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# CSIRO submission on the National Water Reform 2020 Productivity Commission Draft Report 2020)

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# 1 Executive Summary

Over the last decade, Commonwealth and State Governments have developed plans and undertaken research to develop the water resources in some of Australia's large-catchment northern rivers. Three major research projects involving CSIRO have identified the potential water resource assets and catchment characteristics and ecology of rivers basins (Flinders and Gilbert Agricultural Resource Assessment (FGARA, Petheram et al. 2013 a,b); the Northern Australia Water Resource assessment (NAWRA, Petheram et al. 2018 a,b,c) and the Roper River Water Resource Assessment (RoWRA, CSIRO 2019, current).

As a result of these reports, a series of large-catchment northern rivers are now in-scope to support irrigated agriculture. However, the National Water Reform 2020 (Productivity Commission) Draft Report (NWR 2020) does not directly address the challenge for these tropical rivers. This is because the scope of the NWR 2020 does not extend to estuaries and coasts, and does not adequately address the influence of riverine flows as drivers of habitat suitability and estuarine productivity in the coastal ecosystem.

This submission provides background relating to the potential for irrigated agriculture in Australia's tropical rivers, and the potential impact for three tropical fisheries. This background provides the context for a discussion on the implications of omitting considerations relating to estuaries, coasts, and riverine flows in the NWR 2020 report. The submission concludes with four suggested inclusions for additional content, including the proposal to incorporate a chapter describing the landscape and ecological characteristics of tropical rivers, especially their extensive estuaries, and the relevance of seasonal and annual flow characteristics that sustain ecological service provision for coastal ecosystems by river flows.

Abridged versions of full suggested inclusions are listed below.

**Suggested inclusion 1** - The scope of the report could be broadened to:

- better represent northern systems and connections with marine systems;
- provide greater recognition of the critical role of estuaries;
- provide guidance around water management to maintain estuarine functions that are critical to support high-value fisheries and other species; and
- include information specifically for tropical ecosystems.

**Suggested inclusion 2** - Differences in catchments and regional climate projections could be accounted for in the report.

**Suggested inclusion 3** - Water management targets could be amended to account for sustainability of economically valuable species.

**Suggested inclusion 4** - A chapter dedicated to matching water resource management with the environmental water requirements of rivers in Australia's wet/dry tropics is critical to the final NWR 2020 report to address the potential development of irrigated agriculture in Australia's northern tropical river catchments over the next 20 years.

## 2 Relevant CSIRO Capability

CSIRO has delivered research that supports sustainable management of Australian aquatic resources for many decades. Over the years this work has expanded to include work with regional partners, including international governments and industry.

Resource management is an inherently difficult and complex process that must balance competing ecological, economic and social objectives. Meeting these challenges effectively requires innovative new science that combines advanced observing and data management systems with analyses that integrate across biology, ecology, oceanography, social science and economics. A truly interdisciplinary approach is needed to study these complex socioecological systems and to provide effective solutions. CSIRO has this interdisciplinary capability and has applied it to deliver solutions across government, industry, and civil society.

Just as our capability is broad, so are the solutions we have delivered for resource (e.g. fisheries) and natural system (e.g. estuarine and coastal environments) management, which include:

- Advanced observing methods from sensors to genomics to support information systems necessary to detect change and to meet priorities such as State-of-the-Environment reporting
- Assessments of the impacts of human activities on biodiversity, ecosystem function and ecosystem services in catchments, estuarine and coastal systems
- Impact assessment of climate change and extremes on environmental systems
- Coupled socio-economic and biophysical models that explicitly account for human behaviour and activities
- Whole-of-system assessments that integrate social, economic and ecological objectives that are robust to uncertainty and which address trade-offs between competing uses.

Our capability and experience position CSIRO as a leading research organisation in the areas of ecological and socioeconomic impacts of natural resource management along with demonstrated delivery of management strategies and tools.

## 3 Background Information

### 3.1 Potential for irrigated agriculture within Australia's tropical river catchments

#### 3.1.1 Implications for estuaries and coastal regions

Over the last decade, Commonwealth and State Governments have developed plans and undertaken research to develop the water resources of Australia's large-catchment northern rivers. Three major research projects, representing a multi-million dollar research investment, have identified the potential water resource assets and catchment characteristics and ecology of rivers basins.

