new knowledge is developed.
- A key remaining challenge is linking water development in the upper reaches of the rivers with impacts hundreds of kilometres downstream at the end of the catchment. This project could not directly address the explicit connection between upstream development and downstream impacts, but this should be given consideration in terms of predicting impacts.

This project focussed on fisheries and was closely linked to NESP NAERH Project 3.6 which examined the effects of water-resource development on migratory shorebirds. That project identified mechanisms where shorebirds may be affected. It provides another line of evidence that the ecosystem generally may be impacted by water-resource development. In summary, this project has provided important new information about why freshwater flows in the Gulf estuaries and floodplains are essential for banana prawn and barramundi fisheries as well as the broader estuarine ecosystem, and modelled the potential scale of the impact of water extraction on the fisheries. The economic costs associated with this have also been determined. The findings from this study should help to inform water planning for the southern Gulf and the Mitchell water resource planning areas.

References

Broadley, A, Stewart-Koster, B, Kenyon, RA, Burford, MA, and Brown, CJ (2020) 'Impact of water development on river flows and the catch of a commercial marine fishery', *Ecosphere,* 11:e03194.

Burford, MA, Faggotter, SJ, and Kenyon R (2020) *Project 1.4: Contribution of rivers to the productivity of floodplains and coastal areas of the southern Gulf of Carpentaria – Component 1*, final report to the Northern Australia Environmental Resources Hub (NESP).

Burford, MA, and Faggotter, SJ (2021) 'Comparing the importance of freshwater flows driving primary production in three tropical estuaries', *Marine Pollution Bulletin,* 169:112565.

Leahy, SM, Robins, JB (2021) 'River flows affect the growth of a tropical finfish in the wet-dry rivers of northern Australia, with implications for water resource development', *Hydrobiologia,* 848:4311–4333 doi:10.1007/s10750-021-04641-7.

McMahon, JM, Smart, JCR, Robins, J, Burford, M, Stewart-Koster, B, Brown, C, and Ndehedehe, C (2020) *Project 1.4, The value of freshwater in northern Australia: Trade-offs between irrigated agriculture and fisheries in the Gulf of Carpentaria*, Component 2. final report to the Northern Australia Environmental Resources Hub (NESP).

Ndehedehe, C, Burford, MA, Stewart-Koster, B, and Bunn, SE (2020a) 'Satellite-derived changes in floodplain productivity and freshwater habitats in northern Australia (1991-2019)', *Ecological Indicators,* 114:106320.

Ndehedehe, C, Burford, MA, Stewart-Koster, B, and Bunn, SE (2020b) 'Predicting hot spots of aquatic plant biomass in a large floodplain river catchment in the Australian wet-dry tropics', *Ecological Indicators*, 117:106616.

Ndehedehe, CE, Onojeghuo, AO, Stewart-Koster, B, Bunn, SE, and Ferreira, VG (2021) 'Upstream flows drive the productivity of floodplain ecosystems in tropical Queensland', *Ecological Indicators* 125:107546.

Smart, JCR, Curwen, G, and Burford, M. (2021) *Project 1.4. Estimating the economic impact of potential extractions from Gulf rivers on the banana prawn fishery,* Component 2. final report to the Northern Australia Environmental Resources Hub (NESP).