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Estimating the economic impact of potential extractions from Gulf rivers on the banana prawn fishery

Final report (component 4)

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1. Executive summary

The Northern Prawn Fishery (NPF), targeting primarily banana prawn and tiger prawn species off Australia's northern coast, consistently generates the highest annual catch revenue of all fisheries managed by the Australian Commonwealth Government. Large-scale irrigated agricultural developments have been proposed in the Mitchell, Gilbert and Flinders catchments that drain to the south-eastern (SE) Gulf of Carpentaria. Banana prawn fishing grounds in the south-eastern Gulf are regularly the most productive in the NPF and flows down Gulf rivers are known to affect banana prawn stocks. Concerns have been raised that irrigation extractions from these rivers could have significant adverse financial impacts on the NPF. Drawing on prior research linking Gulf river flows to changes in banana prawn catches in the south-eastern Gulf, we produce indicative estimates of the potential impact of irrigation extractions on the financial performance of the average vessel in the NPF. Results suggest that (without reallocation of fishing effort) vessel-level business profit could reduce by between 7% and 12% if currently granted entitlements and planned allocations are extracted from Gulf rivers, or by around 22% if, additionally, major dams are constructed in the Mitchell River. If fishing effort is successfully reallocated to other regions when catches drop in the south-eastern Gulf, some – but not all – of the revenue shortfall can potentially be recovered. These findings suggest that irrigation developments in Gulf river catchments could have significant financial impacts on the NPF. These impacts should be considered carefully before further irrigation development is undertaken in the region.

2. Introduction

The Northern Prawn Fishery (NPF), operating in the Gulf of Carpentaria and the Timor Sea off the northern coasts of Queensland, the Northern Territory and Western Australia, consistently generates the highest annual catch revenue of all fisheries managed by the Australian Commonwealth Government (Steven et al. 2020). The NPF targets mainly the banana prawn (*Penaeus merguiensis* [white banana prawn] and *Penaeus indicus* [redleg banana prawn]), tiger prawn (*Penaeus esculentus* and *Penaeus semisulcatus*) and endeavour prawn (*Metapenaeus endeavouri*, *Metapenaeus ensis*) species in 2 separate fishing seasons (AFMA, 2020; Patterson et al., 2020). The first fishing season (1 April to 15 June) mainly targets the banana prawn species (white banana prawns throughout most of the fishery, and redleg banana prawns in Joseph Bonaparte Gulf in the far west). The second fishing season (1 August to 1 December) mainly targets tiger prawn species (brown and grooved) (Laird, 2021). The fishery is divided into 15 fishing zones for reporting purposes (Figure 1) and – within the designated fishing seasons – is managed by a combination of entry and effort controls which are administered via tradeable boat licences (Class B Statutory Fishing Rights) and tradeable trawl headrope length units (Gear Statutory Fishing Rights), respectively (Laird, 2021). Closure can be triggered early in each season to preserve remaining stocks for spawning if designated catch per unit effort targets cease to be met (AFMA, 2020).

The first fishing season (hereafter the banana prawn season) is managed by limiting the number of boat licences to 52 (from 2007 to present) and, if necessary, via early closure triggered if the catch per unit effort in any of 3 two-weekly monitoring periods in the final 6 weeks of the season falls below a designated threshold. This threshold is set annually at the estimated maximum economic yield, accounting appropriately for year-to-year variations in input costs and prawn prices (AFMA, 2020; Laird, 2021).

Considerable research effort has been devoted to identifying and understanding the environmental factors that potentially affect NPF banana and tiger prawn stocks to inform fisheries management (Bayliss et al., 2014; Plagányi et al., 2021; Venables et al., 2011). For banana prawns, whilst it is well established that wet season (November to March) rainfall and river flows in catchments on the eastern side of the Gulf of Carpentaria affect the subsequent season’s catches in adjacent fishing zones (Broadley et al., 2020; Burford et al., 2010; Vance et al., 2003, 1998), high intrinsic variability has thus far frustrated attempts to produce a predictive population model that can be used to inform management (Larcombe and Green, 2015).

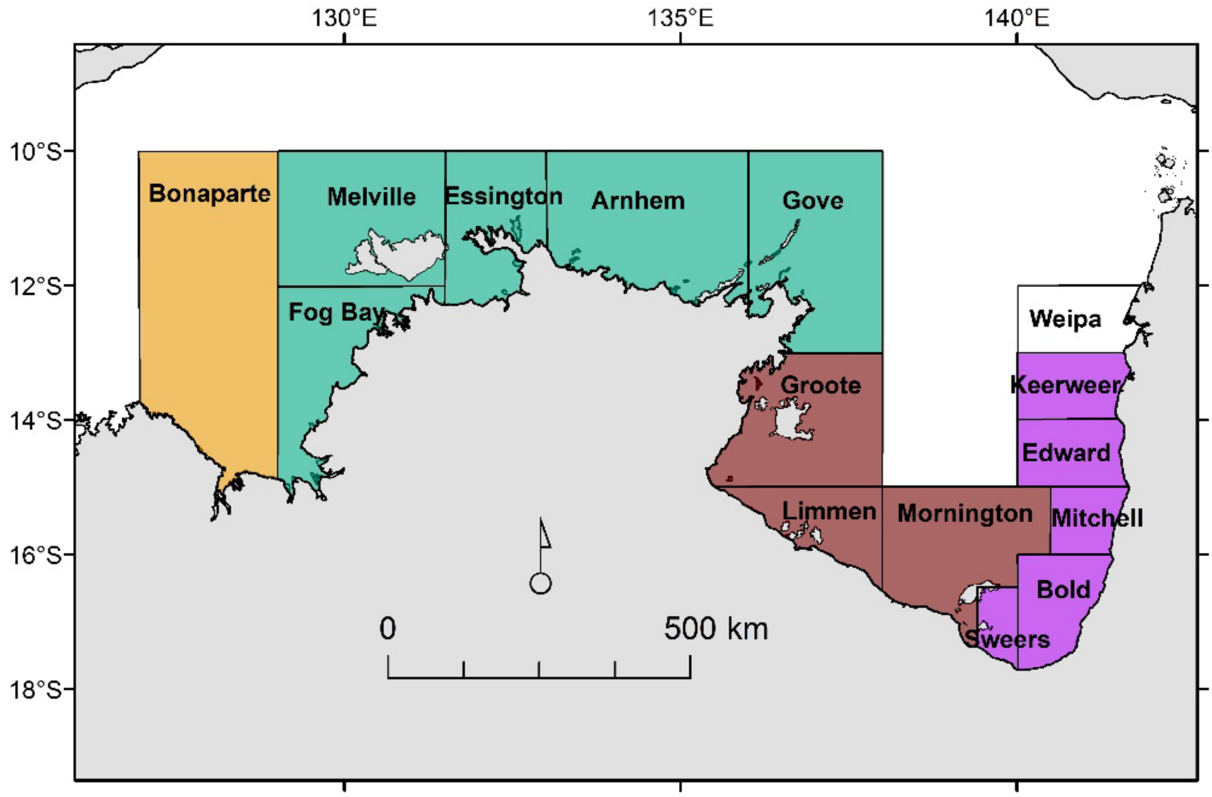

Figure 1. Fishing zones in the Northern Prawn Fishery. Zones in the south-eastern Gulf, western Gulf, Top End and Joseph Bonaparte Gulf are coloured purple, brown, cyan and orange, respectively.

Over recent years, several large-scale irrigated agricultural developments have been proposed in the Mitchell, Gilbert and Flinders catchments, and detailed assessments of the potential for irrigated agricultural development in the region have been produced (Petheram et al., 2018, 2013a, 2013b). Irrigation developments would entail substantial extractions from these rivers, potentially affecting end of system flows which are known to be important for annual recruitment of white banana prawn stocks into the NPF (Duggan et al., 2019). A recent study by Broadley et al., (2020) estimated the impact that potential extractions for irrigated agricultural developments in the Mitchell, Gilbert and Flinders catchments could have on banana prawn catches in fishing zones in the south-eastern Gulf. This short note uses Broadley et al.'s findings, in combination with publicly available data on annual catch and fishing effort at fishing zone resolution, to estimate the potential impact of irrigation extractions from the Mitchell, Gilbert and Flinders rivers on the financial performance of the NPF.

The note proceeds as follows. Section 2 collates historical catch and effort data to quantify the importance and performance of fishing zones in the south-eastern Gulf of Carpentaria in the banana prawn component of the NPF. It also describes prior research that quantifies how differences in economic performance between locations affects the spatial allocation of fishing effort within the NPF. Section 3 summarises Broadley et al.'s estimates of the reductions in banana prawn catch in the south-eastern Gulf that could follow from 3 different potential agricultural development scenarios in the Mitchell, Gilbert and Flinders catchments. Section 4 estimates the economic impacts of those catch reductions on the NPF as a whole, with and without allowing for potential reallocation of fishing effort. Section 5 discusses findings and Section 6 concludes.

