Spreading the risk: management strategies for multi-method inshore fisheries in a changing climate

James Scandol and Jonathan Gillson

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Spreading the risk: management strategies for multi-method inshore fisheries in a changing climate

Final Report to the Fisheries Research and Development Corporation

October 2010

James Scandol and Jonathan Gillson

School of Biological, Earth and Environmental Sciences

University of New South Wales

Sydney, Australia 2052

jscan@doh.health.nsw.gov.au

jonathan.gillson@unsw.edu.au

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PRINCIPAL INVESTIGATOR: Dr J. Scandol

ADDRESS: School of Biological, Earth and Environmental Sciences
University of New South Wales
Sydney, Australia 2052
Telephone: 02 9566 2696 Fax: 02 8580 5108

Objectives

1. Identify the patterns of fishing endorsements that will make NSW fishing businesses more robust to the likely changes in freshwater flow that will result from climate change.

Non Technical Summary

OUTCOMES ACHIEVED TO DATE

This project has provided insight into the complex relationships between fishing activity, revenue, droughts and costs for multi-species, multi-method fisheries in coastal NSW. These outputs will inform policy debate as to the best strategies to manage such fisheries in an increasingly variable climate.

The assumption that fishers who use an increasing diversity of fishing methods to deal with the highly variable patterns of production will have more resilient fishing businesses must be qualified by the increased costs associated when employing this diversity. The research presented here indicates that the best strategy of diversification to employ may include activities outside the fishing sector.

Discussions with staff at Industry and Investment NSW have indicated the results from this project are consistent with existing knowledge, but that the social components of coastal fisheries in NSW are likely to play a more important role in both policy and individual decision-making than was able to be captured by this study.

As government and industry continue to develop longer-term strategies for commercial fisheries in NSW, this report will support the understanding of the role of method diversification as a risk-management strategy. The true scale of diversification required must be recognised. Diversification by using different methods within the coastal fishing sector appears to be inadequate to deal with the loss of income associated with droughts, a primary consequence of climate change in Australia.

Industry and Investment NSW continues to work with the NSW commercial fishing industry to investigate structural changes to the management of commercial fisheries which will lead to improvements in efficiency and profitability. One issue that requires consideration in these deliberations is the highly variable inshore-offshore production that is linked with rainfall in coastal NSW. Such changes are exacerbated during periods of drought and result in significant shifts in the behaviour of fishers. It is expected that such variations in rainfall will continue, and are likely to become more extreme, under projected climate change scenarios.

The research presented here aims to support these reforms by completing an analysis into role of fishing method diversity on revenues and profits in an environment of variable freshwater flows. The primary objective "Identify the patterns of fishing endorsements that will make NSW fishing businesses more robust to the likely changes in freshwater flow that will result from climate change" has been expanded into a broader analysis of the role of fishing method diversity within risk management strategies for a coastal fishing industry experiencing climate change.

The primary results associated with this objective of the project are that losses to revenue associated with the three (economically dominant) methods used in NSW: ocean prawn trawling, estuarine prawn trawling and hauling nets are very significant. Businesses that experienced these losses either did not continue to fish (and presumably the operators generated revenues from non-fishing activities), or compensated for these losses by operating with different fishing methods (e.g. handlines and crab pots). The preliminary conclusion from this analysis is that business involved in ocean prawn trawling, estuarine prawn trawling and hauling nets should retain endorsements in fish trawling and gillnetting to maintain revenue streams during droughts (which are expected to increase in frequency with climate change).

This result is supported by the more general statistical result that increasing method diversity (as measured using the logical equivalent of an index for biological diversity) enables revenue decreases due to drought to be offset. For example, in the Clarence River system, businesses with a method diversity index of 0.127 generated the same revenue under drought conditions as fishers with a method diversity of 0.08 under normal conditions.

Fishing business owners are not, however, motivated simply by revenues, but by costs. This analysis extended the initial proposal by developing a "cost model" which estimated the costs associated with a particular fishing strategy. Costs are very much more difficult to estimate than revenues and so the results based upon profits (revenue minus costs) must be necessarily much more qualified.

This secondary analysis indicated that business that used increasingly diverse methods may decrease the profitability of their businesses because the marginal costs associated with fishing in drought conditions is greater than the marginal revenue. The majority of the fishing profits in NSW come from ocean prawn trawling, estuarine prawn trawling and hauling nets (for sea mullet) during non-drought conditions. During droughts, these businesses appear to lose money. Business owners could likely make more money by diversifying into activities not affected by the drought (which would exclude most coastal fishing).