The Flinders and Gilbert Agricultural Resource Assessment (FGARA, Petheram et al. 2013 a.b); the Northern Australia Water Resource assessment (NAWRA, Petheram et al. 2018 a.b,c) and the Roper River Water Resource Assessment (RoWRA, CSIRO 2019, current) have provided comprehensive water and land assessments of nine catchments in the wet-dry tropics of northern Australia. Together with water resource assessment, the National Environmental Science Program (NESP) has undertaken projects to investigate the impact of water resource development on tropical ecosystems. NESP project 1.4 - 'Links between Gulf Rivers and Coastal Productivity' (Burford et al. 2020) - collected empirical data on estuarine productivity and statistical modelling of past catch data with streamflows to explore the effects of modification of natural flows due to water extraction on Northern Prawn Fishery catch (Broadley et al. 2020). In addition, a current Fisheries Research and Development Corporation (FRDC)-funded project involves development of a quantitative dynamic MICE (Models of Intermediate Complexity for Ecosystem assessments) (Plagányi et al. 2014) model to quantify the impacts of alternative water resource development scenarios on key components of the Gulf of Carpentaria ecosystem, including valuable prawn, barramundi and mud crab fisheries, as well as threatened, endangered and protected species such as sawfish (Plagányi et al. 2020). The project involves extensive stakeholder consultation, and includes the Northern Prawn Fishing Industry Pty Ltd CEO Annie Jarrett as a co-investigator. These projects will quantify levels of water extraction that influence the marine ecosystem and cause significant catch reductions in Gulf of Carpentaria fisheries and explore water management scenarios that optimise benefits for multiple users, including trigger levels below which flow should not be interrupted.

A series of large-catchment northern rivers are now being evaluated as potential locations to support irrigated agriculture. Documenting the landscape, water and ecological asset inventories are the first steps towards the development of water infrastructure and irrigated agriculture in Australia's tropical rivers. The Australian Government has signalled support for the construction of major infrastructure developments to secure water resources to support irrigated agriculture (PMC 2015). "Up to \$3.5 billion in Australian Government funding is available through the 10-year National Water Infrastructure Development Fund (NWIDF) for projects that deliver water to agriculture and primary industry" (Productivity Commission 2020). Water Resource Development (WRD) projects in Australia's tropical river catchments are also eligible for concessional finance from the \$5 billion Northern Australia Infrastructure Facility.

Within tropical ecosystems, estuarine and marine biodiversity, and fisheries productivity and economic performance, depend vitally on maintaining catchment flows as close as practical to

historical seasonal and annual trends. Stakeholder consultation is critical to management decisions regarding quantifying flow requirements, levels of managed flow and the triggers that will sustain end of system flow requirements. Particularly during low flow periods, stakeholder-agreed risk-based minimum flow thresholds will be a critical component of flow management. In Australia's wet/dry tropics, periods of up to 7 years of low flows have been recorded in catchments targeted for irrigated agriculture (although 3-4 years is more common). During consecutive years of low flows, the maintenance of flows that sustain downstream ecosystem services will need to be considered with respect to the requirements of agriculture and other needs such as ecological needs.

Rivers in the wet/dry tropics of northern Australia differ from southern rivers and rivers within inland basins; many are not perennial, often >80% of annual flows occur in three months (wet season), and most have a large estuary (often ~ 100 km long) which, as combined habitats, form a major component of the coastal tropical ecosystem (Eliot and Eliot 2008, Petheram et al. 2008, 2012). In the Australian tropics, >90% of rainfall occurs in the months of January to March and in many northern rivers, streamflow is confined to 3-4 months each year; the remainder of the year is dry and the landscape subject to very high evaporation. In 50% of rivers, >80% of flows occur in the January-March peak period (Petheram et al. 2008). River estuaries are key littoral ecosystems that sustain the juvenile-to-adult phases of many tropical fish and crustacean species - they are refugia in a stressed dry-season environment. In addition, they are critical habitats for key life-history stages of many other species. Estuaries may not support the adult phase of a tropical species; but their capacity as productive habitat during crucial seasonal offshore/inshore migrations sustains the populations of a multitude of species. Habitat stability during the dry season is critical and estuaries provide these stable habitats.