3. Banana prawn catches and fishing effort in the south-eastern Gulf

The majority of the banana prawn catch in the Northern Prawn Fishery is taken during the first fishing season of the year (Figure 2).

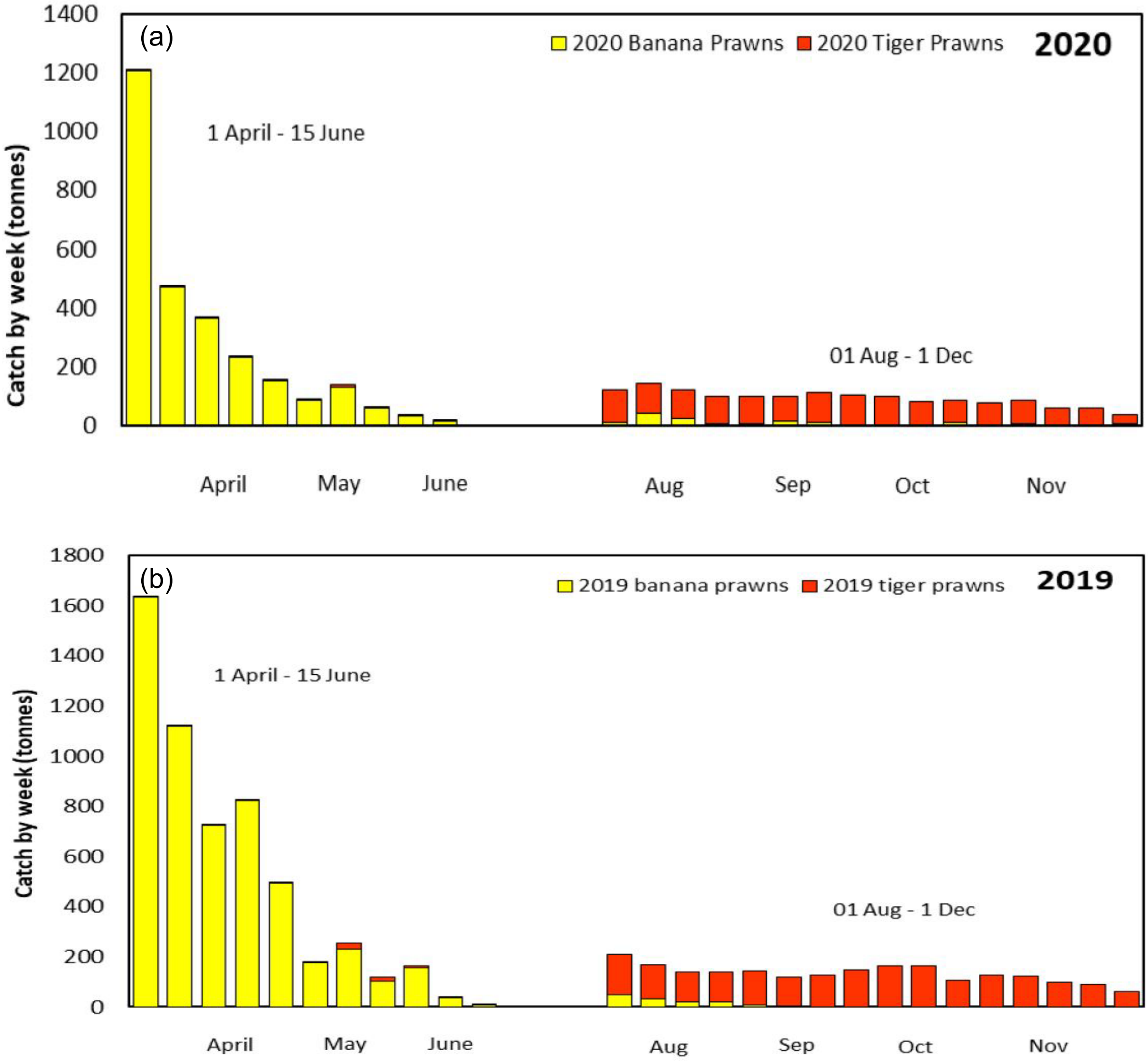

Figure 2. Reported catches of banana prawns (yellow) and tiger prawns (red) during indicative (a) low catch (2020) and (b) high catch (2019) years in the Northern Prawn Fishery. Copied from Laird (2020 Figure 3a, p.10; 2021 Figure 3a, p.10).

Fishing effort during initial weeks of the banana prawn season is typically concentrated in fishing zones on the eastern side of the Gulf of Carpentaria (Figure 3), with 5 zones in the south-eastern Gulf – Keerweer, Edward, Mitchell, Bold and Sweers (Figure 1 and Figure 4; hereafter south-eastern Gulf zones) typically attracting the highest levels of fishing effort, yielding relatively high banana prawn catches and returning the highest levels of catch per unit effort across the banana prawn fishery (Figure 5). The catch per unit effort (CPUE) achieved in the south-eastern Gulf zones (and the Weipa zone immediately to the north) is relatively high because, when the season opens, banana prawns typically occur in large aggregations ('boils') that can be targeted with the assistance of spotter planes (Die anEllis, 1999). Catch per unit effort remains high through the early weeks of the season whilst these aggregations persist. However, CPUE drops thereafter as the remaining stock becomes more dispersed (Figure 2).

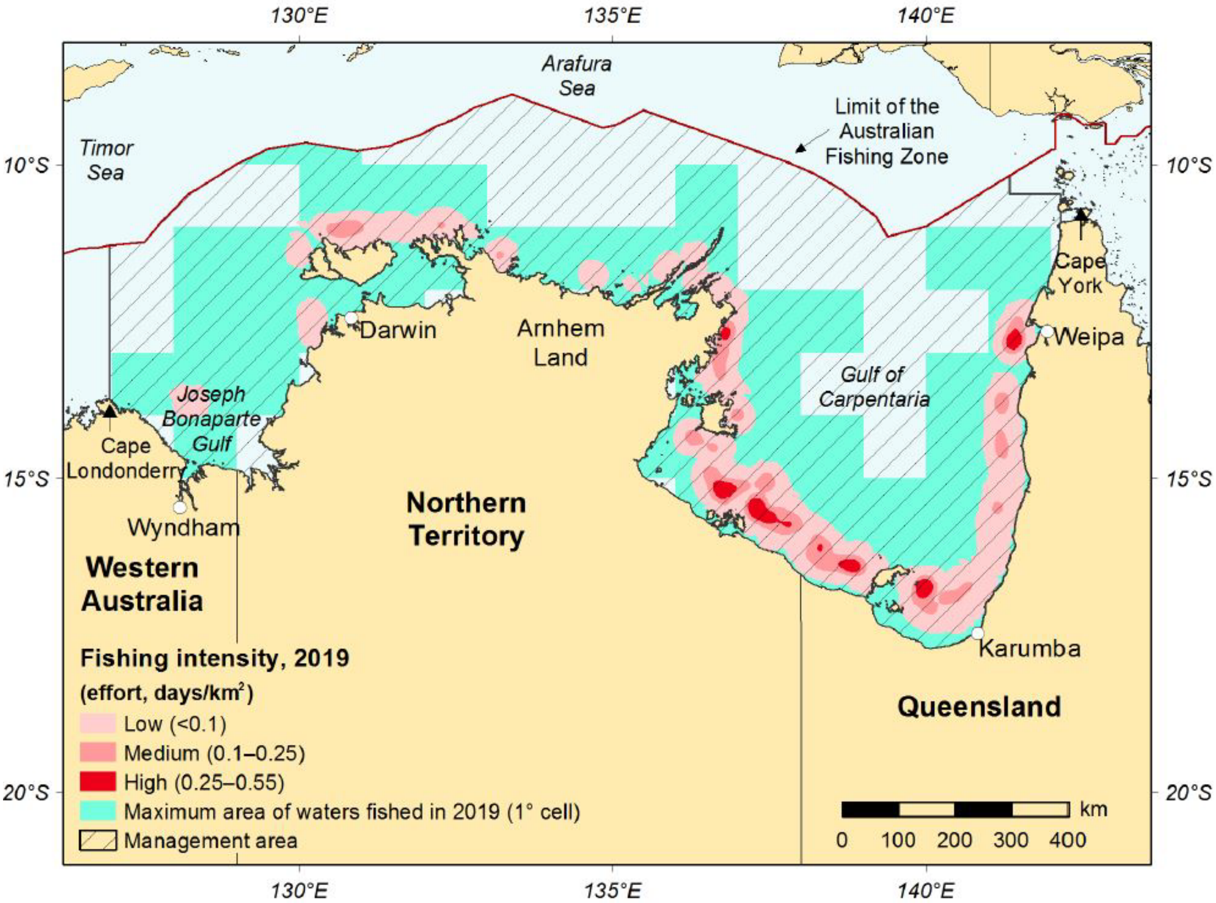

Figure 3. Indicative distribution of fishing effort across the Northern Prawn Fishery. Effort distribution is shown for both fishing seasons (the banana prawn season and the tiger prawn season). Those in the eastern Gulf are from the first (banana prawn) season (Pascoe et al. 2020; Figure 1, p.2). Copied from ABARES (2019; Figure 5.1, p.65) Effort hot spots in the western Gulf of Carpentaria are from the second (tiger prawn) fishing season.