The outcomes from this study could be improved by completing a more robust analysis of fishing business costs. Most of the data sources for costs used in this study are secondary and compromised in various ways. Whether these compromises are large enough to impair the conclusions remains unknown. Sensitivity analyses indicated that large changes to estimated costs and revenues are required before the conclusions from this analysis are altered.

KEYWORDS: Risk, climate change, drought, multi-method fisheries

Acknowledgments

The authors would like to acknowledge the contributions to this project by co investigators Professor Iain Suthers (The University of NSW) and Dr Matthew Ives (Industry and Investment NSW).

This project also had financial and logistic support from the University of NSW Evolution and Ecology Research Centre and Industry and Investment NSW. We thank John Harrison of the Professional Fishermen's Co-operative for providing some sample seafood prices from the Clarence region to compare to those from the Sydney Fish Market. 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 Colin Creighton and Ingrid Holliday for providing constructive comments on this document.

Finally, we thank the Fisheries Research and Development Corporation (particularly Crispian Ashby and Carolyn Stewardson) for their support.

Background

This project is a sub-component of a larger PhD-based project between The School of Biological Sciences (at The University of NSW) and Industry and Investment NSW. PhD candidate Jonathan Gillson has already undertaken a systematic analysis of the relationship between freshwater flows and patterns of fisheries production as recorded in the NSW commercial fisheries logbooks. This larger project has resulted in two publications "Estuarine gillnet fishery catch rates decline during drought in eastern Australia" (Gillson et al. 2009) and "Effects of flood and drought events on multi-species and multi-method coastal fisheries in eastern Australia" (Gillson et al. in review). For the final analysis within Jonathan's PhD dissertation, support from the Fisheries Research and Development Corporation (FRDC) was sought to complete an economic extension.

The key question here is how much fishing-method flexibility should operators retain to deal with the variable patterns of production associated with rainfall, and particularly the drought conditions which are likely to be exacerbated by climate change. Reductions in freshwater flows are also likely to result from additional population pressure in NSW which will inevitably lead to greater demands for freshwater for direct and indirect human consumption.

This project originally aimed to understand the relationships between frequency and diversity of fishing method use and the revenue obtained from these activities as a function of rainfall extremes. Additional discussions with I&I NSW indicated that unless the costs of fishing were also considered, then the outcomes from this project would be compromised. Furthermore, the key characteristic of climate change which was likely to affect fishers was the increasing frequency of droughts.

As a result of these updates, this project was therefore extended with a cost model based upon data collected for the Environmental Impact Statements on commercial fisheries in NSW (completed around 2001). This cost model enabled an estimate of the profitability of a particularly fishing strategy to be calculated.

This report is structured in two parts. This cover report provides a high level summary of the background, methods, results and discussion. The more detailed report on these sections (including full referencing) is provided in Appendix 3. This appendix was written by PhD candidate Jonathan Gillson who did the actual work in the project under the supervision of James Scandol (UNSW), Iain Suthers (UNSW) and Matthew Ives (I&I NSW).

Need

The NSW Department of Primary Industries continues to work with the NSW commercial fishing industry to investigate structural changes to the management of commercial fisheries which will lead to improvements in efficiency and profitability. One issue that requires consideration in these deliberations is the highly variable inshore-offshore production that is linked with rainfall in coastal NSW. Such changes are exacerbated during periods of drought or flood and result in significant shifts in the behaviour of fishers. It is expected that such variations in rainfall will continue, and are likely to become more extreme, under projected climate change scenarios.
This project examined the NSW commercial catch records and seafood price data to ascertain if there are patterns of endorsement holdings that are the basis of more

robust fishing businesses during periods of drought. We expect that many fishers will understand these patterns based upon extensive practical experience, but an empirical confirmation of such patterns will lend additional weight to any associated decisions by government and industry.

This project will also shed light upon an important facet of risk management in fisheries. The textbook economic argument that increased specialisation results in increased efficiency for the economy as a whole must be contrasted with potential lost opportunities for individual fishers in a highly variable environment. The adage "don't put all your eggs in one basket" is likely to be highly applicable for inshore and coastal fisheries in NSW.

Objectives

The single objective for this project was to "Identify the patterns of fishing endorsements that will make NSW fishing businesses more robust to the likely changes in freshwater flow that will result from climate change."

