Fisheries Research 113 (2012) 106–117

Contents lists available at SciVerse ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Spreading the economic risk: Harvesting strategies of multi-method inshore fisheries during drought in eastern Australia

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ARTICLE INFO

Article history:
Received 15 December 2010
Received in revised form 7 September 2011
Accepted 8 October 2011

Keywords:
Economic risk
Climatic variability
Drought
Commercial fisheries

ABSTRACT

Droughts are likely to increase in frequency and severity with climate change, modifying the economic viability of inshore fisheries in regions of hydrological extreme. Variation in the revenue and profit associated with different mixtures of fishing methods between non-drought and drought conditions was examined for commercial fishing businesses in three estuarine and coastal systems in eastern Australia from 1997 to 2007. Mean monthly revenue decreased from 8 to 36% between non-drought and drought. Decreased mean monthly revenue was primarily attributed to reduced revenue generation from ocean prawn trawling (≥20%) and estuarine prawn trawling (≥34%) during drought. Fishing method diversity (measured by a modified form of the Shannon index) and mean monthly revenue were positively related; however, mean monthly profit decreased between non-drought and drought under a range of alternative cost scenarios. Reduced mean monthly profit was primarily attributed to losses from ocean prawn trawling (≥15%) and estuarine prawn trawling (≥30%) during drought. Although diversified harvesting behaviour increased revenue generation, initial results indicated that this marginal economic benefit could have been compromised by the greater costs associated with the increased diversification which reduced overall profitability. Results of this analysis indicated that the commercial fishing sector is a drought-affected industry in New South Wales.

1. Introduction

Understanding connections between climatic variability and fisheries production is an important avenue of investigation (Brander, 2007). Climatic variability strongly influences the production of estuarine and coastal fisheries by modifying the spatial distribution, abundance and species composition of fish communities (Roessig et al., 2004; Lehodey et al., 2006; Brander, 2010). Many studies have focused on climatic effects on commercially-important fish species such as horse mackerel (*Trachurus murphyi*), tuna (*Thunnus albacares*) and cod (*Gadus morhua*) (Klyashtorin, 1998; Lehodey et al., 2003; Fogarty et al., 2008). Concern has, however, also been expressed about the economic impacts of climate change on estuarine and coastal fisheries (Lyne et al., 2003; Hannesson, 2007; Allison et al., 2009). Information on the economic impacts of climate change on estuarine and coastal fisheries is required to inform long–term policy debate and strategic management options (Johnson and Welch, 2010).

Climatic variability has a pivotal role in determining the quantity of freshwater entering coastal marine ecosystems (Gillanders and Kingsford, 2002). Natural variation in freshwater flow influences fisheries production by regulating habitat availability and affecting trophic dynamics in estuarine and coastal systems (Grimes, 2001; Robins et al., 2005; Lamberth et al., 2009). Freshwater *per se*, however, may not be as important in determining the production of estuarine and coastal fisheries as extreme flow events (Gillson et al., 2009). Floods and droughts are extreme flow events that regulate biological productivity in estuarine and coastal systems (Flint, 1985; Martin et al., 1992; Dolbeth et al., 2008). Despite well established connections between freshwater flow and fisheries production (Caddy and Bakun, 1995), the economic impacts of drought on estuarine and coastal fisheries have received little attention.

Diverse multi-species and multi-method fisheries operate along the eastern Australian coastline. Commercial fisheries target penaeid prawns (*Metapenaeus macleayi*, *Melicertus plebejus*, *Metapenaeus bennettae*), finfish (*Acantopagrus australis*, *Platycephalus fuscus*, *Mugil cephalus*), sharks (*Carcharhinus* spp.) and crabs (*Portunus pelagicus*, *Scylla serrata*, *Ranina ranina*) with a gross value of ~AU$350 million per annum (ABARE, 2009). Coastal fish communities and dependent fisheries are affected by flood and drought events in this region (Loneragan and Bunn, 1999; Robins et al., 2005; Ives et al., 2009). Flood and drought events alter the species composition of landings by modifying the distribution and abundance of coastal fish due to changes in salinity (Gillson et al., in press). Salinity has a profound effect on habitat selection, with

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doi:10.1016/j.fishres.2011.10.002

species actively seeking optimum habitat conditions to minimise osmoregulatory costs and maximise growth rates (Edeline et al., 2005; Cardona, 2006; Shen et al., 2009). Differences in the salinity tolerance of euryhaline and stenohaline species are often attributed to the divergent responses of coastal biota to variation in freshwater flow (Gillson, 2011). Both the species composition of landings and the market value of seafood are important bio-economic factors that may drive revenue and profit generation in estuarine and coastal fisheries. Nevertheless, the impacts of drought on the economic performance of estuarine and coastal fisheries in eastern Australia remain unclear.

Eastern Australia experiences relatively extreme hydrological conditions (Finlayson and McMahon, 1988), with climatic variability driving sporadic rainfall and stochastic freshwater flow events (Chiew et al., 1998). Coastal rivers in this region are influenced by alternating flood and drought dominated regimes (Erskine and Warner, 1998). Climatic projections indicate that extreme fluctuations in rainfall will increase the frequency and severity of floods and droughts in eastern Australia (Hennessy et al., 2007). One of the many concerns associated with climate change is the impacts of reduced freshwater flow on estuarine and coastal fisheries (Loneragan and Bunn, 1999; Robins et al., 2005; Ives et al., 2009). Reductions in freshwater flow resulting from climate change could be exacerbated by human population growth increasing demand for water resources (Vörösmarty et al., 2000).

This study examined the economic impacts of droughts on commercial fishing businesses that operate in three estuarine and coastal fisheries in eastern Australia. The aims of this study were to: (i) examine the revenue, costs and profits of different multi-method fishing strategies during non–drought and drought; and (ii) test the hypothesis that diversification of fishing methods increased revenue and profit during non-drought and drought.

2. Methods

2.1. Study areas

Three estuarine and coastal systems along the eastern Australian coastline were selected to investigate the economic impacts of droughts on commercial fishing businesses (Fig. 1). Estuarine fisheries were located in the permanently open lower reaches of the Clarence, Hunter and Hawkesbury Rivers. Adjacent coastal fisheries extended ~30 km onto the continental shelf and ~0.5° north and south of each river system. The spatial extent of coastal fisheries were based on reporting zones used by Industry and Investment New South Wales (coastal zones 2, 5 and 6 (I&I NSW)). These estuarine and coastal fisheries administered by I&I NSW (hereafter referred to as the Clarence, Hunter and Hawkesbury systems) were selected for investigation because they provide the dominant contribution to commercial fisheries harvest in NSW (Table 1).

2.2. Hydrological data

Reductions in rainfall and freshwater flow have been documented in the Clarence, Hunter and Hawkesbury Rivers during drought (Gillson et al., 2009). This study used the governmental declaration of drought-affected areas in the respective catchments to indicate decreased rainfall and freshwater flow in the coastal rivers examined. Monthly drought declaration maps from July 1997 to June 2007 were obtained from I&I NSW (2010). I&I NSW assesses climatic and agricultural factors to officially declare the drought-affected status of an area (www.dpi.nsw.gov.au/drought). Drought-affected areas were based on Rural Lands Protection Board Districts, and no rivers considered were co-located within the same district. Periods of drought declaration were examined for an area surrounding each coastal river and formatted into a dichotomous variable with "0" and "1" representing the absence or presence of drought declaration, respectively.

2.3. Fisheries data

Monthly commercial fisheries catch, effort and Sydney Fish Market price data were compiled from the I&I NSW ComCatch database between July 1997 and June 2007. The Sydney Fish Market is the largest domestic market for seafood in Australia and the cornerstone of NSW seafood sales. Seafood prices formed at the Sydney Fish Market for high volume inshore species are responsive to changes in the volumes sold and indicative of ex-vessel prices received by fishery operators (Smith et al., 1998). Consequently, Sydney Fish Market price data were used as a proxy for farm-gate values of mean monthly price per species (AU$/kg). Fisheries metrics for individual fishing businesses included landings (kilograms per month), effort (days fished per month), revenue (AU$ per month) and profit (AU$ per month) from 27 species groups and 16 fishing methods that contributed >95% of commercial harvest between July 1997 and June 2007 (Tables 2 and 3). Landings and effort per fishing method were aggregated into monthly totals for individual businesses.