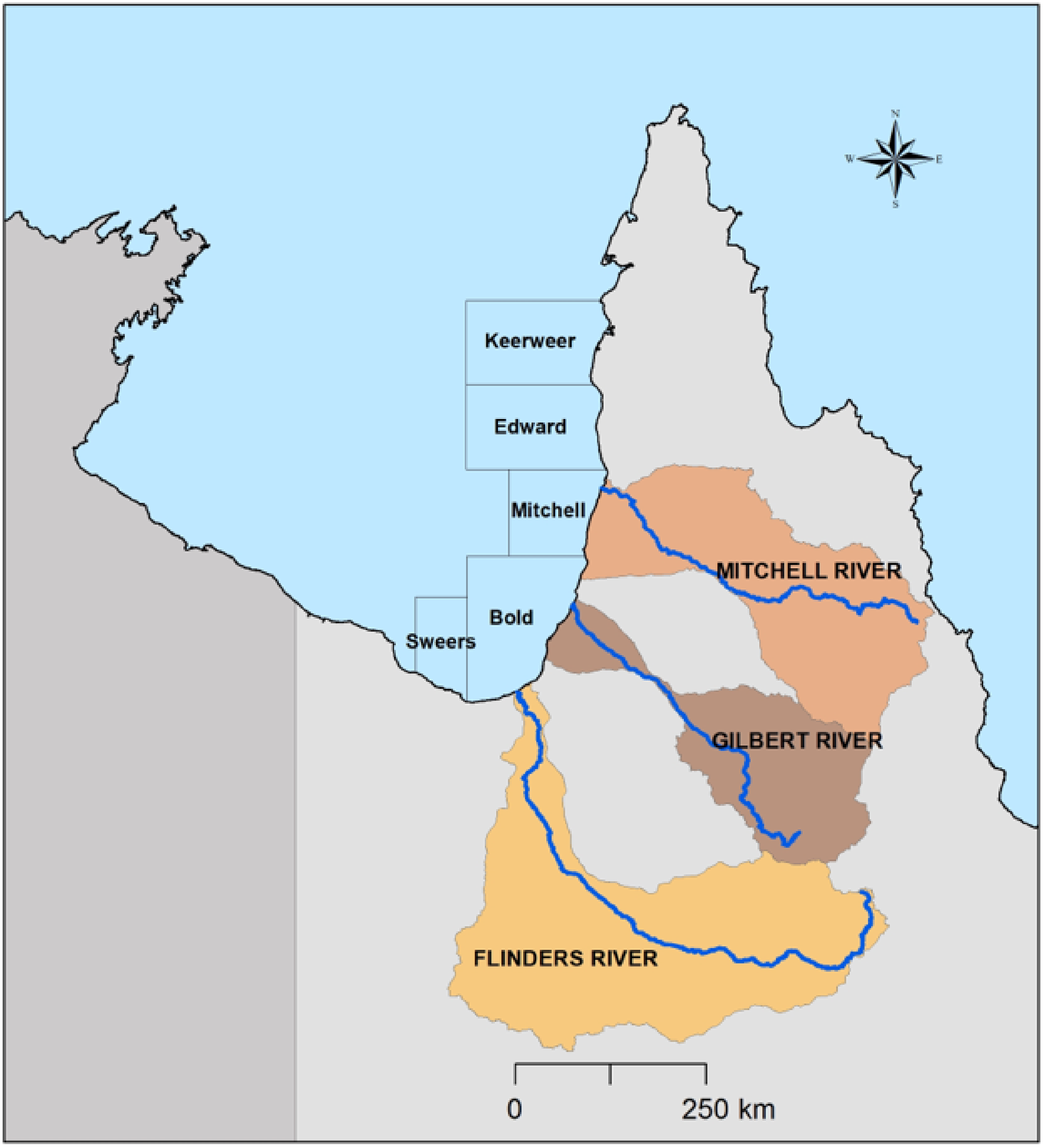

Figure 4. Northern Prawn Fishery fishing zones in the south-eastern Gulf of Carpentaria, showing adjacent river catchments.

As CPUE declines in the south-eastern Gulf, fishing effort is likely to disperse elsewhere. Pascoe et al. (2020) quantified the roles of environmental and economic drivers in the dispersion of NPF fishing effort between regions. Pascoe et al. (2020) had access to individual vessels' logbook data on catch and fishing location, aggregated by month, between 2004 and 2018. Pascoe et al. predicted the share of NPF fishing effort across 3 regions (the Gulf of Carpentaria, the Top End[1], and Joseph Bonaparte Gulf) by month, in response to environmental and economic drivers. In the case of the Bonaparte zone in the

[1] 'Top End' is used here to refer collectively to fishing zones Gove, Arnhem, Port Essington, Melville and Fog Bay (Figure 1).

far west, 2 environmental drivers – prior wet season rainfall and the state of the El Niño cycle – reflect fishers' prior expectations regarding the likely stock of redleg banana prawns in this region. This is known to be influenced by river discharges and tidal range in the Joseph Bonaparte Gulf (Plagányi et al., 2021). Pascoe et al.'s economic drivers of fishing effort reflect the opportunity cost and potential benefit of relocation. Fuel price proxies opportunity cost, whilst the *difference* in revenue per unit effort ($ per boat day) between source and destination locations reflects the potential benefit of relocation. Apart from the Bonaparte fishing zone[2], catches elsewhere during the banana prawn season will be predominantly of white banana prawns, so differences in revenue per unit effort between the Gulf and the Top End will simply reflect differences in CPUE (tonnes per boat day) between these regions (refer to Figure 5a for an indication of differences in CPUE between regions).

[2] Redleg banana prawns usually sell for a higher price than white banana prawns. Redleg prawns attracted a mean premium of 20% over banana prawns over the period 2004–2018 (Pascoe et al. 2020 – Supplementary Information).