In NSW, a fishing business is the financial entity recognised by I&I NSW. This business will likely have several fishing method endorsements attached to it, and the operator (who may own one or several businesses) can determine whether to use a particular endorsement (or method) on a day-to-day basis.

This project sought to identify patterns of endorsements which made a fishing business more robust to the likely changes in freshwater flow resulting from climate change. As indicated above, changes to freshwater flow were represented by drought events which are expected to increase in frequency with climate change. Droughts impact NSW coastal fisheries in complex ways (Gillson et al. 2009), but recent work by Gillson et al. (in review), indicated that both fish stocks and fisheries change during extreme hydrological conditions.

The full analysis that identified the patterns of fishing endorsements that appeared to make NSW fishing businesses more robust to changes in freshwater flow is presented in Appendix 3 (Section 4) but the key points are that:

- Available estimates of revenues and costs indicated that most coastal fishing businesses do not make a profit in NSW. Increases in the use of fishing method diversity (measured using a modified form of the Shannon diversity index) results in increased revenues and costs, but because the marginal costs are higher than the marginal revenues, increasing fishing method diversity appears to result in increased losses.

- Based upon this result, the general conclusion is that operators should diversify outside of the fishing sector to maintain net incomes. Increasing fishing diversity to "spread the risk" may appear to make the business more robust by generating more income, but using the plausible cost model developed for this project, this may actually decrease profits (or increase losses).

- These impacts were particularly acute for fishing businesses that operated with ocean prawn trawls, estuarine prawn trawls and hauling nets, which experienced an average decline in revenue of 27%, 37% and 22%

respectively between non-drought and drought conditions. These businesses appeared to diversify into fish trawling and gillnetting to maintain revenue, but as indicated above this may have had a negative effect on profits.

Methods

A full description of the methods used in this project is provided in Appendix 3, Section 2. Only a summary of the methods is provided here.

This project examined historical catch and effort records in the NSW commercial fisheries logbooks from July 1997 to June 2007 (10 fiscal years) and integrated these with pricing data of seafood from the Sydney Fish Market (SFM) and drought declaration information from Industry and Investment NSW. The fishing business identification codes in the catch effort data were replaced with an anonymous identifier to maintain operator privacy. All seafood prices were inflation-adjusted using the Sydney food Consumer Price Index (CPI) relative to June 2007.

Three adjacent estuarine/oceanic systems were considered in this study: the Clarence River; the Hunter River and the Hawkesbury River. Revenue associated with each fishing method was calculated by summing the landings by the inflation-adjusted price for all species landed by that method.

Costs were estimated using a cost model built upon the cost data collected for the Environmental Impact Statements (EISs) of commercial fisheries in NSW. In comparison to the revenue estimates, costs will necessarily be approximate. Cost information provided in the EISs was the mean cost per business for each fishery. This information required transformations to formulate estimated costs for each individual business.

Cost information was partitioned into fixed costs (independent of fishing effort) and variable costs (dependent upon fishing effort). Total costs per fishing business per month were then calculated by combining the fixed costs and variable costs for a business and then rescaling to the mean cost of the dominant fishery used that month with a fixed co-efficient of variation.

Several judgements were required to develop a plausible cost model for these highly diverse fisheries. Wherever required, conservative decisions were taken to minimise estimated costs associated with fishing. For example, if costs from two fisheries needed to be combined, they weren't simply summed, but rather the costs of the fishery with the highest costs were used. Due to the large variance of the raw costs estimates, the variances were rescaled to reduce the extremes of the distribution of costs.

Sensitivity analyses were performed to determine the effect of the dominant assumptions on the results. Four assumptions were evaluated: total costs per business; average monthly prices; the effect of fixed costs from non-operational (i.e. latent) businesses; and the variability of total costs.

Results

A full description of the results from this project are provided in Appendix 3, Section 3.

Discussion

The full discussion associated with this project is provided in Appendix 3, Section 4.

Commercial fishers will likely find this report of interest, but will inevitably take issue with some of the assumptions used. They will likely argue that the report used prices that were too low, or the cost estimates were too high, or that the strategies used to combine costs for multiple methods were exaggerated. We have included sensitivity analyses to examine the consequences of these assumptions on the results and indicated that it will take large changes (≥ 80%) to these assumptions before the conclusions are reversed. At present, variation in the economic performance of commercial fishing businesses can be attributed to regional climatic variability but not to large-scale patterns of climate change. Results from this study indicate that the commercial fishing sector is a drought-affected industry and that businesses operating prawn fisheries would benefit from financial assistance during drought. Reductions in freshwater flow resulting from drought or increased human water extraction are likely to have negative economic impacts on fishing businesses. It is, therefore, essential that the impacts on estuarine and coastal fisheries are duly recognised when allocating environmental flows.