A "fishing business" represented a separate and identifiable financial entity (New South Wales *Fisheries Management* Act, 1994). Fishing businesses can possess multiple endorsements to operate methods in multiple fisheries. Business owners (usually, but not always, the fishers) utilise these method-based endorsements as they see fit. An endorsement is simply an amendment to a fishing entitlement that permits owners of that entitlement to use particular fishing methods. Fishing methods from five commercial fisheries in NSW were considered (Table 3): Estuary General fishery (multi-method), Estuary Prawn Trawl fishery (single-method), Ocean Hauling fishery (multi-method), Ocean Trawl fishery (dual–method) and the Ocean Trap and Line fishery (multi-method). All five commercial fisheries and their associated fishing methods operated in the Clarence and Hawkesbury systems between 1997 and 2007 (I & I NSW Catch Records, 2010). The prawn set pocket net however was not used in the Estuary General fishery of the Hunter system during the same time period. Endorsements in the Abalone and Lobster fisheries were not considered in this analysis because there is an ambiguous linkage of fishing businesses between these fisheries and the other major commercial fisheries in NSW. Although some overlap exists between fishers that operate in the Lobster fishery and Ocean Trap and Line fishery (Dominion Consulting Pty Ltd, 2006), different business identification codes are used in the catch records so relating these operations at the scale of fishing businesses is highly problematic.

2.4. Revenue

Revenue was calculated as:

$$R_{m,b,t} = \sum_{s} C_{m,b,s,t} \cdot \bar{P}_{s,t}$$

where $R_{m,b,t}$ is revenue for fishing method m from business b in month t (Australian dollars), $C_{m,b,s,t}$, is the landings of species s for fishing method m from business b in month t (kilograms) and $\bar{P}_{s,t}$ is the mean market price per kilogram of species s in month t from Sydney Fish Market.

Nominal revenue per method was adjusted for inflation using the Sydney food Consumer Price Index (CPI) relative to June 2007 ($\mathrm{CPI}_{\mathrm{June2007}} = 1$) to give revenue per method. The Sydney food CPI was obtained from the Australian Bureau of Statistics

Table 1
Systems selected to investigate the economic impacts of drought on commercial fishing businesses that operate in three estuarine and coastal fisheries in eastern Australia.

System	Latitude and longitude	Fisheries bioregion	Fishing businesses	Mean landings (tonnes/month)	Percent of fisheries harvest	Mean effort (days/month)	Mean revenue (AU$000/month)	Months of drought
Clarence	29°25′37.20″S, 153°22′19.20″E	Northern	191	149 (±6.3)	16	1160 (±53.4)	522.9 (±44.2)	38
Hunter	32°54′54.00″S, 151°48′03.59″E	Central	91	79 (±8.7)	9	444 (±32.6)	167.9 (±27.7)	31
Hawkesbury	33°34′10.20″S, 151°18′32.40″E	Central	86	62 (±7.2)	7	478 (±22.0)	113.9 (±15.3)	29

Fisheries bioregion refers to defined latitudinal regions for commercial fisheries (Pease, 1999). Fishing businesses represent the mean number of fishing businesses operating per month. Mean landings (tonnes/month), percent of fisheries harvest, mean effort (days/month) and mean revenue (AU$000/month) indicates mean landings in tonnes per month, the percentage contribution to monthly commercial fisheries harvest in NSW, mean effort in days per month and mean revenue in AU$ 000s per month, respectively, between July 1997 and June 2007. Standard error values for fisheries parameters shown in parenthesis. Months of drought describes the number of drought declared months in each catchment out of a total of 120 months.

Table 2
Selected species used to investigate the economic impacts of drought on commercial fishing businesses that operate in three estuarine and coastal fisheries in eastern Australia.

Species	Mean landings (tonnes/month)	Mean revenue (AU$000/month)
Eastern king prawn (*Melicertus plebejus*)	36.2 (±1.5)	716.5 (±27.0)
School prawn (*Metapenaeus macleayi*)	43.1 (±3.5)	299.2 (±28.6)
Sea mullet (*Mugil cephalus*)	112.5 (±16.2)	198.6 (±31.5)
Yellowfin bream (*Acanthopagrus australis*)	10.4 (±0.7)	89.5 (±46.7)
Sand whiting (*Sillago ciliata*)	4.2 (±0.2)	43.2 (±3.0)
Giant mud crab (*Scylla serrata*)	2.1 (±0.2)	34.8 (±3.0)
Silver trevally (*Pseudocaranx georgianus*)	13.0 (±0.7)	34.1 (±2.5)
Blue spotted flathead (*Platycephalus caeruleopunctatus*)	7.8 (±0.3)	25.6 (±1.1)
Mulloway (*Argyrosomus japonicus*)	3.3 (±0.1)	24.7 (±1.6)
Sand mullet (*Myxus elongatus*)	17.8 (±1.5)	21.8 (±2.5)
Whaler sharks (*Carcharhinus* spp.)	4.8 (±0.3)	14.9 (±1.2)
Blue swimmer crab (*Portunus pelagicus*)	2.2 (±0.1)	13.5 (±8.9)
River eels (*Anguilla* spp.)	3.9 (±0.2)	12.6 (±1.8)
Australian sardine (*Sardinops neopilchardus*)	3.5 (±0.6)	11.9 (±3.9)
Dusky flathead (*Platycephalus fuscus*)	2.0 (±0.1)	10.2 (±0.4)
Tailor (*Pomatomus saltatrix*)	1.6 (±0.1)	8.4 (±1.1)
Largehead hairtail (*Trichiurus lepturus*)	0.9 (±0.2)	8.0 (±4.7)
Yellowtail scad (*Trachurus novaezelandiae*)	4.2 (±0.2)	7.0 (±0.6)
Luderick (*Girella tricuspidata*)	5.6 (±0.6)	6.7 (±0.8)
Trumpeter whiting (*Sillago maculata*)	1.5 (±0.2)	5.9 (±1.3)
Sandy sprat (*Hyperlophus vittatus*)	1.7 (±0.3)	5.6 (±1.6)
Estuary squid (*Uroteuthis* spp.)	2.5 (±0.1)	5.5 (±0.5)
Silver biddy (*Gerres subfasciatus*)	1.5 (±0.2)	4.0 (±0.7)
Catfish (*Siluriformes* spp.)	1.5 (±0.1)	2.8 (±0.4)
Goldspot mullet (*Liza argentea*)	1.7 (±0.1)	2.0 (±0.2)
River garfish (*Hyporhamphus regularis ardelio*)	0.4 (±0.1)	1.5 (±0.1)
Silver scat (*Selenotoca multifasciatus*)	1.0 (±0.2)	1.4 (±0.2)

Mean landings (tonnes/month) and revenue (AU$000/month) refer to mean landings in tonnes per month and mean revenue in AU$000's per month, respectively, between July 1997 and June 2007. Standard error values for fisheries parameters shown in parenthesis. Landings and revenue information presented for species that provided the dominant contribution (≥95%) to commercial fisheries harvest in NSW.

Table 3
Selected fishing methods used to investigate the economic impacts of drought on commercial fishing businesses that operate in three estuarine and coastal fisheries in eastern Australia.