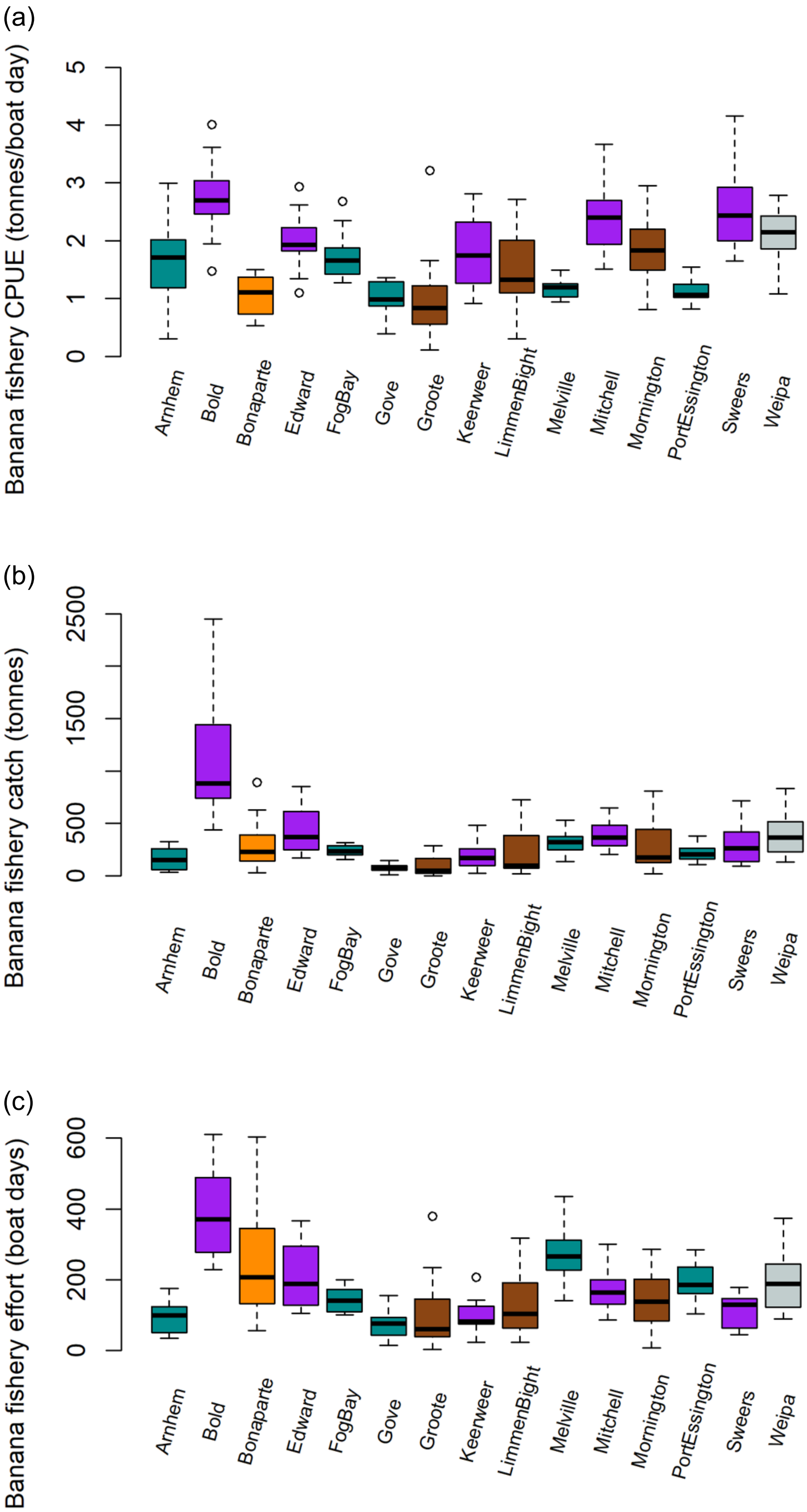

Figure 5. Catch per unit effort (a), catch (b) and fishing effort (c) by fishing zone in the banana prawn fishery 2007–2020. Zones in the south-eastern Gulf, western Gulf, Top End and Joseph Bonaparte Gulf are shown in purple, brown, cyan and orange, respectively. Data from Laird (2021; Appendix 1, Tables 12–26 p.59–66).

Pascoe et al.'s results indicate that, all else equal and based on 2004–2018 data, a $1,000 difference in revenue per boat day between source and potential destination regions will drive a 0.7% re-allocation of effort share between the Gulf and the Top End, and a 0.2% re-allocation of effort share between the Gulf and the Bonaparte fishing zone (Pascoe et al., 2020; Table 1, p.3). The average prices over the 2004–2018 period were $11,100 per tonne for white banana prawns and $13,450 per tonne for redleg banana prawns[3] (both in FY2018–19 AUD$). At these prices, a difference in catch per unit effort of 0.4 tonnes per boat day between fishing locations would be expected to drive approximately a 3% re-allocation of fishing effort share between the Gulf and the Top End, and approximately a 1% re-allocation of fishing effort share between the Gulf and the Bonaparte fishing zone.

Northern Prawn Fishery vessel and gear licencing arrangements underwent significant revision in 2007. A buyback program reduced the number of boat licences to 52 (from 95) and reduced the total number of headrope length units by 34% to align total fishing effort appropriately to achieve maximum economic yield (Laird, 2021). Fleet size has remained constant at 52 boat licences since 2007. To explore whether Pascoe et al.'s relationships regarding the distribution of fishing effort among regions might still apply after the fleet restructured in 2007, we investigated correlations among the shares of banana prawn fishing effort between the south-eastern Gulf, fishing zones in the western Gulf (Mornington, Limmen and Groote: hereafter 'western Gulf'), the Weipa zone, the Bonaparte fishing zone, and the Top End over the 2007–2020 period (whilst the size of the fleet has remained stable at 52 licenced vessels). Results are shown in Figure 6.

[3] Data from Pascoe et al., 2020; Supplementary Information, Figure S2: data extracted with https://apps.automeris.io/wpd/.

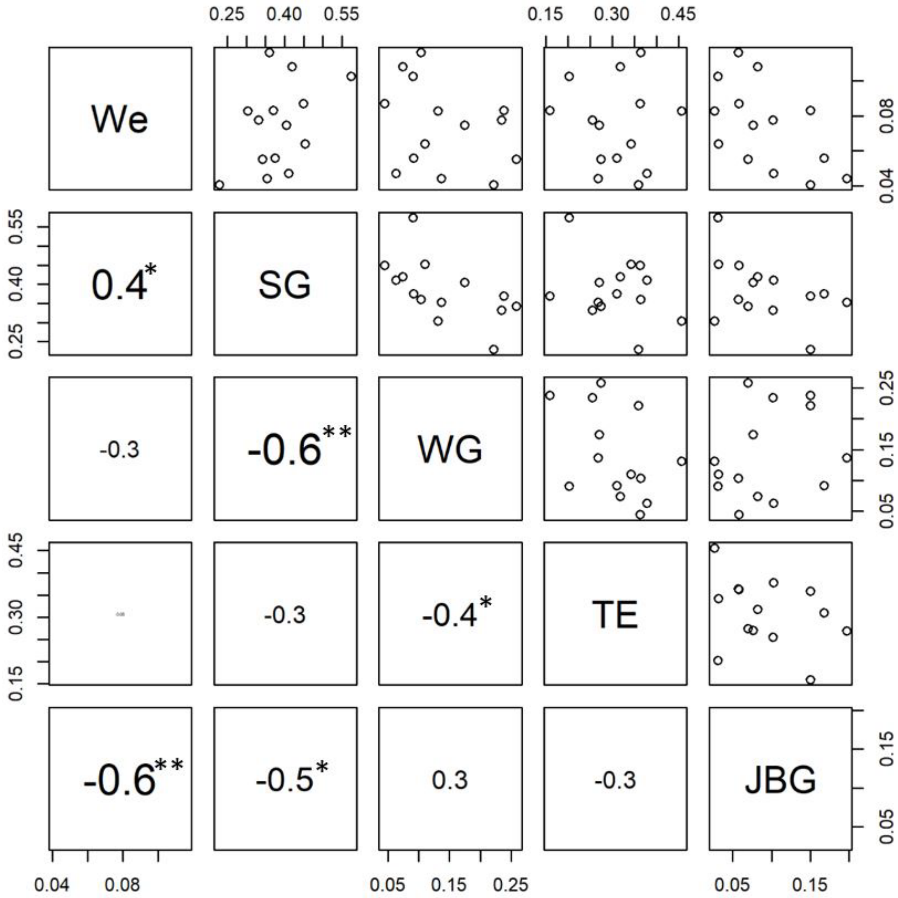

*Figure 6. Correlations among the shares of fishing effort in the banana prawn fishery between the Weipa zone (We), the south-eastern Gulf (SG), the Mornington, Limmen and Groote zones in the western Gulf (WG), the Top End (TE), and the Bonaparte zone in Joseph Bonaparte Gulf (JBG) over the period 2007–2020. The upper quadrant shows data scatterplots of effort shares in the zones or regions concerned. The lower quadrant reports correlations between zones and/or regions, with font size reflecting the strength of the correlation and stars indicating statistical significance: * p < 0.1, ** p < 0.05.*

Correlations in Figure 6 suggest that effort in the banana prawn fishery continued to be exchanged between the south-eastern Gulf and the western Gulf, Joseph Bonaparte Gulf, and – to a lesser extent – the Top End, once fleet size stabilised in 2007. This accords with Pascoe et al.'s findings based on earlier data.

The high catch per unit effort performance of the south-eastern Gulf zones is evident in Figure 5a and again in Figure 7, in which the slopes of the fitted regression lines reflect average catch per unit effort for the regions and zones concerned over the years 2007–2020. The relative slopes of the regression lines in Figure 7b illustrate the difference in average revenue per unit effort between the south-eastern Gulf and the western Gulf, the Top End and Joseph Bonaparte Gulf[4]. The relative slopes in Figure 7b suggest that if fishing effort were to be reallocated from the south-eastern Gulf (if, for example, south-eastern Gulf catches were low in any particular year), the most likely recipient regions would be the western Gulf or Joseph Bonaparte Gulf.

[4] In Figure 7, catches from the Bonaparte region have been multiplied by the mean difference in price between redleg prawns and white banana prawns to reflect their higher revenue yield per tonne caught.