Benefits and Adoption

The primary beneficiaries from this research are Industry and Investment NSW and the commercial fishers of NSW. This report confirms that fishers experience significant reductions in revenue during droughts and that, on average, using an increased diversity of fishing methods does increase revenue.

Therefore policies that restrict the endorsements held by operators so they are forced to fish with restricted numbers of methods will therefore compromise the ability of businesses to diversify fishing activities and harvest the available aquatic resources (which will increase revenues). There is, however, a downside to encouraging this diversity. The model used in the research presented here indicates that the marginal increase in revenue is less than the marginal increase in costs. On the basis of this result, I&I NSW should be encouraging fishers to diversity outside the fishing sector during times of drought. As droughts are expected to increase as a result of climate change, a long term adaptation strategy would be for operators to diversify into sectors unaffected by rainfall (which is likely to exclude most types of fishing and farming).

The results of this project will be used by I&I NSW to inform ongoing policy development with regards to specialisation and diversification of commercial fishing in NSW.

Further Development

The primary weakness of the research presented here is the model used to estimate the costs of fishing. The information used here was based upon a survey of the fisheries used in the Environmental Impact Statements for the 1999-2000 fiscal period. This information is relatively old and, more importantly, does not capture the variability in costs that would likely be experienced by the fishing businesses within a fishery. We expect the costs within the Estuary General Fishery to have been particularly poorly estimated due to the diversity and complexity of methods used in this fishery.

Improved cost information would be difficult to obtain unless a representative sample of operators permitted a confidential but detailed examination of the financial operation of their businesses. However, this is very unlikely to happen because of privacy standards and expectations.

Planned Outcomes

This project planned to deliver an improved understanding of the patterns of endorsement holding in NSW which are robust to the changes in production associated with highly variable freshwater flows. The analysis refined these plans by focussing on the effect of droughts (used as a proxy for climate change) and extending these analyses to both costs as well as benefits.

The simplistic result from this research is that the loss to revenues from methods particularly vulnerable to drought (ocean prawn trawling, estuarine prawn trawling and hauling nets) can be compensated by using methods which appear to be less susceptible to drought (e.g. fish trawling, hand lines and crab pots). However, the more important result is that the marginal revenues from using this extra diversity of fishing methods will very likely be out-weighed by the increased marginal costs. If the true costs of regulating multiple fishing methods were included in the analysis, the conclusions would be even more pessimistic about the value of method diversification (particularly if methods with significant environmental impacts were included). This argument would, of course, depend upon the relative environmental impacts and management costs associated with different fishing methods.

Entities owning NSW fishing businesses would, from an economic perspective, be better off to diversify outside the fishing sector (i.e. a sector unaffected by drought) to improve their robustness to climate change. However, fishing businesses in NSW are social as well as economic phenomena, and I&I NSW will inevitably ensure that any developments to management or policy will take into account the social dimensions of these fisheries.

Conclusion

Drought events, which will increase with climate change in eastern Australia, redistributed revenue and profit among fishing methods, modifying the economic performance of commercial fishing businesses. Reductions in revenue and profit were most pronounced for businesses that operated with ocean prawn trawling, estuarine prawn trawling and hauling nets during drought conditions.

Modelled estimates of profit were highly dependent on costs incurred by businesses that operated in multiple fisheries. Although diversification of harvesting behaviour can function as a risk-reduction strategy for fishers during periods of resource uncertainty, this phenomenon was only marginally evident for commercial fishing businesses in NSW.

Diversified harvesting behaviour increased revenue generation, but this marginal economic benefit was compromised by an apparent increase in costs. Commercial fishers would benefit from diversifying their employment outside the coastal fishing industry to maintain net incomes during drought conditions.

Alterations to the economic performance of commercial fishing businesses during drought have important implications for the management of multi-method inshore fisheries in a changing climate. Understanding the coupled socio-economic impacts of drought events on commercial fishing businesses is essential when considering the wider implications of climate change on coastal fisheries.

References

Full references for this report are provided in Appendix 3 Section 7.