Fishery	Fishing method	Method abbreviation	Mean landings (tonnes/month)	Mean effort (days/month)	Mean revenue (AU$000/month)
Estuary General	Gillnets	GI	61.4 (±2.2)	711 (±10.7)	155.7 (±4.0)
	Hauling net	HN	32.1 (±4.8)	276 (±14.4)	85.0 (±12.4)
	Prawn set pocket net	PN	4.7 (±0.6)	69 (±9.8)	34.6 (±6.3)
	Crab pot	CP	2.3 (±0.1)	89 (±5.6)	33.8 (±2.8)
	Eel trap	EE	3.8 (±0.2)	127 (±6.2)	12.3 (±1.6)
	Bait net	BN	3.4 (±1.0)	12 (±1.48)	8.9 (±7.7)
	Handline	LI	1.1 (±0.1)	72 (±3.2)	8.6 (±3.0)
	Fish trap	FT	0.8 (±0.1)	51 (±4.8)	6.1 (±1.8)
	Bullringing	BU	0.5 (±0.1)	10 (±1.8)	1.9 (±1.5)
Estuary Prawn Trawl	Estuarine prawn trawl	EP	37.1 (±2.9)	854 (±53.1)	255.7 (±25.8)
Ocean Hauling	Hauling net	HN	62.6 (±11.5)	244 (±34.4)	123.9 (±51.9)
	Purse seine net	PS	5.7 (±0.7)	17 (±1.6)	15.7 (±2.2)
	Bait net	BN	3.2 (±0.6)	7 (±1.5)	9.6 (±1.9)
Ocean Trawl	Ocean prawn trawl	OP	49.5 (±2.4)	779 (±20.8)	772.7 (±41.1)
	Fish trawl	FW	14.8 (±0.8)	196 (±4.1)	44.6 (±11.9)
Ocean Trap and Line	Fish trap	FT	6.7 (±0.4)	337 (±10.3)	31.0 (±1.8)
	Handline	LI	5.7 (±0.4)	355 (±14.6)	27.1 (±3.0)

Mean landings (tonnes/month), effort (days/month) and revenue (AU$000/month) refer to mean landings in tonnes per month, mean effort in days per month and mean revenue in AU$ 000's per month, respectively, between July 1997 and June 2007. Standard error values for fisheries parameters shown in parenthesis. Landings, effort and revenue information presented for fishing methods that provided the dominant contribution (≥95%) to commercial fisheries harvest in NSW.

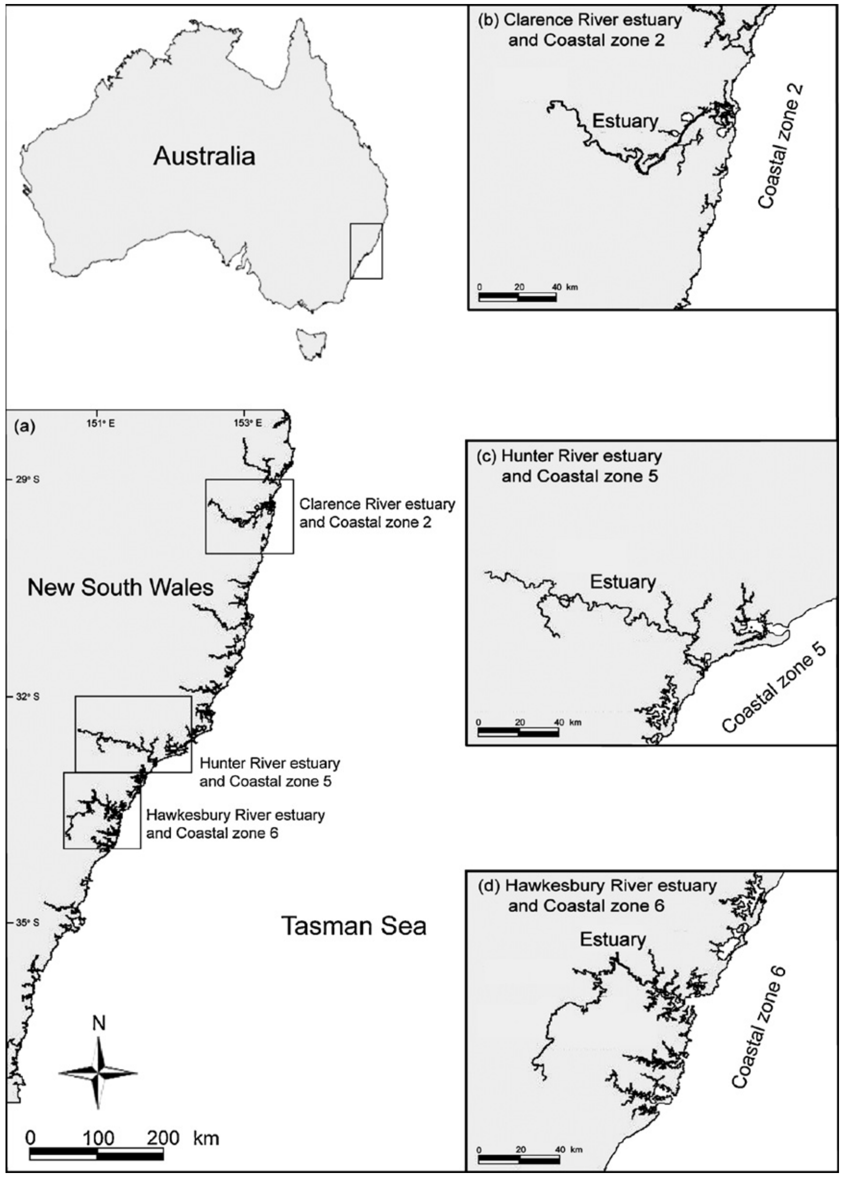

Fig. 1. Location of three estuarine and coastal systems selected to investigate the economic impacts of droughts on commercial fishing businesses in eastern Australia (a). Estuarine and coastal reaches shown in relation to the Clarence (b), Hunter (c) and Hawkesbury (d) Rivers. The estuarine systems encompassed an area from the upper limit of tidal influence to the downstream estuarine limit. Coastal systems extended from the downstream estuarine limit to ~30 km offshore and ~0.5° north and south of each river.

(ABS) for quarterly periods between July 1997 and June 2007 (www.abs.gov.au/AUSSTATS).

2.5. Costs

A cost model containing parameterised assumptions of cost variability was developed to examine profits associated with fishing activity. Information on the mean monthly cost of fishing was available, but not the variability of these costs experienced across the fleet. The cost model was further complicated by the constraint that mean monthly cost was only available by fishery. Therefore, the costs associated with different methods within a fishery could not be differentiated. For single-method fisheries the cost calculation was straightforward, but for multiple-method fisheries the cost calculation required assumptions about how the costs accrued within a fishery and a business.

Costs for individual businesses were partitioned into fixed-monthly costs (including sunk costs) and variable-monthly costs. Fixed-monthly costs were considered to be independent of fishing effort, while variable-monthly costs were assumed to be a function of fishing effort. Fixed costs were incurred on a monthly or annual basis such as licences, registration fees, insurance, governmental costs, equipment and maintenance. Variable costs were dependent on the amount of fishing effort undertaken, and in this study consisted of labour and fuel costs. The labour payment process varied depending on the scale of the fishing business. Large businesses with a corporate structure paid their owner/s wages or shares of the profit, while small businesses made nominal income payments directly to their owner/s. Information on fixed and variable costs per business from each fishery were derived from economic assessments undertaken by Dominion Consulting Pty Ltd (2001, 2002a,b, 2004, 2006) for the 1999–2000 fiscal period (Table 4). Nominal

Table 4
Mean monthly costs per fishing business (AU$) for the 1999–2000 fiscal period.

Fishery	Fixed cost	Variable cost	Total cost
Estuary General	1900	4600	6500
Estuary Prawn Trawl	4500	4900	9400
Ocean Hauling	3200	6200	9400
Ocean Trawl	8600	9000	17600
Ocean Trap and Line	3900	5700	9600

Mean monthly costs per fishing business were obtained from economic assessments undertaken by Dominion Consulting Pty Ltd for the 1999–2000 fiscal period (Dominion Consulting Pty Ltd, 2001, 2002a,b, 2004, 2006). Values presented to the nearest AU$100.

fixed and variable cost proportions were inflation-adjusted using the Fuel Price Index (FPI) and Labour Price Index (LPI) from the ABS relative to June 2000 ($FPI_{June2000}$ and $LPI_{June2000} = 1$).