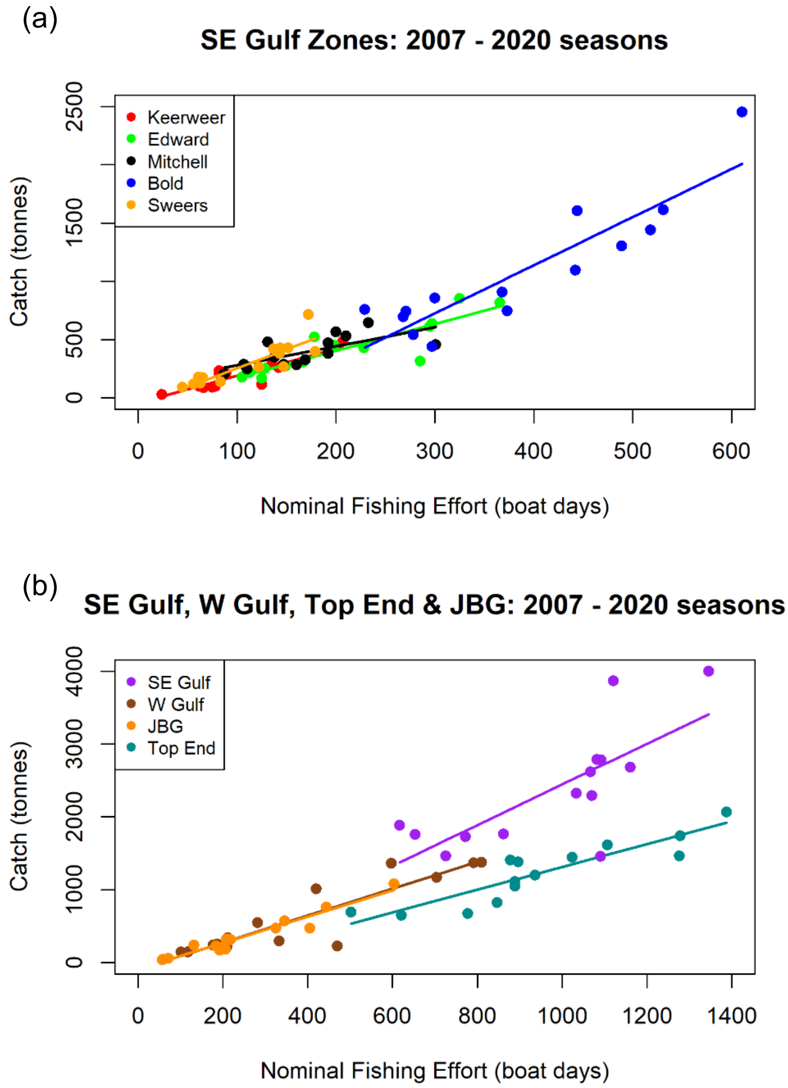

Figure 7. Catch-per-unit-effort relationships in the NPF banana prawn fishery for: (a) Individual fishing zones in the south-eastern Gulf, and (b) the south-eastern Gulf, western Gulf, Top End and Joseph Bonaparte Gulf (JBG) over the years 2007–2020 (since fleet size stabilised at 52 vessels). All fitted regression lines are statistically significant at p < 0.01 or better. Catches from JBG have been re-scaled to reflect the mean price premium of redleg prawns over banana prawns so that the plotted slopes reflect differences in average revenue per unit effort.

3.1 Impact of river flows on banana prawn catch

Broadley et al. (2020) used time series data (1984–2011) on: 1. modelled end of catchment flows from the Mitchell, Gilbert and Flinders rivers; 2. a satellite-derived index of outgoing longwave radiation above the Gulf of Carpentaria (which provides an indication of storminess); and 3. vessel log-book catch data across 6 nautical mile spatial grids to estimate a hierarchical spatio-temporal Bayesian model to predict how the size and spatial distribution of banana prawn catch in the south-eastern Gulf[5] would be expected to vary with changes in flows down the 3 rivers. Broadley et al. categorised end of catchment flows for each of the rivers into low, medium, high and very high categories using k-means clustering on derived 1900–2011 end of system flows (Broadley et al., 2020; Table 3, p.12). Several

[5] In the Keerweer, Edward, Mitchell, Bold and Sweers catch zones (Figure 1).

flow category combinations among the 3 rivers occurred frequently in both the historical (1900–2011) and calibration (1984–2011) flow datasets, with 4 flow category combinations collectively occurring 50% of the time in both datasets (Table 1; derived from Broadley et al. (2020; Table 3, p.12)). Broadley et al.'s model provided an excellent fit to the spatio-temporal prawn catch data and performed robustly under 100 cross-validation runs with random 20% data hold-out.

Table 1. Flow patterns in the Flinders, Gilbert and Mitchell rivers, categorised using k-means clustering on end of system flow data from 1900–2011. Percentage occurrence of each flow pattern is reported for the historical dataset and in the 1984–2011 dataset used for calibration of Broadley et al.'s predictive model of banana prawn catches. See Broadley et al. (2020) Table 3 and text for further details.

Flow pattern	**River**			**1900–2011**	**1984–2011**
	Flinders	Gilbert	Mitchell	% occurrence	% occurrence
1	low	low	low	22	18
2	low	low	medium	10	14
3	low	medium	high	6	11
4	medium	medium	medium	12	7
			Total	**50**	**50**

Broadley et al. used their model to predict how banana prawn catches in the south-eastern Gulf would be affected by 3 different scenarios for potential agricultural development (Table 2) under the 4 flow patterns of Table 1. Additionally,2 further flow patterns: all 3 rivers at high flow, and all 3 rivers at very high flow (which occurred on 4% and 2% of occasions, respectively, in the 1900–2011 flow series) were examined. The 3 agricultural development scenarios comprised currently granted surface water extraction entitlements (Scenario A); currently granted entitlements plus future planned surface water allocations (Scenario B); and Scenario B plus construction of multiple, major in-stream dams in the Mitchell River catchment (Scenario C). Refer to Broadley et al. (2020; Table 1 and accompanying text) for further details.

Table 2. Extraction scenarios used to model the impact of potential agricultural developments in the Mitchell, Gilbert and Flinders catchments on banana prawn catches in the south-eastern Gulf. See Broadley et al. (2020); Table 1 and text for further details.

Scenario	Description	Reduction in end-of-system flow (GL)		
		Flinders	Gilbert	Mitchell
A	Granted surface water entitlements	206	126	20
B	Granted entitlements and planned surface water allocations	266	489	70
C	Granted entitlements, planned allocations and major dams in the Mitchell	266	489	3425

Broadley et al.'s model predicts the catch reductions shown in Table 3 under the different flow patterns and extraction scenarios. For comparison, over the years 2007–2020, since the size of the NPF fleet stabilised at 52 vessels, the mean, median, 25th percentile and 75th percentile total banana prawn fishery catches from the south-eastern Gulf have been 2386 tonnes, 2308 tonnes, 1759 tonnes, and 2756 tonnes, respectively.

Modelled end of catchment flows for the Mitchell, Gilbert and Flinders rivers through to 2019 have recently been obtained from CSIRO (after Broadley et al.'s modelling had been completed). These data enable flow categorisation for thirteen years since the NPF fleet size stabilised at 52 vessels: 2007–2019 (Table 4). Flow patterns for which Broadley et al. predicted banana prawn catch reductions under the 3 agricultural development scenarios occurred 5 times during this period. This enables the economic consequences of Broadley et al.'s predicted catch reductions to be explored in the context of the current NPF for years in which catch and fishing effort, by zone, are publicly available.

Table 3. Predicted reductions in banana prawn catch in the south-eastern Gulf under extraction scenarios A, B and C (Table 2) and flow patterns 1–4 (Table 1) plus (high, high, high) and (very high, very high, very high) from Broadley et al. (2020; Supplementary Materials, Appendix S1, Tables S4–S6, p.7–8).

Extraction scenario A: Granted entitlements					
Flow pattern		**River**		**Predicted decline in catch**	
	Flinders	Gilbert	Mitchell	tonnes	95% CI
1	low	low	low	52.2	45.3 - 59.9
2	low	low	medium	34.7	30.4 - 39.5
3	low	medium	high	51.6	44.7 - 59.1
4	medium	medium	medium	56.7	49.4 - 65.2
8	high	high	high	22.5	16.7 - 35.4
10	very high	very high	very high	5.2	3.4 - 15.9
Extraction scenario B: Granted entitlements + planned allocations					
Flow pattern		**River**		**Predicted decline in catch**	
	Flinders	Gilbert	Mitchell	tonnes	95% CI
1	low	low	low	184.5	161.7 - 209.9
2	low	low	medium	178.9	155.2 - 206.0
3	low	medium	high	197.5	169.2 - 228.9
4	medium	medium	medium	226.3	199.4 - 256.9
8	high	high	high	38.8	22.6 - 62.0
10	very high	very high	very high	26.1	9.8 - 51.8
Extraction scenario C: Granted entitlements + planned allocations + Mitchell dams					
Flow pattern		**River**		**Predicted decline in catch**	
	Flinders	Gilbert	Mitchell	tonnes	95% CI
1	Low	low	low	568.5	498.8 - 646.3
2	Low	low	medium	373.5	323.8 - 430.1
3	Low	medium	high	371.4	313.3 - 436.8
4	Medium	medium	medium	425.7	376.1 - 482.0
8	High	high	high	305.3	223.3 - 414.4
10	very high	very high	very high	348.7	227.2 - 524.2

Table 4. Flow patterns in the Flinders, Gilbert and Mitchell rivers for the years 2007–2019, from modelled end-of-system flows (flow data kindly supplied by Dr Justin Hughes, Research Scientist, CSIRO), categorised using the flow boundaries determined by Broadley et al. (2020) from 1900–2011 data via k-means clustering (see Broadley et al. (2020; Table 2, p.12) for river-specific flow category boundaries). L, M, H, VH denote the low, medium, high and very high flow categories, respectively.