Appendix 1: Intellectual Property

Appendix 3 for this final report (the Gillson Report) is a standalone document that is not part of the project materials. The intellectual property of the Gillson Report is retained by Jonathan Gillson.

Appendix 2: Staff

Jonathan Gillson

Appendix 3: The report by Jonathan Gillson is attached

Spreading the risk: management strategies for multi-method inshore fisheries in a changing climate

Jonathan Gillson

Fisheries and Marine Environmental Research Laboratory,
School of Biological, Earth and Environmental Sciences,
University of New South Wales, NSW 2052, Australia

Abstract

Drought events will increase in frequency and severity with climate change, modifying the economic viability of coastal fisheries that operate in regions of hydrological extreme. Variation in the revenue and profit of different fishing methods between non-drought and drought conditions were examined for commercial fishing businesses that operated in three adjacent estuarine and coastal systems in eastern Australia from 1997 to 2007. Mean monthly revenue decreased from 8-36% between periods of non-drought and drought. Decreased mean monthly revenue was primarily attributed to reductions in revenue generation from ocean prawn trawling (≥ 20%) and estuarine prawn trawling (≥ 34%) during drought. Fishing method diversity (measured by the Shannon index) and mean monthly revenue and were positively related. Estimated reductions in mean monthly profit under alternative cost scenarios ranged from 5-94% between non-drought and drought. Reduced mean monthly profit was also primarily attributed to losses from ocean prawn trawling (≥ 15%) and estuarine prawn trawling (≥ 27%) during drought. In contrast to revenue, mean monthly profit and fishing method diversity were negatively related. Results indicated that drought events redistributed revenue and profit among fishing methods. Single-method fisheries that target penaeid prawns exhibited the most pronounced economic losses during drought. Although diversification of harvesting behaviour increased revenue generation, this marginal economic benefit appeared to be compromised by decreased profitability due to businesses incurring higher costs with increased fishing method diversity.

Keywords: Drought; multi-method fisheries; multi-species fisheries; method diversity; economic risk; climate change

1. Introduction

Understanding connections between climatic variability and coastal fisheries production is an important avenue of investigation (Brander 2007). Climatic variability strongly influences coastal fisheries production by modifying the spatial distribution, abundance and species composition of coastal fish communities (Roessig *et al.* 2004; Lehodey *et al.* 2006; Brander 2010). Many studies have focused on the impacts of climatic variability on commercially important species such as 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 coastal fisheries (Lyne *et al.* 2003; Hannesson 2007; Allison *et al.* 2009). Information on the economic impacts of climate change on coastal fisheries is required to inform long-term policy and strategic management issues (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 variability in freshwater flow strongly influences coastal fisheries production by altering habitat availability and trophic dynamics in coastal marine ecosystems (Grimes 2001; Robins *et al.* 2005; Lamberth *et al.* 2009). Freshwater flow *per se*, however, may not be as important in determining coastal fisheries production as extreme hydrological events (Gillson *et al.* 2009). Flood and drought events are pulse disturbances 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 coastal fisheries production (Caddy and Bakun 1995), the economic impacts of drought on 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 (Gillson *et* *al.* in review). Nevertheless, the impacts of drought on the economic performance of 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). Climate change is expected to result in extreme fluctuations in rainfall that will increase the frequency and severity of flood and drought events in eastern Australia (Hughes 2003). One of the many concerns associated with climate change is the effects of reduced freshwater flow on coastal fisheries production (Loneragan and Bunn 1999; Robins *et al.* 2005; Ives *et al.* 2009). Climate-induced reductions in freshwater flow are likely to be exacerbated by human population growth increasing demand for freshwater (Vörösmarty *et al.* 2000).

This study examined the economic impacts of drought events on commercial fishing businesses from three adjacent estuarine and coastal systems in eastern Australia. The primary objective was to identify patterns of fishing endorsements that will make fishing businesses more robust to the likely changes in freshwater flow that will result from climate change. This objective was associated with the following tasks: (i) examine the revenue and profit of different fishing methods during non-drought and drought, and (ii) determine whether diversification of harvesting behaviour increased revenue and profit during non-drought and drought.