Estuaries change during the wet season; they become dynamic systems with large freshwater through-flows, and, after taking advantage of habitat stability during the dry season, many of the species that reside in tropical estuaries have evolved to take advantage of the annual wet season's estuarine-inputs to enhance their population or emigrate to habitats more favourable to later life-history stages (Burford et al. 2020).

Australia's tropical estuaries also are critical habitat for Threatened, Endangered and Protected species such as freshwater sawfish, freshwater whiprays, river sharks and snub-fin dolphins. Freshwater whiprays and river sharks occupy euryhaline (brackish) waters within tropical estuaries (Thorburn et al. 2003; Pillans, et al. 2009; Pillans 2014). Freshwater sawfish occupy marine, estuarine, and riverine habitats; importantly, freshwater up-river habitats are critical for juvenile sawfish, they move up to 400 km upstream after adult female sawfish pup in tropical river estuaries (Pillans 2014). Snubfin dolphin also use estuarine and coastal marine habitats (Palmer et al. 2011, 2014).

Wet season dynamic flows cause disruption to riverine and estuarine ecology that includes estuarine/river connectivity, nutrient inputs, emigration cues, enhanced estuarine and nearshore productivity, and estuarine/floodplain connectivity. Tropical populations can pulse by number and biomass in response to large flood flows which enhance habitat connectivity, ecosystem productivity and migration cues.

In the Australian tropics, several crustacean and fish species that inhabit estuaries during their life history are high-value fishery species that are harvested seasonally in remote regions of the tropics. The population of these harvested species benefit from the pristine habitats of remote northern Australia. Uninterrupted natural stream flows are characteristic of these pristine

habitats and seasonal monsoon flows to estuarine habitats are key to population stability. Moreover, for several harvested species, high flood flows during the wet season support high population levels and strong economic returns from their fisheries. Historically, the remote operation of these annual harvest fisheries along the northern Australian coast has been supported by a very low level of anthropogenic activity across the catchments and coasts. Annual wet season flows vary markedly in the tropics and during years of low wet season flows, fishery catches can be low and marginally economic. In contrast, the frequency of high-level wet season flows ensures that bumper harvests occur regularly enough for the long-term economic viability of tropical fisheries. In addition to the economic benefits of these fisheries, Traditional Owners rely on them for sustenance, and to maintain cultural practices and ecological knowledge developed over thousands of years. As well, recreational fishers target species such as barramundi as a highly prized catch during both individual fishing expeditions and via a developing charter industry.

The impacts of natural streamflow modification within northern rivers on the habitats, habits and populations has the potential to impact key fishery species, such as three high-value species; banana prawns, barramundi and mudcrabs.

**Table 1 Prominent tropical Australian fisheries species with a life history stage that resides within estuaries of wet/dry tropical rivers, including those catchments suitable for irrigated agriculture in northern Australia (Bayliss et al. 2014; Laird 2020).**

<i>Fishery</i>	<i>Species fished</i>	<i>Tonnage (10-year average)</i>	<i>Proportion of catch</i>	<i>Fishery value (combined)</i>
<b><i>NPF</i></b>	Banana prawns	4942	68%	\$110 M 2019
	Tiger prawns	1750	24%	
	Endeavour prawns	501	7%	
<b><i>Inshore Net (Queensland)</i></b>	Barramundi	793	66%	<\$20 M
	King threadfin	300	25%	
	Blue threadfin	80	7%	
	Queenfish	20	2%	
<b><i>Mudcrab</i></b>	Mudcrab (NT)	215	60%	<\$20 M
	Mudcrab (Qld)	183 (130 in 2017)	40%	

### 3.1.2 Suggested inclusions in relation to tropical rivers and National Water Reform

The current National Water Initiative (NWI) proposes “...to ensure that proposals for investment in new or refurbished water infrastructure continue to be assessed as economically viable and ecologically sustainable prior to the investment occurring” (Productivity Commission 2020). The Environmental Management section of the Executive Summary of the NWR 2020 Report states that an aim is “clearly specifying environmental objectives and outcomes; ensuring adequate low-flow provisions; integrating environmental water management with waterway and catchment management; identifying institutional responsibility for waterway management; creating adaptive monitoring programs; and developing clear processes to adapt environmental management objectives as changes in climate necessitate”.