Year	Flinders	Gilbert	Mitchell	Flow pattern
2007	M	M	H	
2008	L	M	H	3
2009	M	H	VH	
2010	VH	VH	H	
2011	M	M	M	4
2012	M	H	VH	
2013	H	M	M	
2014	L	L	M	2
2015	L	L	H	
2016	L	L	L	1
2017	M	M	M	4
2018	L	M	M	
2019	M	H	M	

4. Estimating the economic impact of reductions in catch

Preceding sections quantified the relative performance of the different regions in the Northern Prawn Fishery banana prawn fishery, and collated evidence to suggest that the relationship identified by Pascoe et al. (2020) between differences in revenue per unit effort and the reallocation of fishing effort between regions probably still remained relevant after the NPF fleet stabilised at 52 vessels in 2007. In this section we use: Broadley et al.'s predicted catch reductions (Table 3); reported data on banana prawn catches and fishing effort by fishing zone 2007–2020 (Laird, 2021); and differences in the average revenue per unit effort return from banana prawn fishing regions (Figure 7b), to provide an indication of the potential impact of agricultural development in Gulf catchments on the economic performance of the NPF. We do this knowing the size and inter-zone distribution of catches and fishing effort that eventuated in 2008, 2011, 2014, 2016 and 2017 – years in which river flow patterns matched those for which Broadley et al. predicted catch reductions under the aforementioned 3 extraction scenarios. From the perspective of the NPF as a whole, we note that the banana prawn catch contributes, on average, close to 60% of total NPF catch revenue annually (Steven et al. 2020).

4.1 Reduction in revenue, profit and return to capital: no effort reallocation

As a starting point, we produce indicative estimates of the reductions in revenue to the NPF banana prawn fishery, boat-level cash income, boat-level business profit, and the change in boat-level return to full equity, that would follow from Broadley et al.'s predicted catch reductions in the south-eastern Gulf fishing zones in 2008, 2011, 2014, 2016 and 2017 (Table 3) under each potential extraction scenario (Table 2). Initially, we assume no reallocation of fishing effort between regions. We further assume that extractions from the Mitchell, Gilbert and Flinders rivers only affect banana prawn catches in the south-eastern Gulf, and thus that banana prawn catches remain unchanged in all other fishing zones. Results are shown in Table 5.

Revenue reductions are calculated using the white banana prawn price for the banana prawn fishing season concerned from data provided by Pascoe et al. (2020; Supplementary Materials[6]), and assuming that 52 vessels are operating in the NPF each year (Patterson et al., 2020; Table 5.2, p.68). Data on estimated boat-level cash income, boat-level business profit, and the value of capital at full equity[7] for the average vessel operating in the NPF in the relevant year are obtained from Mobsby et al. (2019; data table: Table 2). These data report the financial performance of the average vessel in each financial year, as obtained via an annual survey. Please refer to Mobsby et al. for a detailed description of the survey and the data collected. Approximately 30 of the 52 vessels operating in the NPF are usually included in the annual survey.

[6] Pascoe et al., 2020; Supplementary Information, Figure S2: data extracted with https://apps.automeris.io/wpd.

[7] Capital at full equity includes the capital value of the boat and all gear, together with the value of the licence and headrope quota required to allow the boat to operate in the NPF.

Table 5. Estimated reductions in revenue to the NPF, boat-level cash income, boat-level business profit and boat-level return to capital in nominated years based on Broadley et al.'s (2020) predicted catch reductions under 3 potential extraction scenarios from the Mitchell, Gilbert and Flinders rivers (Table 2). Estimates assume ***no reallocation of fishing effort****. All values reported in FY2018-19 AUD$.*

Extraction scenario A: Granted entitlements									
Year	Flow pattern	SE Gulf catch reported (tonnes)	Predicted catch reduction (tonnes)	Revenue loss to NPF(k$)	Revenue loss per boat (k$)	Reduction in cash income per boat (%)	Reduction in business profit per boat (%)	Rate of return to full equity (%)	
								before extractions	after extractions
2008	LMH	2679	51.6	471.1	9.1	2.6	3.1	6.3	6.2
2011	MMM	3871	56.7	458.7	8.8	2.4	2.8	8.9	8.6
2014	LLM	2787	34.7	406.3	7.8	1.7	1.9	9.9	9.8
2016	LLL	1763	52.2	766.3	14.7	1.9	2.0	16.6	16.3
2017	MMM	1881	56.7	856.7	16.5	n/a	n/a	n/a	n/a
Extraction scenario B: Granted entitlements + planned allocations									
Year	Flow pattern	SE Gulf catch reported (tonnes)	Predicted catch reduction (tonnes)	Revenue loss to NPF(k$)	Revenue loss per boat (k$)	Reduction in cash income per boat (%)	Reduction in business profit per boat (%)	Rate of return to full equity (%)	
								before extractions	after extractions
2008	LMH	2679	197.5	1803.2	34.7	9.8	11.9	6.3	5.6
2011	MMM	3871	226.3	1830.8	35.2	9.6	11.0	8.9	8.0
2014	LLM	2787	178.9	2094.9	40.3	8.9	9.9	9.9	9.0
2016	LLL	1763	184.5	2708.5	52.1	6.6	6.9	16.6	15.5
2017	MMM	1881	226.3	3419.4	65.8	n/a	n/a	n/a	n/a
Extraction scenario C: Granted entitlements + planned allocations + Mitchell dams									
Year	Flow pattern	SE Gulf catch reported (tonnes)	Predicted catch reduction (tonnes)	Revenue loss to NPF(k$)	Revenue loss per boat (k$)	Reduction in cash income per boat (%)	Reduction in business profit per boat (%)	Rate of return to full equity (%)	
								before extractions	after extractions
2008	LMH	2679	371.4	3390.9	65.2	18.5	22.3	6.3	5.0
2011	MMM	3871	425.7	3443.9	66.2	18.1	20.8	8.9	7.3
2014	LLM	2787	373.5	4373.7	84.1	18.7	20.7	9.9	7.9
2016	LLL	1763	568.5	8345.6	160.5	20.2	21.3	16.6	13.2
2017	MMM	1881	425.7	6432.3	123.7	n/a	n/a	n/a	n/a

Revenue loss to the NPF is calculated using the white banana prawn price for the relevant banana prawn season from Pascoe et al. (2020; Supplementary Information, Figure S2: data extracted with https://apps.automeris.io/wpd/). Revenue loss per boat is calculated assuming 52 vessels operate in the NPF. Reductions in boat cash income, boat business profit and rate of return to full equity (i.e. return to capital in the boat and gear plus the value of headrope quota and licences) obtained using data on boat cash income, business profit and business capital from Mobsby et al., (2019).

Table 6. Estimated reductions in revenue to the NPF, boat-level cash income, boat-level business profit and boat-level return to capital in nominated years based on Broadley et al.'s (2020) predicted catch reductions under 3 potential extraction scenarios from the Mitchell, Gilbert and Flinders rivers (Table 2). Estimates ***include reallocation of fishing effort****. All values reported in FY2018–19 AUD$.*

Year	Flow pattern	SE Gulf catch reported (tonnes)	Predicted catch reduction in south-eastern Gulf (tonnes)	Revenue loss to NPF(k$)	Revenue loss per boat (k$)	Reduction in cash income per boat (%)	Reduction in business profit per boat (%)	Rate of return to full equity (%) before extractions	Rate of return to full equity (%) after extractions
Extraction scenario A: Granted entitlements									
2008	LMH	2679	51.6	184.9	3.6	1.0	1.2	6.3	6.3
2011	MMM	3871	56.7	240.0	4.6	1.3	1.4	8.9	8.7
2014	LLM	2787	34.7	58.7	1.1	0.3	0.3	9.9	9.9
2016	LLL	1763	52.2	408.1	7.8	1.0	1.0	16.6	16.4
2017	MMM	1881	56.7	360.3	6.9	n/a	n/a	n/a	n/a
Extraction scenario B: Granted entitlements + planned allocations									
2008	LMH	2679	197.5	707.9	13.6	3.9	4.7	6.3	6.1
2011	MMM	3871	226.3	957.7	18.4	5.0	5.8	8.9	8.4
2014	LLM	2787	178.9	302.8	5.8	1.3	1.4	9.9	9.8
2016	LLL	1763	184.5	1442.4	27.7	3.5	3.7	16.6	16.0
2017	MMM	1881	226.3	1437.8	27.7	n/a	n/a	n/a	n/a
Extraction scenario C: Granted entitlements + planned allocations + Mitchell dams									
2008	LMH	2679	371.4	1331.2	25.6	7.3	8.8	6.3	5.8
2011	MMM	3871	425.7	1801.6	34.6	9.5	10.9	8.9	8.0
2014	LLM	2787	373.5	632.1	12.2	2.7	3.0	9.9	9.7
2016	LLL	1763	568.5	4444.6	85.5	10.8	11.4	16.6	14.8
2017	MMM	1881	425.7	2704.8	52.0	n/a	n/a	n/a	n/a

Revenue loss to the NPF is calculated using the white banana prawn price for the relevant banana prawn season from Pascoe et al. (2020; Supplementary Information, Figure S2: data extracted with https://apps.automeris.io/wpd). Revenue loss per boat is calculated assuming 52 vessels operate in the NPF. Reductions in boat cash income, boat business profit and rate of return to full equity (i.e. return to capital in the boat and gear plus the value of headrope quota and licences) obtained using data on boat cash income, business profit and business capital from Mobsby et al., (2019).