Total costs were calculated using:

$$TC'_{b,t} = \max_{m(f)}[FC_{m(f),t}] + \max_{m(f)}[VC_{m(f),t} \cdot E_{m,b,t}]$$

where $TC'_{b,t}$ is total cost for business b in month t (Australian dollars), $\max[FC_{m(f),t}]$ is the maximum fixed cost for fishery f (over methods m within f) in month t (Australian dollars), $\max[VC_{m(f),t}]$ is the maximum variable cost for fishery f (over method m within f) in month t (Australian dollars). $E_{m,b,t}$ is the fishing effort for method m from business b in month t.

The assumption that monthly fixed and variable costs were capped at the maximum effort for a particular business was used to represent the reduced costs of deploying multiple gears within a month. This assumption also prevented costs from becoming unrealistically high in multi-method fisheries. For example, if a business operated low cost methods such as crab pots and high cost methods such as ocean prawn trawling, only the costs associated with ocean prawn trawling were included. Monthly total costs per business were standardised (using a z-transformation) to a distribution with a specified mean and standard deviation. The mean was that of the average monthly costs from Dominion Consulting Pty Ltd (2001, 2002a,b, 2004, 2006) (see Table 4). The standard deviation of costs across businesses in a month was modelled by assuming a specific coefficient of variation (C_V) of either 25%, 50% or 75% (hereafter referred to as cost-variability scenarios). This standardisation prevented the standard deviation of the costs experienced by businesses becoming unrealistically large.

2.6. Profit

Profit was calculated as:

$$\pi_{b,t} = \sum_m (R_{m,b,t}) - (TC'_{b,t})$$

where $\pi_{b,t}$ is the profit for business b in month t (Australian dollars), $R_{m,b,t}$ is revenue for fishing method m from business b in month t (Australian dollars) and $TC'_{b,t}$ is total cost for business b in month t (Australian dollars).

In accordance with the nominal cost adjustment, nominal revenue was inflation–adjusted using the Sydney food CPI relative to June 2000 ($CPI_{June2000} = 1$) before calculating monthly profit per method. Profits under alternative cost-variability scenarios were examined to determine the effects of increased cost-variability on profit.

2.7. Sensitivity analyses

Sensitivity analyses were performed to examine the robustness of profit outputs by altering key parameter values. Firstly, mean monthly market price per species was increased by 20%, 40% and 60% to determine effects on profit. Preliminary examination of percentage differences in the mean market price of eastern king prawn (*Melicertus plebejus*), school prawn (*Metapenaeus macleayi*), sea mullet (*Mugil cephalus*) and yellowfin bream (*Acanthopagrus australis*) revealed that prices from the Sydney Fish Market were 5–50% lower than the Professional Fishermen's Association. This comparison between national seafood prices from the Sydney Fish Market and local seafood prices from the Professional Fishermen's Association enabled an identification of any discrepancies in mean monthly market price per species between the two fish receivers. Secondly, costs were decreased by 20%, 40% and 60% to examine effects on profit. Finally, fixed costs incurred by non–operational (i.e. latent) businesses during drought were summed with total costs to estimate effects on profit. There was a reduction in the mean number of fishing businesses that operated during months of drought in the Clarence (32 ± 2.8% standard error, SE), Hunter (20 ± 3.4%) and Hawkesbury (33 ± 3.5%) systems. These sensitivity analyses were employed because the cost (and associated profit) calculations required far more assumptions than the revenue calculations.

2.8. Data analysis

2.8.1. Temporal trends in drought

Time periods that were most frequently drought declared were investigated by determining the percentage contribution of each month, season and year to the total number of drought declared months in each river catchment. Temporal auto–correlation in months of non-drought and drought were examined using a two-sided runs test for statistical independence. Each two-sided runs test was performed using the runs.test() function in the "tseries" library (Trapletti and Hornik, 2011) with R 2.13.0 (R Development Core Team, 2011).

2.8.2. Harvesting behaviour between non–drought and drought

A preliminary investigation of mean monthly revenue per method revealed that revenue generation decreased when businesses operated beyond a certain number of methods (Fig. 2). The number of methods required to saturate revenue generation was five or less in the Clarence system and two or less in the Hunter and Hawkesbury systems. Based on these findings, numbers of methods were categorised into two distinct groups for each system: less than five methods or more than five methods for the Clarence system; and less than two methods or more than two methods for the Hunter and Hawkesbury Systems. One-tailed Fisher's exact tests were then employed to compare proportional differences in the number of businesses that operated different numbers of methods during non-drought and drought. Fisher's exact tests evaluated the presence of non–random associations between numbers of methods used by businesses during non-drought and drought.

2.8.3. Revenue (or profit) between non–drought and drought

Mean monthly revenue (or profit) (this notation indicates that the same analysis was repeated for revenue and profit) during non-drought and drought was standardised by dividing the sum of monthly revenue (or profit) by the number of non-drought and drought months in each river. This standardisation procedure prevented differences in mean monthly revenue (or profit) being a result of an unbalanced number of non-drought and drought months. Profits under alternative cost-variability scenarios were compared to baseline profit values during non-drought. A similar approach was used to examine profit under the alternative economic scenarios within the sensitivity analyses.