2. **Materials and methods**

2.1. Study Areas

Three adjacent estuarine and coastal systems along the eastern Australian coastline were selected to investigate the economic impacts of drought events on commercial fishing businesses (Figure 1). Estuarine fisheries entering the Tasman Sea consisted of the permanently open lower reaches of the Clarence, Hunter and Hawkesbury River systems. Adjacent coastal fisheries extended ~30 km onto the continental shelf and ~0.5° north and south of each river system (i.e. coastal zones 2, 5 and 6). The spatial extent of coastal fisheries were based on reporting zones used by the Industry and Investment New South Wales (I&I NSW). These estuarine and coastal fisheries were selected for investigation because they provide the dominant contribution to commercial fisheries harvest (Table 1).

2.2. Hydrological data

Reductions in rainfall and freshwater flow have been reported in the Clarence, Hunter and Hawkesbury Rivers during drought events (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 examined coastal rivers. 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, with no investigated river systems co-located within the same district. Periods of drought declaration were examined for an area surrounding each coastal river system and formatted into a categorical 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.

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 summed into monthly totals for individual business.

A "fishing business" represented a separate and identifiable financial entity (New South Wales *Fisheries Management* Act 1994). Fishing methods from five commercial fisheries were considered: 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). Fishing businesses can possess endorsements to operate with multiple-methods in multiple fisheries and the owners of these businesses (usually the fishers) will utilise endorsements as they see fit.

2.4. Revenue

Monthly revenue for each fishing business was calculated using the following procedure. Monthly landings per species were multiplied by the mean monthly market price of that species to give the mean monthly revenue per species. Monthly revenues per species were then summed over species for each fishing method to provide the nominal revenue per method for individual businesses. Nominal revenue per method was then inflation-adjusted using the Sydney food Consumer Price Index (CPI) relative to June 2007 ($CPI_{June2007} = 1$) to give revenue per method. The Sydney food CPI was obtained from the Australian Bureau of Statistics (ABS) for quarterly periods between July 1997 and June 2007 (www.abs.gov.au/AUSSTATS).

Inflation-adjusted revenue was calculated as follows:

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

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.

2.5. Costs

An estimation of fishing costs was required to examine the profits associated with fishing activity. Information was available on the average costs of fishing, but not the variability of these costs experienced across the fleet. To provide an estimation of profit per business, a cost model was developed which contains parameterised assumptions of the variability of costs. The cost model was further complicated by the constraint that cost information was only available by fishery. Therefore the costs associated with different methods within a fishery could not be differentiated. For single-method fisheries this was relatively straightforward, but for multiple-method fisheries this 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 increase (see details below) with 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. Information on fixed and variable costs per business from each fishery were derived from economic assessments undertaken by Dominion Consulting Pty Ltd (2001; 2002a; 2002b; 2004; 2006) for the 1999-2000 fiscal period (Table 4). Nominal 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* (which used method *m*) in month *t* (Australian dollars), max[$VC_{m(f),t}$] is the maximum variable cost for fishery *f* (which used method *m*) in month *t* (Australian dollars) and $E_{m,b,t}$ is the fishing effort for method *m* from business *b* in month *t*.

Estimation of monthly total costs per business consisted of two components: The fixed costs were estimated using the maximum fixed costs for a fishing method per business in a month. The costs for a method were assumed to be the same as the costs for the fishery from which the method was associated. Variable costs were dealt with in a similar manner. This simplification was required to stop the costs becoming unrealistically high. For example, if a business operated with 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.

Finally, monthly total costs per business were standardised (using a z-transformation) to a distribution with an identical mean value to that of monthly costs per business from Dominion Consulting Pty Ltd (2001; 2002a; 2002b; 2004; 2006) for the most costly fishery used that month. The variances of costs across businesses in a month were modelled by standardising the data to a fixed coefficient of variation (CV) of 25%, 50% and 75% (hereafter referred to as cost-variability scenarios). This standardisation was required as the variance of the raw calculated costs was unrealistically large.

2.6. Profit

Monthly profit per method for individual businesses was calculated by subtracting monthly costs per method from monthly nominal revenue per method for individual businesses. In accordance with the nominal cost adjustment, nominal revenue was also inflation-adjusted using the Sydney food CPI relative to June 2000 ($CPI_{June2000}$ = 1) to give profit per method. Profits under alternative cost-variability scenarios were examined to determine the effects of increased cost-variability on profit.

Inflation-adjusted profit was calculated as follows:

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

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).