4.2 Reduction in revenue, profit and return to capital: with effort reallocation

Section 2 identified that fishing zones in the south-eastern Gulf generally deliver the highest catch per unit effort in the banana prawn fishery (Figure 5a, Figure 7[b]), and that significant negative correlations exist between the shares of fishing effort applied to the south-eastern Gulf, the western Gulf and Joseph Bonaparte Gulf within the banana prawn fishery (Figure 6). Section 2 also described how Pascoe et. al. (2020) quantified the allocation of fishing effort between regions in the NPF when differences emerge in revenue per unit effort ($ per boat day). Here we use these findings in combination to estimate how fishing effort could potentially reallocate from the south-eastern Gulf to the western Gulf, the Top End and Joseph Bonaparte Gulf if banana prawn catches in the south-eastern Gulf were to reduce as predicted by Broadley et al. (2020) following extractions from the Mitchell, Gilbert and Flinders rivers. We then repeat our calculations of indicative reductions in NPF banana prawn revenue to the NPF, boat-level cash income, boat-level business profit and boat-level return to full equity for the years 2008, 2011, 2014, 2016 and 2017 allowing for the (lower) reductions in banana prawn catch across the fishery that would follow after the estimated reallocations of effort when catches in the south-eastern Gulf reduce.

To estimate reallocation of banana prawn fishing effort between the south-eastern Gulf, the western Gulf, the Top End and Joseph Bonaparte Gulf, we proceed as follows for each year of interest (2008, 2011, 2014, 2016 and 2017).

1. We calculate the revenue per unit effort from the south-eastern Gulf, the western Gulf, the Top End and the Joseph Bonaparte Gulf, using reported catches, reported fishing effort and prawn prices[8] for the years concerned.
2. We reduce the banana prawn catch in the south-eastern Gulf as predicted by Broadley at al. (2020) for each irrigation extraction scenario under the relevant flow pattern for the year concerned (Table 3 and Table 4).
3. We calculate the reduction in effort days required in the south-eastern Gulf when the catch in the south-eastern Gulf reduces (assuming initially that catch per unit effort in the south-eastern Gulf remains unchanged).
4. Drawing on Pascoe et al.'s (2020) finding that effort shares among fishing regions are influenced by the *differences* in revenue per unit effort between regions, we calculate the differences in revenue per unit effort between the south-eastern Gulf and the western Gulf, the Top End, and Joseph Bonaparte Gulf before and after the catch reduction in the south-eastern Gulf.
5. We scale the differences in revenue per unit effort between regions using the coefficients estimated by Pascoe et al. that report the changes in effort share between regions that follow from a $1,000 difference in revenue per boat day. This recognises that a larger difference in revenue per unit effort will be required to induce a given shift of effort share from the south-eastern Gulf to Joseph Bonaparte Gulf, than from the south-eastern Gulf to the western Gulf or the Top End.

[8] We use the redleg banana prawn price to calculate revenue per unit effort for the Joseph Bonaparte fishing zone, and the white banana prawn price to calculate revenue per unit effort elsewhere.

6. From Step 5 we calculate the relative *changes* in the scaled differences in revenue per unit effort between the fishing regions that would arise when catches are reduced in the south-eastern Gulf.
7. We reallocate the reduction in fishing effort in the south-eastern Gulf (from Step 3) among the other fishing regions, in proportion to the relative changes in the scaled differences in revenue per unit effort calculated in Step 6. As catches reduce in the south-eastern Gulf, 'spare' fishing effort is reallocated to other regions. Regions with higher scaled revenue per unit effort receive a higher proportion of this reallocated effort.
8. We increase banana prawn catches from the western Gulf, the Top End and Joseph Bonaparte Gulf appropriately for the predicted increases in fishing effort in each region, using the average catch per unit effort reported for the relevant region that year.
9. We adjust the predicted reduction in catch revenue across the NPF to account for higher catches from the other fishing regions as effort folds back in the south-eastern Gulf and switches to other regions. This reduces the indicative financial impacts of the potential irrigation extractions from Gulf rivers on the NPF as a whole, and on the average vessel in the fleet, in the years concerned.

Results are shown in Table 6.

4.3 Results summary

The indicative financial impacts in Table 5 and Table 6 suggest that the potential implications of the 3 extraction scenarios for boat-level financial performance are as follows:

- For extraction Scenario A (granted entitlements), revenue losses per boat vary between $9,000 and $17,000 without reallocation of effort, and between $1,000 and $8,000 with full reallocation of effort.
- For extraction Scenario B (granted entitlements plus planned allocations), revenue losses increase to between $35,000 and $66,000 per boat without effort reallocation, and between $6,000 and $28,000 with effort reallocation.
- For extraction Scenario C (Scenario B plus major dams in the Mitchell catchment), revenue losses increase to between $65,000 and $161,000 per boat without effort allocation, and between $12,000 and $86,000 with effort reallocation.
- Reductions in business profit per boat are relatively modest under Scenario A (less than 3% without reallocation of effort, and less than 1.5% with effort reallocation), but increase considerably under Scenario B (between 7% and 12% without reallocation of effort, and between 1.5% and 6% with effort reallocation). Under the highest extraction scenario business profit per boat reduces by 21 to 22% without effort reallocation, or by 3 to 11% with effort reallocation.
- Boat-level return to full equity is relatively robust against extraction Scenarios A and B, but under extraction Scenario C drops by a maximum of more than 3% without effort reallocation, or by a maximum of almost 2% when effort reallocation is assumed.

5. Discussion

Under the assumption of no reallocation of effort, the indicative impacts of a given extraction scenario on per-boat cash income, business profit and return to full equity remain relatively constant across the 4 different flow patterns (Table 5). It is important to note that irrigation extractions appear likely to impose financial impacts on the banana prawn fishery under all 4 of the flow patterns considered (LLL, LLM, LMH and MMM), i.e. impacts are *not* restricted to the LLL flow combination. For example, (assuming no reallocation of effort) per-boat business profit is predicted to reduce by 3%, 11% and 21% under increasing extraction scenarios when all rivers are in their medium flow category. In total, the 4 flow patterns for which indicative financial impacts are assessed in Table 5 occurred for 50% of the time in the historical flow record (Table 1). This suggests that (assuming no reallocation of fishing effort) annual per-boat business profit might be expected to reduce by between 7% and 12% for half of the time if granted irrigation entitlements and currently planned irrigation allocations are extracted from the Gulf rivers. Under the same assumptions, if extractions increase through construction of large dams in the Mitchell catchment annual per-boat business profit could be expected to drop by more than 20% for half of the time (Table 5). These would be very significant financial impacts on the profitability of the Northern Prawn Fishery as a whole[9].

The assumption of no reallocation of effort may be unduly pessimistic; however, conversely, the assumption of full reallocation of effort (Table 6) may be somewhat optimistic. Since the south-eastern Gulf generates the highest banana prawn fishery revenue per unit effort across the NPF, reallocation of fishing effort elsewhere can never full compensate for the drop in revenue caused by lower catches in the south-eastern Gulf (Figure 5). The effectiveness of effort reallocation varies considerably between years depending on how well other regions are fishing compared to the south-eastern Gulf. For example, the financial impact of a predicted 373.5 tonne reduction in banana prawn catch from the south-eastern Gulf under extraction Scenario C could potentially be significantly reduced by reallocation of effort in 2014 (final section of Table 6, compared with Table 5). This is because, in 2014, the western Gulf was almost as productive as the south-eastern Gulf, so reallocated effort would (at least in theory) be able to recover the majority of the lost catch revenue. In contrast, reallocation of effort appeared to be considerably less effective in reducing the financial impact of the predicted 568.5-tonne reduction in catch in the south-eastern Gulf in 2016. This is because, for that year, revenue per unit effort from the south-eastern Gulf was more than double that of the other regions, so – at best – only around half of the 'lost' revenue can be recovered via the reallocated effort. This emphasises that in some years the financial performance of the banana prawn fishery as a whole can be heavily reliant on cost-effective catches from the south-eastern Gulf. It would therefore be unwise to rely on effort reallocation to make good shortfalls in revenues from the south-eastern Gulf in all years. Pragmatically, indicative impacts of extractions from the Mitchell, Gilbert and Flinders rivers will probably lie between those estimated in Table 5 and Table 6.