To achieve these aims for the next decade of Australian water resource development, national water reform will need to address water resource management to sustain environmental water and ecosystem service provision to tropical estuaries and estuarine dependent species within the geographic locations of likely development of irrigated agriculture.

The NWR 2020 however does not address the challenge for tropical rivers. The scope of the NWR 2020 does not extend to estuaries and coasts, nor the influence of riverine flows as drivers of habitat suitability and estuarine productivity in the coastal ecosystem. We suggest the NWR 2020 consider incorporating a chapter describing the landscape and ecological characteristics of tropical rivers, especially their extensive estuaries, and the relevance of seasonal and annual flow characteristics that sustain ecological service provision for coastal ecosystems by river flows.

## 3.2 Three tropical fisheries that are dependent on tropical river estuaries

Banana prawns (*Penaeus merguensis*) are characterised by an annual inshore/offshore life history where the adults occupy relatively shallow coastal waters (10-30 m deep) and highly fecund females spawn large numbers of eggs which develop into pelagic larvae. During their juvenile phase however they are estuarine residents and over about 3-4 weeks, the larvae advect inshore on current and tides to move up the large estuaries of tropical Australian rivers to become benthic residents within the mudbank-mangrove forest matrix in estuarine tributaries. They reside within the estuary for 3-4 months and as they grow, they move to downstream estuarine habitats from where they emigrate offshore to grow to adults. Natural mortality and fish predation is high within estuarine habitats, and the population suffers mortality that can reach 20% per week. Forty years of biological research has demonstrated that large catches of banana prawns in the offshore fishery are directly related to high-level flood flows that cue estuarine juvenile banana prawns to emigrate offshore to marine habitats where mortality is lower, the population thrives, and they are harvested annually (Vance et al. 1998, Duggan et al. 2019, Broadley et al. 2020). Within-catchment water extraction or impoundment to support irrigated agriculture has the capacity to reduce the level and seasonality of annual river flows and hence reduce the contribution of the annual banana prawn population to the offshore fishery.

Barramundi (*Lates calcarifer*, a large catadromous predator) are characterised by an inshore/riverine life history and they occupy estuaries and close-inshore habitats as adults. They spawn in the lower estuary and the larvae and small juvenile fish are estuarine. Juvenile fish however move upstream to freshwater riverine and floodplain aquatic habitats. Access to freshwater floodplain habitats is dependent on the level of high river flows, overbank inundation, access to floodplain



billabongs, and the creation of shallow floodplain aquatic habitats during the wet season. During the ensuing dry season, juvenile barramundi occupy permanent waterhole refugia in both the mostly dry river channels and on the floodplains. As small adults, barramundi are all males and they spend ~1-3 years in freshwater habitats. Subsequent high-level wet season flows reconnect the refugia and male barramundi emigrate downstream to the estuary where they mix with females to ensure successful annual spawning events in the lower estuary. Within the estuary, individual male barramundi transform to become females and they remain females for their ~ 30-year life. They are fished as female fish using net selectivity and closed seasons to ensure only large reproductively mature fish that have contributed to the subsequent generation are harvested. For barramundi, high level flows ensure connectivity of both floodplain and riverine habitats and riverine and estuarine habitats to sustain high population levels. Barramundi fishery catch is lagged by 1-6 years as they are a longer lived species and high-level flows as juveniles and male fish support palustrine and riverine habitat connectivity that sustains a large population which emigrates downstream to the estuarine fished population 3-6 years hence (Robins et al., 2005; Balston 2009; Crook et al. 2017).