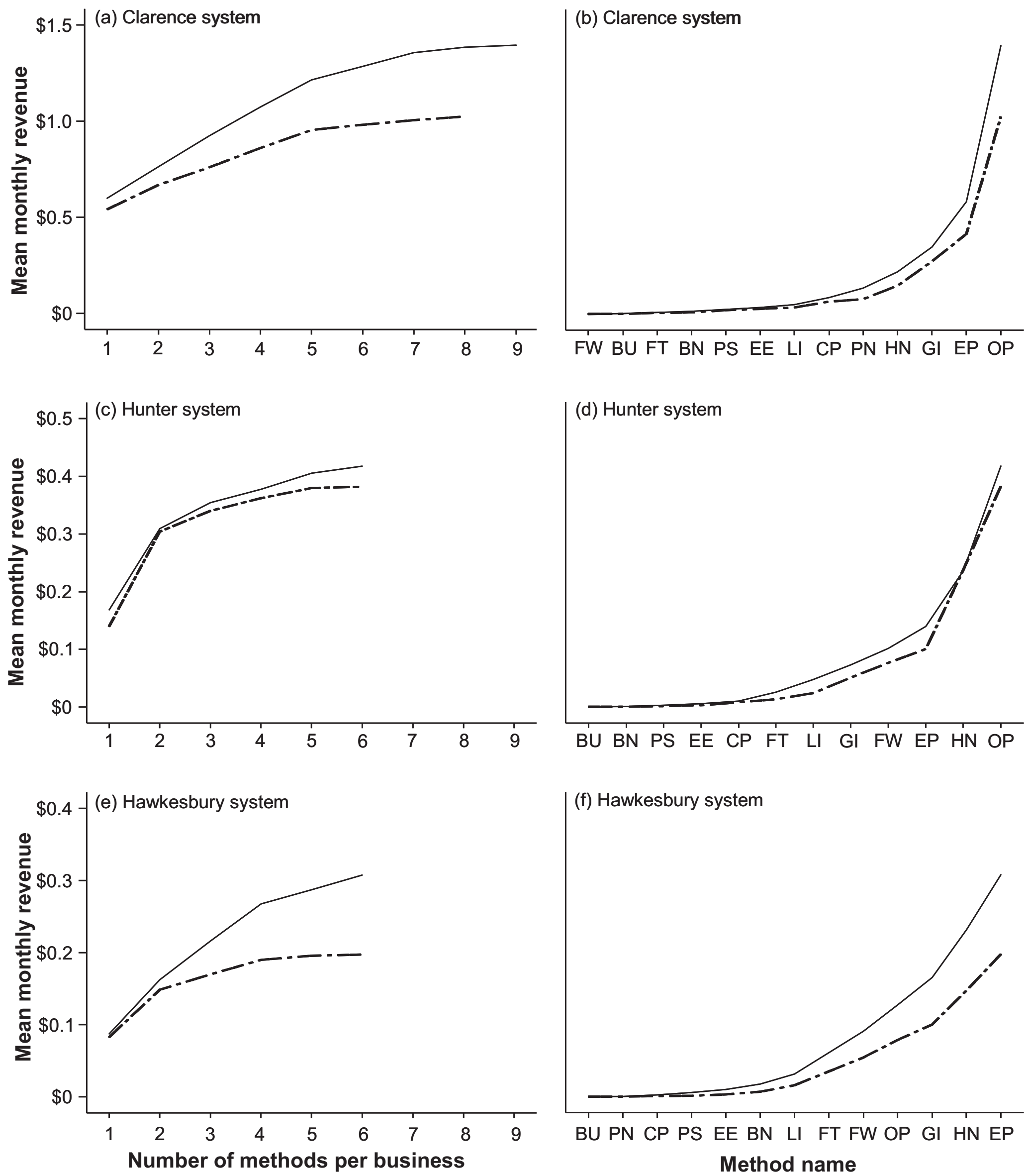

Fig. 2. Cumulative mean revenue per month in millions of Australian dollars generated from different fishing methods during non-drought (solid line) and drought (dotted line) conditions for the Clarence, Hunter and Hawkesbury systems from July 1997 to June 2007. See Table 3 for details of fishing method abbreviations. Revenue is standardised by the number of drought declared months in each river system.

2.8.4. Revenue and fishing method diversity

Mean revenue, when businesses operated one or more fishing methods per month, was calculated to determine the contribution of different fishing methods to revenue during non-drought and drought. We employed the Shannon index (Shannon, 1948) to measure fishing method diversity during multiple-method months. The Shannon index provided a suitable measure of fishing method diversity because it quantified variation and uncertainty (information entropy) in patterns of fishing method use. A modified form of the Shannon index was calculated using monthly effort per method from individual businesses rather than the usual application of species abundance. Mean monthly values for revenue and the Shannon index were calculated from all businesses.

The equation used to calculate fishing method diversity was:

$$H'_{b,t} = -\sum_{m} P_{m,b,t} \cdot \ln(P_{m,b,t})$$

In which

$$P_{m,b,t} = \frac{E_{m,b,t}}{\sum_m E_{m,b,t}}$$

where $H'_{b,t}$ is the modified Shannon index value for business b in month t and $E_{m,b,t}$ is the fishing effort (in days) for method m from business b in month t and $P_{m,b,t}$ is the proportion of fishing effort for method m at time t for business b.

2.8.5. Seasonality of revenue and fishing method diversity

Seasonality within the revenue and fishing method diversity time series was investigated using simple decomposition methods. The R function decompose() was used to remove the seasonal trend that was evident in both time series and calculate the smoothed trend data that could be compared to the timing of drought events. This analysis was not repeated for the profit time series because the data were not as credible, and therefore need to be interpreted via sensitivity analyses.

Austral seasons were also calculated and added to the datasets for the regression analysis. These seasons were defined as: summer (December–February), autumn (March–May), spring (September–November) and winter (June–August). Summer was used as the reference period when season was included as a covariate. Preliminary analyses used month [1,12] as a discrete variable to model seasonality; it was, however, determined that individual months were rarely significant in the analyses and that using four seasons provided an effective balance between excluding all seasonality and over-parameterising the model with 11 additional parameters.

2.8.6. Regression analysis of revenue

Two-phase regression analysis was performed to examine the predictors of revenue. Given the likely dependencies between consecutive observations, an auto-correlation parameter was incorporated into the second phase of the analysis. The first phase used the ordinary least squares function (lm, in the standard R library) to identify the covariates within non-zero coefficients that predicted mean monthly revenue from drought, season and fishing method diversity. First order interactions between the covariates were investigated, but were never significant. After the non–significant covariates were removed from the model, the auto-correlation between consecutive residuals was calculated with the R function "acf". Partial auto-correlation in the residuals was also investigated, but only first order auto-correlation was identified. The second phase of the regression analysis used generalized least squares (R function gls within the library nlme, Pinheiro et al., 2011). The first order auto-correlation coefficient from the first phase of the analysis was used in the GLS model. This modelling approach was based on a procedure for analysing time series suggested by Cowpertwait and Metcalfe (2009).

Mean monthly revenue was $\log_{10}$ transformed to stabilise variances. After transformation, mean monthly revenue was normally distributed (Lilliefors' test) with no evidence of heteroscedasticity (standardised quantile plots).

3. Results

3.1. Temporal trends in drought

Prolonged periods of non-drought were interspersed by sporadic periods of drought in the Clarence, Hunter and Hawkesbury systems (Fig. 3). The majority of drought events ($\geq$70%) occurred between 2003 and 2006. Drought events most frequently arose during spring (September–November) and summer (December–February) months. Two-sided runs tests detected significant temporal correlation in months of non-drought and drought (all $P < 0.0001$, two-sided Runs test).

3.2. Harvesting behaviour between non-drought and drought

Numbers of businesses that operated different fishing methods between non-drought and drought exhibited considerable variation in the Clarence, Hunter and Hawkesbury systems. A significant difference in the proportional number of businesses that operated one to five methods compared to five or more methods between non-drought and drought was evident in the Clarence system (One tailed Fisher's exact test, $P < 0.05$). This difference was characterised by an 11% increase in the number of businesses that operated fewer methods (1–5) during drought compared to non–drought in the Clarence system. In the Hunter and Hawkesbury systems, there were significant differences in numbers of businesses that operated one to two methods compared to two or more methods between non-drought and drought (One tailed Fisher's exact test, $P < 0.05$). In contrast to the to the Clarence system, more businesses operated one to two methods during drought compared to non-drought in the Hunter (10%) and Hawkesbury (8%) systems.

3.3. Revenue between non-drought and drought

Mean monthly revenue was lower during drought compared to non-drought in the Clarence (27%), Hunter (8%) and Hawkesbury (36%) systems (Fig. 2). Cumulative mean monthly revenue increased in proportion to the number of fishing methods used during non-drought and drought, however, the marginal benefit of using more methods declined in all systems. Rates of revenue generation decreased after businesses operated five or more methods in the Clarence system. Similar results were identified for the Hunter and Hawkesbury systems, with diminishing returns when businesses operated two or more methods. Fishing methods that primarily contributed to decreased mean monthly revenue between non-drought and drought were ocean prawn trawling ($\geq$20%) and estuarine prawn trawling ($\geq$34%). Methods that provided a relatively smaller contribution to decreased mean monthly revenue between non-drought and drought were gillnets ($\geq$15%) and hauling nets ($\geq$16%).

3.4. Revenue and fishing method diversity

Mean monthly revenue was significantly lower during winter (coefficient = −0.07 with a 95% confidence interval from −0.13 to −0.02) and spring (coefficient = −0.09 with a 95% confidence interval from −0.14 to −0.04) when compared to summer, with the model possessing a fitted residual auto-correlation (ϕ) of 0.71 in the Clarence System (Table 5). No significant relationships between mean monthly revenue and fishing method diversity, or mean monthly revenue and drought declaration were evident in the Clarence system.