[9] Recall that the impacts on per-boat cash income, per-boat business profit and per-boat return to full equity shown in Table 5 and Table 6 are calculated for participation in the NPF over a full financial year (i.e. for fishing during the banana prawn season *and* the tiger prawn season), even though the catch reductions in the south-eastern Gulf are applied only to the banana prawn fishery.

In years such as 2008, when there was significant catch in the Joseph Bonaparte Gulf and the redleg banana prawn price was considerably higher than the white banana prawn price, revenue per unit effort from the Bonaparte fishing zone can be substantially higher than that from the western Gulf or the Top End. Under such conditions Joseph Bonaparte Gulf would be a preferred location for effort reallocation should catches in the south-eastern Gulf fall short of expectations. Over the 2007 to 2016 banana prawn seasons, the highest revenue per unit effort advantage delivered by the Joseph Bonaparte Gulf over fishing grounds in the western Gulf or the Top End was approximately $7,000 per boat day (in 2008). This potential advantage is not currently accessible, however, as the redleg banana prawn fishery in Joseph Bonaparte Gulf has been closed for 5 years from 2021, following a total catch of only 48 tonnes in 2019 (AFMA, 2020; Patterson et al., 2020). If the redleg banana prawn fishery in Joseph Bonaparte Gulf remains closed indefinitely this could further increase the economic impact of catch reductions in the south-eastern Gulf by removing a potentially productive alternative fishing ground.

The indicative financial impacts calculated here assume that revenue per unit effort is the only performance parameter that changes as fishing effort is reallocated between fishing zones. It is possible that operating costs may also differ between fishing zones, but we have not accounted for this here. An advantage of the concentration of fishing effort in the south-eastern Gulf, particularly during the first 4 to 6 weeks of the banana prawn season (Figure 2), is that it allows support vessels to be stationed in that area which reduces the time and cost incurred in fishing vessels steaming to and from support ships to offload catch and reprovision with ice etc. These cost efficiencies would be lost if fishing effort was dispersed more widely.

The indicative estimations produced in this report of the financial impacts of irrigation extractions from the Mitchell, Gilbert and Flinders rivers are derived from publicly available data on annual catch, effort and revenue at fishing zone resolution[10] (Figure 1). Further insights into potential reallocation of effort could benefit from access to finer temporal and spatial resolution data on catch and effort from vessel log-books, but this remains an opportunity for further research.

[10] Reallocation of effort among fishing zones in our calculations is informed by Pascoe et al.'s coefficients that link differences in revenue per boat day to changes in the share of total fishing effort between fishing regions Pascoe et al. (2020). Pascoe et al.'s coefficients were derived from vessel log-book data, aggregated monthly during the fishing seasons.

6. Summary

Changes in flows from the Mitchell, Gilbert and Flinders rivers have been shown to affect banana prawn catches in the south-eastern Gulf (Broadley et al., 2020).The south-eastern Gulf is the most productive region of the Northern Prawn Fishery's banana prawn fishery. The banana prawn catch contributes, on average, close to 60% of total NPF catch revenue annually (Steven et al. 2020). Drawing on Broadley et al.'s predictions of catch reductions in the south-eastern Gulf, this note estimated indicative NPF-wide impacts on vessel-level financial performance that could result from potential irrigation extractions from the Mitchell, Gilbert and Flinders rivers. Results suggest that (without reallocation of fishing effort) vessel-level business profit could reduce by between 7% and 12% for at least half of the time if currently granted entitlements and planned allocations were extracted from Gulf rivers, or by around 22% for at least half of the time if major dams are constructed in the Mitchell River in addition to granted entitlements and planned allocations. If fishing effort is reallocated to other regions when catches drop in the south-eastern Gulf some – but not all – of the revenue shortfall could potentially be recovered.

Assuming full reallocation of fishing effort, indicative reductions in annual vessel-level business profit are between 1.5% and 6% under currently granted entitlements and planned allocations, or between 3% and 11% when major dams are constructed in the Mitchell, in addition to granted entitlements and planned allocations. These indicative impacts assume that revenue per unit effort is the only performance parameter that changes as fishing effort is reallocated between fishing zones. In reality, operating costs are also likely to increase as fishing effort becomes more dispersed. Our indicative estimates of financial impact may therefore be conservative. These findings suggest that irrigation developments in Gulf river catchments could have significant financial impacts on the NPF. These impacts should be considered carefully before further irrigation development is undertaken in the region.

References

AFMA, 2020. Northern Prawn Fishery Directions and Closures. Australian Fisheries Management Authority, Canberra.

Bayliss, P., Buckworth, R., Dichmont, C., 2014. Assessing the water needs of fisheries and ecological values in the Gulf of Carpentaria Final Report prepared for the Queensland Department of Natural Resources and Mines (DNRM).

Broadley, A., Stewart-Koster, B., Kenyon, R.A., Burford, M.A., Brown, C.J., 2020. Impact of water development on river flows and the catch of a commercial marine fishery. Ecosphere 11, e03194. https://doi.org/10.1002/ecs2.3194

Burford, M., Kenyon, R., Whittle, M., Curwen, G., 2010. River flow impacts on estuarine prawns in the Gulf of Carpentaria.

Die, D.J., Ellis, N., 1999. Aggregation dynamics in penaeid fisheries: banana prawns (Penaeus merguiensis) in the Australian Northern Prawn Fishery. Mar. Freshw. Res. 50, 667–675.

Duggan, M., Bayliss, P., Burford, M.A., 2019. Predicting the impacts of freshwater-flow alterations on prawn (Penaeus merguiensis) catches. Fish. Res. 215, 27–37. https://doi.org/10.1016/j.fishres.2019.02.013

Laird, A., 2021. Northern Prawn Fishery Data Summary 2020. Australian Fisheries Management Authority, Canberra.

Larcombe, J., Green, R., 2015. Northern Prawn Fishery, in: Patterson, H., Georgeson, L., Stobutzki, I., Curtotti, R. (Eds.), Fishery Status Reports 2015. Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.

Mobsby, D., Curtotti, R., Bath, A., 2019. Australian fisheries economic indicators report 2017: financial and economic performance of the Northern Prawn Fishery. ABARES, Canberra,.

Pascoe, S., Hutton, T., Plagányi, É., Deng, R.A., Miller, M., Moeseneder, C., Eves, S., 2020. Influence of environment and economic drivers on fishing effort in Australia’s redleg banana prawn fishery. Fish. Res. 227. https://doi.org/10.1016/j.fishres.2020.105555

Patterson, H., Larcombe, J., Woodhams, J., Curtotti, R., 2020. Fishery status reports 2020. Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra, ACT, Australia. https://doi.org/10.25814/5f447487e6749

Petheram, C., Watson, I., Bruce, C., Chilcott, C., 2018. Water resource assessment for the Mitchell catchment: An overview report.

Petheram, C., Watson, I., Stone, P., 2013a. Agricultural resource assessment for the Gilbert catchment.

Petheram, C., Watson, I., Stone, P., 2013b. Agricultural resource assessment for the Flinders catchment.

Plagányi, É., Deng, R.A., Hutton, T., Kenyon, R., Lawrence, E., Upston, J., Miller, M., Moeseneder, C., Pascoe, S., Blamey, L., Eves, S., 2021. From past to future:

Understanding and accounting for recruitment variability of Australia's redleg banana prawn (Penaeus indicus) fishery. ICES J. Mar. Sci. 78, 680–693. https://doi.org/10.1093/icesjms/fsaa092

Steven, A., Mobsby, D., Curtotti, R., 2020. Australian fisheries and aquaculture statistics 2018. ABARES, Canberra.

Vance, D.J., Bishop, J., Dichmont, C.M., Hall, N., McInnes, K., Taylor, B.R., 2003. Management of white banana prawn stocks of the Gulf of Carpentaria: separating the effects of fishing from the environment.

Vance, D.J., Haywood, M.D.E., Heales, D.S., Kenyon, R.A., Loneragan, N.R., 1998. Seasonal and annual variation in abundance of postlarval and juvenile banana prawns Penaeus merguiensis and environmental variation in two estuaries in tropical northeastern Australia: a six year study. Mar. Ecol. Prog. Ser. 163, 21–36.

Venables, W., Hutton, T., Lawrence, E., Rothlisberg, P., Buckworth, R., Hartcher, M., Kenyon, R., 2011. Prediction of common banana prawn potential catch in Australia's Northern Prawn Fishery. CSIRO, Canberra, Australia.