Mudcrabs (*Scylla serrata*) are characterised by an inshore/offshore life history, however, unlike banana prawns, both their juvenile and adult phase are estuarine residents. Ovigerous adult female mudcrabs emigrate offshore to release their eggs in marine waters and their pelagic larvae return inshore to reach their estuarine habitats where they settle to a benthic existence at the mangrove forest interface or within seagrass vegetation after about 3 months. Juvenile mudcrabs are tolerant of low-salinity conditions within an estuary (3-45 ppt) and benefit from the freshwater flows delivering nutrients and stimulating productivity within estuarine habitats. Adult crabs are less tolerant to low-salinity estuaries, though they thrive in brackish conditions. Mudcrabs emigrate from estuaries that are subject to freshwater events during high-level floods and move to coastal littoral habitats. The relationship between flows and mudcrab populations is less well defined than for banana prawns and barramundi, however, several researchers have found a positive correlation between flow and commercial mudcrab catch (Meynecke et al. 2010, 2012), and recent regional analyses of multiple environmental drivers have confirmed the influence of flow on catch, but with regional differences (Robins et al. 2020).

Characteristically for Australia's tropical estuaries, each year over the last four months of the dry season (September to December), the estuaries provide stable habitats for the settlement and benthic recruitment of juvenile fish and crustaceans following annual reproductive events. Estuarine macrophytes (mangroves, seagrass and algae) provide the juvenile phase protection from predation (Kenyon et al. 1995; Vance et al. 2002), while microphytobenthos sustains primary production and estuarine foodwebs (Burford et al. 2012, 2016; Duggan et al. 2014). After occupying the stable estuary to survive and grow, the onset of the wet season changes the estuarine environment and the habitats available to estuarine residents. Freshwater inflows transport sediments, deliver nutrients, lower salinities, create mechanical forces and scouring, inundate over-bank habitats, connect ephemeral habitats, and modify tidal inflows. Each species has evolved to use one or more of these annual opportunities to enhance their population or move to a habitat suitable for the next phase of their life history. The timing and volume of wet season flows and floods are critical to estuarine conditions and species response to the monsoon-driven river flows.

Water resource development has the potential to modify the level and timing of historical flow regimes that are characteristic of tropical Australian rivers. Water extraction or impoundment may reduce flow volumes, consequentially reducing crustacean and fish populations, and population biomass available to be fished. Sequential years of reduced flows due to water

diversion for irrigation may increase the frequency of low-level flow years and hence increase the years of uneconomic catches to a level where the long-term economic viability of the fishery is compromised (Broadley et al. 2020). In the Ord River estuary, uncharacteristic high-level perennial flows that are non-typical dry season conditions for tropical rivers reduce the salinity of the estuary to near-freshwater. Intolerance of freshwater by juvenile banana prawns precludes settlement to the upper section of the estuary and inhabitation of a portion of their historical habitat by juvenile banana prawns (Kenyon et al. 2004). Perennial flows down the Ord River has reduced the overall extent of juvenile banana prawn habitat in the Cambridge Gulf estuarine-complex. In Australia's wet/dry tropics, species have evolved life-strategies to match the high variability and timing of historical flows, and flows that vary from these seasonal and annual patterns debilitate long-term population stability.

Changes to the timing of flows, particularly early season flows that enter the estuary at the end of the annual dry season, can modify flow-cued behaviour such as emigration, and upstream migration, as well as modify the delivery of nutrient loads to the estuary and nearshore habitats.

Medium to long-term effects on tropical estuaries from flow modification are reduction of nutrient transport and flux in estuarine and coastal habitats (Burford et al. 2020), and changes to the deposition regime within the estuary and to coastal soft-sediment geo-morphology (Asbridge et al. 2016).

## 4 NWR 2020 report – estuaries, coasts, and riverine flows

In its current form, the NWR 2020 report is terrestrial and ‘inland-wetland’ focussed. Much of the text describing catchments and water resources, the examples provided for a range of situations, and the language used throughout the document is derived from a terrestrial perspective. Hence, consideration of the impact of water resource development on the ‘terrestrial fringe’ - i.e. estuaries and coasts does not appear anywhere in the document. Managing tropical river stream flows to sustain the natural sequence and quanta of monsoon-driven flows to tropical estuaries following water resource development is not a subject addressed in the NWR 2020 report. Hence, sustaining the ecosystem services provided to the fish and crustaceans that inhabit tropical estuaries is not addressed, and it would greatly increase the utility of the document if the NWR 2020 report could include content relating to tropical river landscapes, hydrology or ecosystems, particularly ecosystems at the terrestrial/marine interface.