Generalized least squares regression models revealed significant positive relationships between mean monthly revenue and fishing method diversity in the Hunter (coefficient = 1.30 with a 95% confidence interval from 0.22 to 2.38) and Hawkesbury (coefficient = 4.14 with a 95% confidence interval from 3.05 to 5.23) systems (Table 5). Mean monthly revenue was significantly higher during autumn when compared to summer in the Hunter (coefficient = 0.19 with a 95% confidence interval from 0.11 to 0.27) and Hawkesbury (coefficient = 0.10 with a 95% confidence interval from 0.02 to 0.18) systems. There was a significant reduction in mean monthly revenue during spring (coefficient = −0.10 with a 95% confidence interval from −0.19 to −0.01) when compared to summer in the Hunter system. The autoregressive terms (ϕ) for these two systems were 0.41 and 0.34, respectively. No interaction terms between fishing method diversity and drought declaration were significantly different from zero. The GLS regression models for the Hunter and Hawkesbury Systems identified positive coefficients for the relationship between mean monthly revenue and fishing method diversity, and negative coefficients for the relationship between mean monthly revenue and drought declaration.

3.5. Profit between non-drought and drought

The analysis of profits consistently resulted in many fishing businesses operating at a loss (i.e. costs were greater than revenues). This outcome was likely a result of over-estimating the costs of fishing effort in multi-method fisheries and was a limitation of the cost information available for this analysis. For this reason, we shall not present the calculated profit (i.e. loss) values directly, but report only the outcomes of the sensitivity analysis associated with the profit calculations. The general result was, however, that mean monthly losses under alternative cost-variability scenarios

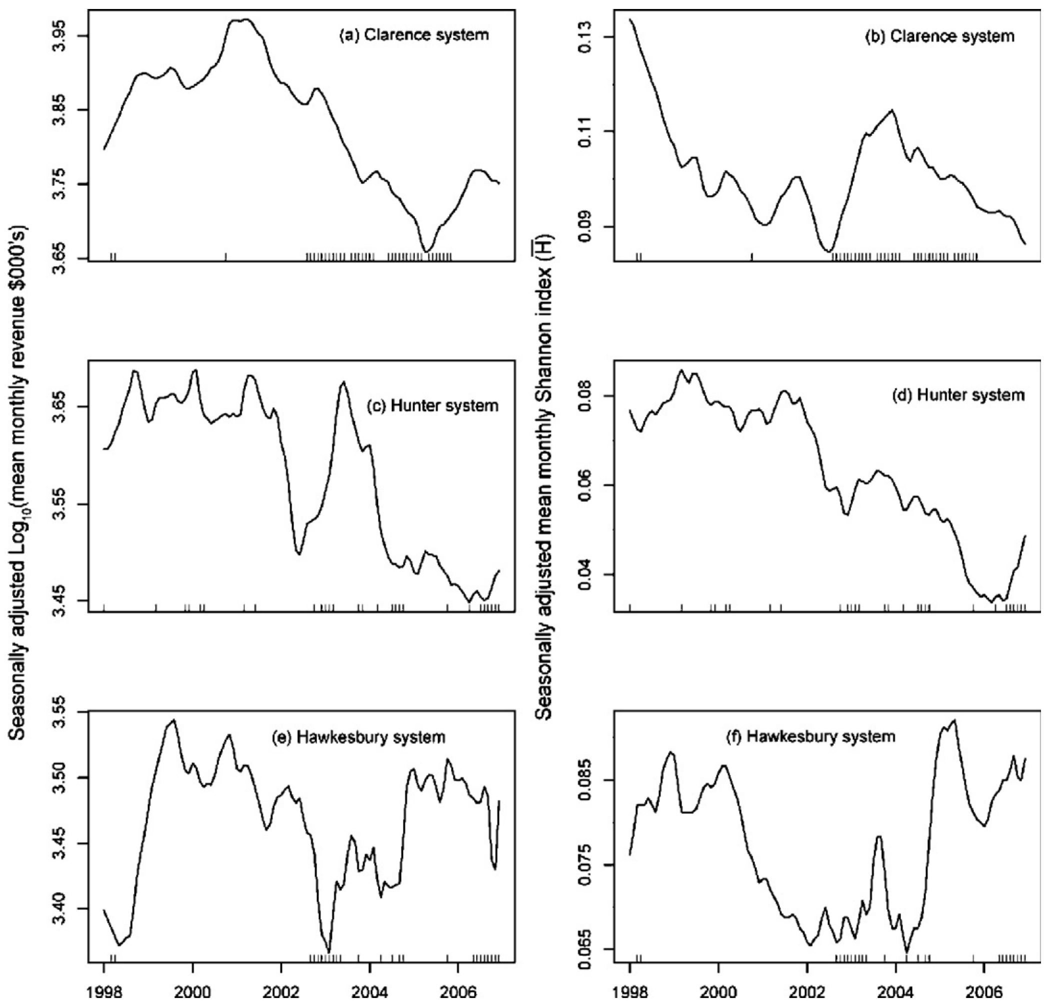

Fig. 3. Temporal trends in seasonally adjusted $\log_{10}$ mean monthly revenue and fishing method diversity (Shannon index, $\bar{H}'$) for the Clarence, Hunter and Hawkesbury systems from July 1997 to June 2007. Note that the vertical black lines on the bottom of the plots indicate periods of drought declaration.

Table 5
Results from generalized least squares regression models with AR(1) auto-correlated errors for mean monthly revenue for the Clarence (CR), Hunter (HU) and Hawkesbury (HK) systems. Only significant ($P > 0.05$) covariates were included in the final model.

System	Model	Coefficient (95% CI)	RSE
CR	$\overline{R}_t \sim I + S_t + \text{AR}(1)$	Winter −0.07 (−0.13, −0.02) Spring −0.09 (−0.14, −0.04) AR(1) ϕ 0.71	0.12
HU	$\overline{R}_t \sim \text{I} + \overline{H'}_t + D_t + S_t + \text{AR}(1)$	Diversity 1.30 (0.22, 2.38) Drought −0.09 (−0.15, −0.02) Autumn 0.19 (0.11, 0.27) Spring −0.10 (−0.19, −0.01) AR(1) ϕ 0.41	0.15
HK	$\overline{R}_t \sim I + \overline{H'}_t + D_t + S_t + \text{AR}(1)$	Diversity 4.14 (3.05, 5.23) Drought −0.15 (−0.22, −0.08) Autumn 0.10 (0.02, 0.18) AR(1) ϕ 0.34	0.14

Model details provided for $\log_{10}$ transformed revenue data; $n = 120$. RSE represents the residual standard error. $\overline{R}_t$ refers to the mean revenue in month t; $\overline{H'}_t$ denotes the mean fishing method diversity in month t; and $D_{t,}$ the drought declaration in month t. Austral seasons (S_t) were categorised into summer* (December–February), autumn (March–May), winter (June–August) and spring (September–November). Intercept terms (I) were always non-zero but are not reported. *Summer was used as the reference season.

were always greater during drought (Fig. 4). Profits also exhibited considerable variation under alternative assumptions (Fig. 5). For example, increased market price of seafood and decreased costs were associated with decreased losses during non–drought and drought. The addition of fixed costs incurred by latent businesses increased losses during drought in the Clarence (43%), Hunter (40%) and Hawkesbury (46%) systems.

4. Discussion

Examination of fishery-dependant data from commercial fishing businesses revealed a range of patterns in the economic impacts of drought on estuarine and coastal fisheries. Results from this study indicate that reductions in freshwater flow due to drought or increased human water extraction are likely to have negative

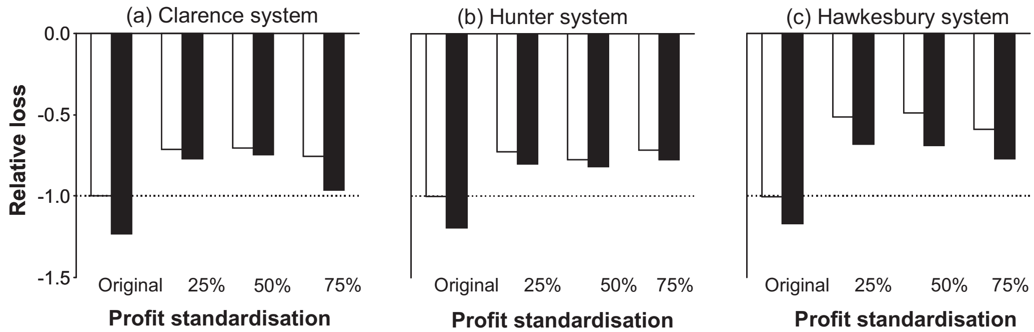

Fig. 4. Sensitivity analyses indicating the effects of variability in monthly costs on profit during non-drought (white) and drought (black) conditions for the Clarence, Hunter and Hawkesbury systems. Subfigures illustrate the relative loss as the coefficient of variation of cost increases from the non-drought baseline (dotted line). Costs have been standardised by mean costs per fishing business with a fixed 25%, 50% and 75% coefficient of variation.

economic impacts on fishing businesses that operate in the estuarine and coastal systems of eastern Australia. Climate change is predicted to increase the frequency and severity of droughts in this region (Hennessy et al., 2007), which will place additional demands on freshwater resources (Kundzewicz et al., 2007). Understanding the patterns in revenues and costs associated with fishing under such conditions has provided insight into the types of fishing businesses that will be more robust to climate change.