2.7. Sensitivity analyses

Sensitivity analyses were performed to examine the robustness of profit outputs by altering key parameter inputs. 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*), sea mullet (*Mugil cephalus*), school prawn (*Metapenaeus macleayi*) and yellowfin bream (*Acanthopagrus australis*) between Sydney Fish Market and the Professional Fishermen's Association revealed that market prices varied by +5-43%. Secondly, costs were decreased by 20%, 40% and 60% to verify effects on profit. Finally, fixed costs incurred by non-operational businesses during drought were summed with total costs to estimate effects on profit. Fewer businesses operated during drought in the estuarine and coastal fisheries associated with the Clarence (32%), Hunter (20%) and Hawkesbury (33%) Rivers.

2.8. Data analysis

One-tailed Fisher's exact tests were employed to compare proportional differences in the number of businesses that operated with different fishing methods during non-drought and drought. Mean monthly revenue/profit during non-drought and drought were calculated by normalising the sum of monthly revenue/profit by the number of non-drought and drought months in each river system. This normalisation procedure prevented differences in mean monthly revenue/profit resulting from an unbalanced number of non-drought and drought months. Differences between mean monthly revenue and costs during non-drought and drought were examined using box and whisker plots. Profits under alternative cost-variability scenarios were compared to baseline profit values during non-drought. An identical technique was used to examine profit under the alternative economic scenarios from sensitivity analyses.

Mean revenue/profit, when businesses operated with two or more fishing methods per month (hereafter referred to as multiple-method months), were calculated to determine the contribution of different fishing methods to revenue/profit during non-drought and drought. Single-method months were excluded from calculations of mean revenue/profit given that this study was interested in the incremental benefit of fishing method diversity within a month, and not revenue and profit *per se*. The Shannon index has been frequently used to measure species diversity in coastal marine ecosystems (Gray 2000). This study, however, employed the Shannon index to measure fishing method diversity during multiple-method months. A modified form of the Shannon index was calculated using relative monthly effort per method from individual businesses rather than relative species abundance.

The modified form of the Shannon index used here is given by:

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

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 for method *m* from business *b* in month *t*.

Mean monthly values for revenue/profit and the Shannon index were calculated from all businesses. Ordinary least squares regression was adopted to examine the relationship between mean monthly revenue/profit, the Shannon index and drought declaration. Regression models consisted of two covariates, one fixed factor (hydrological condition) with two levels (non-drought and drought) and one continuous response covariate (mean Shannon index, $(\overline{H}')$). 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). Log transformations were not applied to mean monthly profit as this was not required.

3. Results

3.1. Harvesting behaviour

Numbers of businesses that operated with different fishing methods between non-drought and drought exhibited considerable variation in the estuarine and coastal fisheries associated with the Clarence, Hunter and Hawkesbury Rivers (Figure 2). Significant proportional differences in numbers of businesses that operated with one to five methods between non-drought and drought were evident in the estuarine and coastal fisheries associated with the Clarence River (One tailed Fisher's exact test, $P < 0.05$). More businesses (11%) operated with one to five methods during drought compared to non-drought. There were significant differences in numbers of businesses that operated with one to two methods between non-drought and drought in the estuarine and coastal fisheries associated with the Hunter and Hawkesbury Rivers (One tailed Fisher's exact test, $P < 0.05$). More businesses operated with one to two methods during drought compared to non-drought in the estuarine and coastal fisheries associated with the Hunter (10%) and Hawkesbury (8%) Rivers.

3.2. Revenue among fishing methods

Mean monthly revenue was significantly lower during drought compared to non-drought in the estuarine and coastal fisheries associated with the Clarence (27%), Hunter (8%) and Hawkesbury (36%) Rivers (Figure 3). 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 with five or more methods in the estuarine and coastal systems associated with the Clarence River. Similar results were identified for the estuarine and coastal systems associated with the Hunter and Hawkesbury Rivers, with a diminishing increase in mean monthly revenue when businesses operated with two or more methods.

Fishing methods that primarily contributed to decreased mean monthly revenue between non-drought and drought were ocean prawn trawling (≥ 20%) and estuarine prawn trawling (≥ 34%). Methods that provided a relatively smaller contribution to decreased mean monthly revenue between non-drought and drought were gillnets (≥ 15%) and hauling nets (≥ 16%).

3.3. Revenue and fishing method diversity

Regression models revealed significant positive relationships between mean monthly revenue and the Shannon index during non-drought and drought (Figure 4). Interaction terms between the Shannon index and drought declaration were non-significant ($P \geq 0.05$). Main effects regression models identified positive coefficients for the relationship between mean monthly revenue and the Shannon index, and negative coefficients for the relationship between mean monthly revenue and drought declaration (Table 5).