In addition, there is no acknowledgement within the document that maintaining natural flows or components of natural flows can generate positive economic returns from the exploitation of a naturally occurring asset that can be sustainably harvested under natural flow conditions (e.g. a fishery). Yet, given the projections of northern tropical catchments being open to the development of irrigated agriculture, tropical rivers with extensive, productive estuaries that support major northern fisheries may become key river catchments subject to water resource development and management.

An extension of the terrestrial underpinning of the NWR 2020 report ensures that the ‘Environmental Management’ (Section 8) has a ‘high conservation value - species, habitat, community’ paradigm that defines the targets of environmental water allocation. Integral environmental values are identified: such as TEP species, floodplain connectivity, instream refugia, sustaining wetland and riparian communities, and pest management. There is no reference to economic value of a harvested species or the use of environmental water to maintain the population level or value of a harvested species or a habitat that is vital to a harvested species. Hence, a harvested resource such as a fishery is not identified as a value integral to requiring environmental management or provisioning. Given the extension of water resource development to the northern tropical rivers, this is a significant gap in the scope of the NRM 2020 report.

Many of the water management concepts in Chapter 8 and Chapter 13 ‘Investment in Major Water Infrastructure’ have direct relevance to estuaries and coasts; but need to be adapted to be workable for the marine and estuarine ecosystem. Kenyon et al. (2017) reported to identify and collate current and future Water Resource Development pertinent to the Northern Prawn Fishery; a fishery dependent on critical estuarine habitats in the Gulf of Carpentaria for the juvenile phase of the prawn harvest. In part, they reported best-available ecological knowledge to develop a conceptual framework to understand the impact of flow modification on catch and flow-catch prediction. The ‘Environmental Water Management’ (flow rules and triggers, protection of environmental assets) and ‘Waterway Management’ (longitudinal and lateral connectivity) components of Figure 8.3 **‘The integration of environmental and complementary waterway management’** show strong overlap with water management principles and rules promoted by Kenyon et al. (2017). The NWR 2020 report’s Chapters 8 and 13 recognise a paradigm for environmental water management with direct relevance to estuarine systems; but does not apply it to the typical estuarine ecosystem of Australian tropical rivers.

Within Australia's wet/dry tropics, maintaining historical catchment flow patterns is critical for estuarine biodiversity and fisheries productivity and economic performance. Currently, a repository of scientific knowledge continues to accumulate to support stakeholder consultation and definition of management criteria that are vital to quantifying flow requirements and management protocols. For example, Broadley et al. (2020) identified that in low river flow years, water extraction for irrigated agriculture may reduce prawn catch in the NPF by a large proportion (~50%); reducing an already low projected catch to uneconomic levels. In contrast, harvesting water from high-level flows was predicted to reduce catch by a relatively small proportion and hence maintain a likely large fishery catch. Water managers could draw on examples from the state-of-the-art Harvest Strategy approaches used for Australian tropical fisheries which specify pre-agreed rules for actions in response to indicators, so to avoid ad hoc arguments whenever indicators change. Management criteria and response triggers could be incorporated in the Water Resource Plans (see Queensland's Water Plan (Gulf) 2007) that are developed by Queensland and Northern Territory water resource managers to manage catchment water resources to support multiple users, including irrigated agriculture and estuarine and coastal harvest fisheries. Due to the ~ 3-month annual monsoon-driven seasonal flows in Australia's tropical rivers, and particularly during low flow years, stakeholder-agreed risk-based flow management and minimum flow thresholds will be a critical for flow management.

## 5 Suggested inclusions

CSIRO presents the following four suggested inclusions for additional work to extend the NWR 2020 Report to include consideration of estuaries and coasts, and the influence of riverine flows as drivers of habitat suitability and estuarine productivity in the coastal ecosystem.