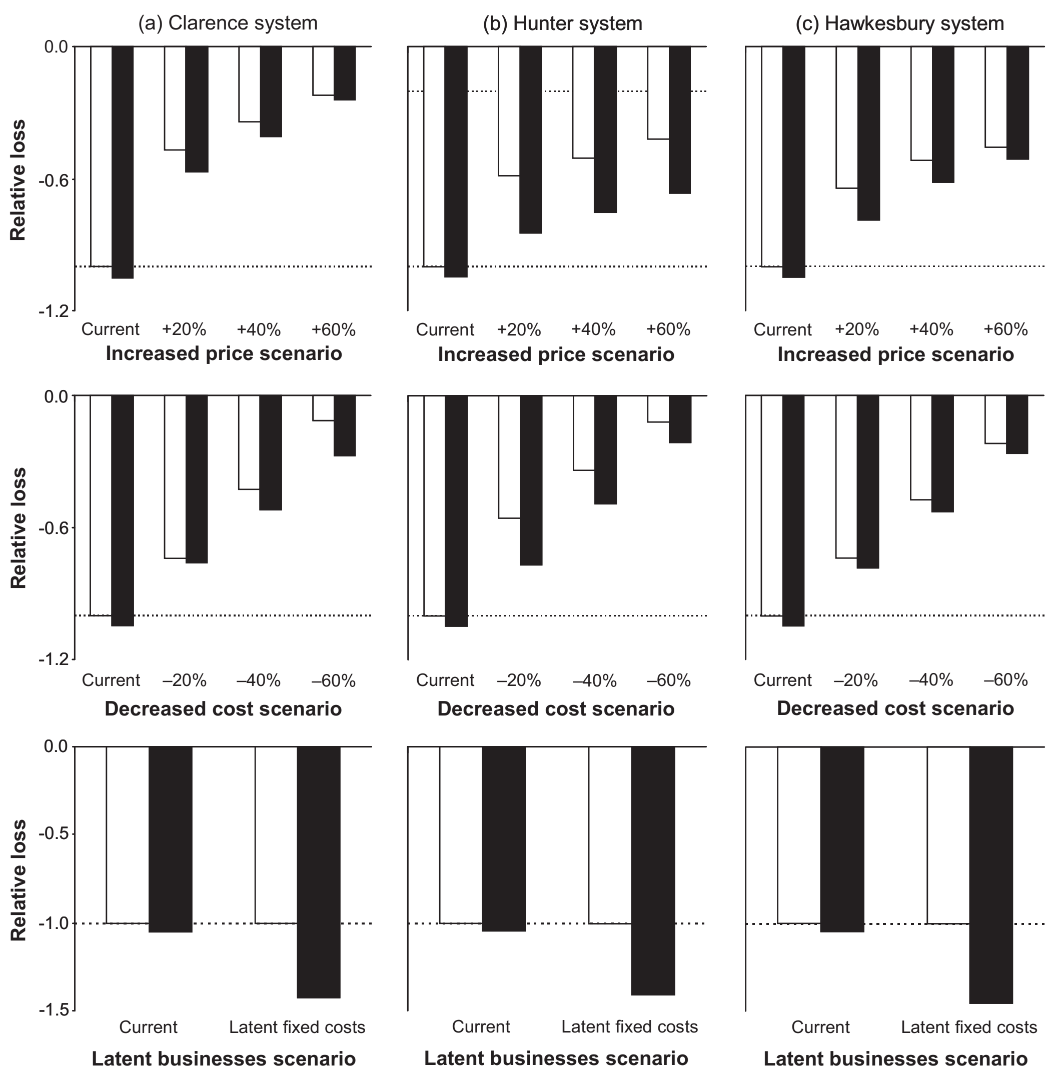

Fig. 5. Sensitivity analyses indicating the effects of increased market price of seafood, decreased costs and the addition of fixed costs incurred by drought latent businesses on profit during non-drought (white) and drought (black) conditions for the Clarence, Hunter and Hawkesbury systems. Subfigures illustrate relative loss due to changes in market price, costs and fixed costs incurred by drought latent businesses from the non-drought baseline (dotted line). Results presented for a mean monthly cost coefficient of variation of 50%.

Differences in revenue and profit between non-drought and drought were method, season and system specific. Droughts were associated with reductions in the revenue and profit of fishing businesses. Businesses that operated ocean prawn trawls and estuarine prawn trawls primarily contributed to reductions in revenue and profit during drought. Spring and summer droughts had the most pronounced impacts on revenue and profit due to the high frequency of drought events during these seasons. Relationships between revenue and fishing method diversity were highly significant ($P < 0.05$, Table 5), but the initial results indicated the positive revenue–diversity relationship shifted to a negative profit–diversity relationship once costs were included into the analyses. This result indicated that either, fishers altered their harvesting behaviour and operated less profitable methods during drought, or, more likely, that the costs of fishing effort within a multi-method fishery were being over-estimated. More information on how costs accrue in multi-method fisheries is required to provide confirmation of these patterns. Some of the variability underlying differences in revenue and profit between non–drought and drought may be related to factors such as bioregion (Pease, 1999), estuarine geomorphology (Saintilan, 2004), degree of river regulation within the catchment (Drinkwater and Frank, 1994), and the life history of individual species (Robins et al., 2005).

Fewer businesses operated during drought suggesting that fisher's temporally sourced income from employment unrelated to commercial fishing. Fishers often engage in alternative employment when income falls below the opportunity cost of fishing (Gordon, 1991). A substantial proportion of the businesses examined (20%) supplement income from enterprises (e.g. agriculture, construction and tourism) outside the fishing industry (Dominion Consulting Pty Ltd, 2001, 2002a,b, 2004, 2006). Fishers' entry and exit strategies from the fishing industry depend on their economic situation (Opaluch and Bockstael, 1984). This sustainable livelihoods approach allows fishers to supplement income from activities unrelated to fishing during periods of resource uncertainty (Allison and Horemans, 2006). Fishing is a high-risk occupation that is prone to seasonal and cyclical fluctuations in resource abundance, some of which are highly unpredictable in occurrence. Fishers that pursue diversified livelihood strategies can reduce the risk of livelihood failure by spreading income generation over more than one income source (Allison and Horemans, 2006). Diversification can appear to maintain the economic performance of fishers during periods of environmental variability (Andrew et al., 2007), but this analysis shows the potential complexities of these relationships. Artisanal fishers that operate in small–scale fisheries (particularly in low income countries) possess a high degree of flexibility to diversify their livelihood strategies due to low capital investment in fishing assets (Allison and Ellis, 2001; Smith et al., 2005). In contrast, commercial fishers that operate in large-scale industrialised fisheries (particularly in high income countries) possess a low degree of flexibility to diversify their livelihood strategies due to high capital investment in fishing assets (Salas and Gaertner, 2004). Our results suggest that income augmentation from employment unrelated to fishing may represent an effective strategy for businesses to endure droughts and remain in the commercial fishing industry for the long-term. Method diversification within the commercial fishing industry has subtle strengths and weaknesses as illustrated by the research presented here.

Harvesting strategies are influenced by the economic outcomes of previous fishing activities (Branch et al., 2006). Alterations to fishing activity were evident between non-drought and drought. Businesses that operated ocean prawn trawls and estuarine prawn trawls during non-drought altered their harvesting behaviour to generate revenue from fish trawls and gillnets during drought. Commercial fishers' in NSW modify their harvesting behaviour to exploit alterations to the catchability of fishery species that arise during flood and drought events (Gillson et al., in press). Adjustments to harvesting behaviour permit fishers' to target the increased catchability of high-value (market price) estuarine migrant species (e.g. school prawn) during flood and high-value marine estuarine-opportunist species (e.g. yellowfin bream) during drought.

This study incorporated various assumptions regarding the operational characteristics of fishing businesses. Firstly, determining the costs of businesses that operated in multiple fisheries with multiple methods was problematic. This issue was resolved by considering maximum costs per business within a fishery and examining alternative cost-variability scenarios. Secondly, the cost model adopted a labour cost function dependent on fishing effort. Fishers' labour costs, however, can fluctuate with income (Charles, 1989). This may have inhibited the analyses given that no information on the relationship between labour costs and income existed. Thirdly, the analyses focused on the economic characteristics of fishing businesses. Harvesting behaviour, however, represents a dynamic combination of socio-economic factors (Salas and Gaertner, 2004). Information on social patterns of harvesting behaviour may have improved our understanding of business responses to drought not explained by economics. Fishers often forgo income for lifestyle and autonomy (Dominion Consulting Pty Ltd, 2001, 2002a,b, 2004, 2006). Fourthly, fishing behaviour can be associated with other demographic and socio-economic factors (e.g. age, educational status and housing tenure) not considered here. These additional dimensions to the characteristics of fishing operations could readily generate contrasting results for profitability to those presented here. Despite the various limitations, this study provided an illustration of the economic impacts of drought on fishing businesses and revealed the economic role that fishing method diversity could play under circumstances of climatic variability.

4.1. Revenue between non-drought and drought conditions

Mean monthly revenue was lower during drought (Fig. 2). Ocean prawn trawling and estuarine prawn trawling exhibited the most pronounced reductions in revenue. This result was not surprising given that positive relationships between freshwater flow and landings of penaeid prawns have been reported in eastern Australia (Loneragan and Bunn, 1999; Robins et al., 2005; Ives et al., 2009). Increased freshwater flow results in the increased catchability of penaeid prawns due to reductions in salinity enhancing emigration rates from estuarine to coastal systems (Racek, 1959; Ruello, 1973; Glaister, 1978). Reductions in revenue from prawn trawlers during drought resulted from decreased landings of penaeid prawns rather than market price fluctuations. Variation in the market price of eastern king prawns ($C_V = 19\%$) and school prawns ($C_V = 25\%$) was relatively low compared to landings of these two species from ocean prawn trawling ($C_V = 60\%$) and estuarine prawn trawling ($C_V = 76\%$). Future reductions in freshwater flow due to droughts are projected to decrease commercial landings of penaeid prawns in eastern Australia (Ives et al., 2009). Our results indicated that decreased landings of penaeid prawns during drought reduced revenue generation from ocean prawn trawling and estuarine prawn trawling.

Gillnets and hauling nets provided a smaller contribution to decreased revenue during drought. Sea mullet dominated revenue generation from gillnets ($\geq 45\%$) and hauling nets ($\geq 65\%$) providing the greatest contribution to decreased revenue from these methods during drought. Positive relationships between freshwater flow and landings of sea mullet have been reported in eastern Australia (Gillson et al., 2009). Increased freshwater flow results in the increased catchability of sea mullet due to reduced salinity stimulating migration and schooling into alternative habitat.

Differences in fishing method diversity and drought declaration coefficients revealed the contrasting effects of method diversification and drought events on revenue generation. Method diversification increased revenue generation in the Hunter and Hawkesbury systems, while drought events decreased revenue generation. Decreased revenue during drought can to some extent be compensated by diversifying harvesting behaviour to increase revenue generation (Fig. 3). Businesses that harvested with multiple fishing methods possessed an inherent flexibility to generate revenue from a range of species. Diverse harvesting strategies represent a form of economic resilience for fishers during periods of resource uncertainty (Hilborn et al., 2001). Detection of diminishing returns indicated that diverse harvesting strategies only maximised revenue generation to a degree. Rates of increased revenue generation slowed when businesses operated beyond a certain number of methods. The number of methods required to saturate revenue generation was five or less in the Clarence system and two or less in the Hunter and Hawkesbury systems.

4.2. Profit between non-drought and drought conditions

The modelling presented here indicated that many businesses exhibited losses due to costs exceeding revenue. Businesses were not expected to generate large profits given that the majority of operators in the Estuary General (∼80%), Estuary Prawn Trawl (∼90%), Ocean Hauling (∼75%), Ocean Trawl (∼59%) and the Ocean Trap and Line (∼72%) fisheries had previously been noted to operate below "long-term economic viability benchmarks" (Dominion Consulting Pty Ltd, 2001, 2002a,b, 2004, 2006). However, modelled estimates of losses under alternative cost-variability scenarios and a range of economic assumptions were consistently greater during drought (Figs. 4 and 5). We must reiterate that the cost component of this analysis required many more assumptions than the revenue component, therefore the conclusions associated with profits are highly qualified.

Profits generated by businesses were dependent on market price and estimates of cost. Sensitivity analyses indicated that increased market prices and decreased costs reduced losses during non–drought and drought (Fig. 5). Businesses on average, only moved into profit when market prices and costs were increased or decreased, respectively, by very substantial amounts. Once fixed costs incurred by latent businesses were factored into profit models, losses increased considerably (≥40%) during drought. This result highlighted the importance of incorporating fixed costs incurred by latent fishing businesses into profit models to provide a better understanding of the economic impacts of drought on estuarine and coastal fisheries.

Harvesting strategies represent an economic trade-off between revenue generation and the cost of fishing activities (Sampson, 1991). This analysis indicated that businesses that operated a diversity of fishing methods to increase revenue generation during drought may have employed an economic risk-reduction strategy that compromised profitability in the process. Only improved information on how costs accrue in multi-method fisheries will clarify this result.

5. Conclusion

Droughts were associated with reductions in the revenue and profit of commercial fishing businesses that operated in the estuarine and coastal fisheries of NSW. Reductions in revenue and profit were most pronounced for businesses that operated ocean prawn trawls and estuarine prawn trawls during drought. The findings presented here indicate that the economic performance of estuarine and coastal fisheries can be drought-affected. Although diversification of harvesting behaviour can function as a risk-reduction strategy for fishers during periods of resource uncertainty (Hilborn et al., 2001), this phenomenon was only marginally evident for commercial fishing businesses in eastern Australia. Diversified harvesting behaviour increased revenue generation, but this marginal economic benefit could be compromised by the larger costs associated with increased diversification which reduced profitability. The later result must be qualified until improved information on how costs accrue in multi-method fisheries is available. Utilising employment opportunities outside the commercial fishing industry probably offers fishers the most effective strategy to improve economic resilience in the face of drought.

Acknowledgements

Special thanks must go to the Fisheries Research and Development Corporation, Industry and Investment New South Wales and the University of New South Wales Evolution and Ecology Research Centre for providing funding for this project. This study would not have possible without the submission of monthly catch returns and continued support from commercial fishers in New South Wales. Thanks to John Harrison from the Professional Fishermen's Co-operative for sourcing local seafood price data. This project was also supported by the New South Wales Fisheries Research Advisory Body, Clarence Professional Fishermen's Association and the South-East Australia Climate Change Programme. We are also grateful to Matthew Ives, Iain Suthers and two anonymous reviewers for providing constructive comments on the research presented here.

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