### Suggested inclusion 1 - Scope of the Report

The scope of the report could be broadened to better represent northern systems and connections with marine systems: NWR 2020 has an inland basin/ riverine habitat/ terrestrial wetland focus; rivers with long-established irrigated agriculture and subject to periodic drought conditions. Climate projections demonstrate both recent-decade and a continuing reduction in precipitation over coming decades. These rivers are characteristic of the southern portion of the Australian continent.

The report could include greater recognition of the critical role of estuaries: Australia's tropical rivers have extensive estuaries (often 100 km long) that are dry-season refugia for many fish and crustacean species, as well as threatened-endangered-protected species (TEPS) including large-bodied icon species, during the ~9 month annual no/minimal flow regime of the majority of tropical rivers. Estuaries are the 'engine room' for many high-value fishery species, supporting key life history stages of harvested (commercial and recreational) species, and species have evolved their life history in tandem with the seasonally and annually pulsed flows in the wet/dry tropics.

To address these issues, we suggest the NWR 2020:

- include a new chapter describing the landscape and ecological characteristics of tropical rivers, especially their extensive estuaries, and the relevance of seasonal and annual flow characteristics that sustain ecological service provision for coastal ecosystems by river flows.
- be extended to provide guidance around water management to maintain estuarine functions that are critical to support high-value fisheries and other species as no water resource management to sustain environmental flows and ecosystem service provision to estuaries is addressed in the NWR 2020 report. 50 years of tropical fisheries research in Australia has demonstrated that natural flows and high-level flows sustain the populations and peak catches of many harvested species. A water management target for the future provision of stream flows to sustain the habitats and migration cues of high-value fishery species is absent from the NWR 2020 report.
- Add information specifically for tropical ecosystems: The 'Environmental Water Management' and 'Waterway Management' of Chapter 8 of the NWR 2020 report show strong overlap with water management principles and rules recently espoused for Australia's tropical rivers that would sustain both fish and crustacean species, including high value species subject to sustainable harvest. The theme from Chapter 8 could be adapted to river water management within tropical ecosystems.

## Suggested inclusion 2 - Differences in catchments and regional climate projections

Differences in catchments and regional climate projections should be accounted for: the Australian and State Governments are planning to develop the water resources of Australia's large-catchment northern rivers in the wet/dry tropics; the catchment/estuarine/marine ecosystem of rivers in Australia's wet/dry tropics is very different to the inland basin catchments' ecosystem of rivers themed in the NWR 2020 report. Climate projections for Australia's tropics are uncertain, some models project an increase in rainfall in northern ecosystems; whereas other models project decreasing rainfall. Precipitation in Australia's tropics is highly variable both seasonally (a 9-month dry season) and annually (wet season rainfall can vary by one order of magnitude). There are also additional climate factors which interact with river flows to influence estuarine and marine system dynamics, including that this region is experiencing some of Australia's most substantial changes in sea level, and future El Nino events are expected to intensify.

## Suggested inclusion 3 - Water management targets

Water management targets should account for sustainability of economically valuable species: Chapter 8 of the report describes environmental management to sustain connectivity between riverine and floodplain wetland habitats, triggers for environmental flows, water management to support populations of aquatic species and other environmental targets. The targets in Chapter 8 are 'conservation targets' of species, habitats and TEPS. There is no concept of sustainable harvest of economic species as a management target for 'environmental flows', e.g. sustainable fishery harvest. This is in addition to the need to maintain species supporting recreational activities and businesses, as well as Indigenous cultural needs.

## Suggested inclusion 4 - Matching water resource management with the environmental flow requirements

A chapter dedicated to matching water resource management with the environmental flow requirements of rivers in Australia's wet/dry tropics is critical to the final NWR 2020 report to address the potential development of irrigated agriculture in Australia's northern tropical river catchments over the next 20 years. This chapter would address one of the recommendations of the report; but with estuaries and riverine connectivity as the target ecosystem components: "Natural resource management programs should give priority to the key environmental assets identified in water planning processes, provide funding and undertake the required works to protect those assets. During periods of water scarcity, natural resource management should focus on the protection of reserves and refuges and making sure that their regenerative capacity is protected (8.1)".

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