3.4. Profit under cost-variability scenarios

Mean monthly revenue and costs were markedly different during non-drought and drought (Figure 5). Not only were estimated costs considerably higher than revenue (~4×), but estimated costs also exhibited more variability around the mean. Mean monthly losses under alternative cost-variability scenarios were higher during drought (Figure 6). Increased cost-variability was associated with decreased losses. Only costs with a 75% coefficient of variation were attributed to increased losses in the estuarine and coastal systems associated with the Clarence and Hawkesbury Rivers.

3.5. Profit under economic scenarios

Profit exhibited considerable variation under alternative economic scenarios (Figure 7). 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 estuarine and coastal systems associated with the Clarence (43%), Hunter (40%) and Hawkesbury (46%) Rivers.

3.6. Profit and fishing method diversity

Regression models revealed significant negative relationships between mean monthly profit and the Shannon index during non-drought and drought (Figure 8). Increased cost-variability was associated with increased coefficients for the significant negative relationship between mean monthly profit and the Shannon index (Table 6). Significant interaction terms between the Shannon index and drought declaration ($\overline{H'}_t \times D_t$) were identified for regression models that incorporated mean monthly profit with a 50% ($\beta_1 =$ 19.98, $P = 0.04$, df = 116) and 75% ($\beta_1 = -50.15$, $P < 0.01$, df = 116) cost coefficient of variation in the estuarine and coastal fisheries associated with the Clarence River. Main effects regression models revealed significant negative coefficients for the relationship between mean monthly profit and the Shannon index during non-drought and drought.

4. Discussion

Examination of fishery-dependant data from individual commercial fishing businesses revealed a range of patterns in the economic impacts of drought on multi-method inshore fisheries. Results from this study indicate that reductions in freshwater flow resulting from drought or increased human water extraction are likely to have negative economic impacts on fishing businesses that operate in the estuarine and coastal systems of eastern Australia. Climate change is expected to increase the severity and frequency of drought events in this region (Hennessy *et al*. 2007), which place additional demands on available freshwater resources (Oki and Kanae 2006). 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.

Differences in revenue and profit between non-drought and drought were business, method and system specific. Drought events were associated with reductions in the revenue and profit of commercial fishing businesses. Businesses that operated with ocean prawn trawling and estuarine prawn trawling primarily contributed to significant reductions in revenue and profit during drought. Relationships between revenue/profit and fishing method diversity were highly significant ($P < 0.01$), but yielded coefficients of opposite sign (Tables 5-6). Once costs were included into the analyses, the positive revenue-diversity relationship shifted to a negative profit-diversity relationship. This result indicated that fishers altered their harvesting behaviour and operated with less profitable methods during drought.

Other research in this field has indentified that natural variability in freshwater flow regulates the physical, chemical and biological properties of coastal marine ecosystems (Skreslet 1986). Accordingly, 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 freshwater regulation in the catchment (Drinkwater and Frank 1994) and the life history of individual species (Robins *et al.* 2005).

Knowledge regarding the freshwater flow requirements of coastal marine ecosystems is limited (Gillanders and Kingsford 2002). Commercial fisheries that operate in the estuarine and coastal systems of eastern Australia require a sufficient amount of freshwater flow to maintain biological productivity (Loneragan and Bunn 1999; Robins *et al.* 2005; Gillson *et al.* 2009). It is, therefore, essential that the impacts on estuarine and coastal fisheries are duly recognised when allocating environmental flows.

Relatively fewer businesses operated during drought suggesting that fishers 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 employment opportunities (e.g. agriculture, construction and tourism) outside the fishing industry (Dominion Consulting Pty Ltd 2001; 2002a; 2002b; 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). Income augmentation from employment unrelated to commercial fishing represented an efficient strategy for businesses to economically endure drought events and remain in the fishing industry for the long-term.

Harvesting strategies are primarily driven by the economic outcomes of previous fishing activities (Link and Tol 2006). Alterations to fishing patterns were evident between non-drought and drought. Businesses that operated with ocean prawn trawling and estuarine prawn trawling altered their harvesting behaviour to primarily generate revenue from fish trawls and gillnets during drought. Commercial fishers' modify their harvesting behaviour to opportunistically exploit alterations to the catchability of coastal species that arise during drought events (Gillson *et al.* in review). Adjustments to harvesting behaviour permit fishers' to target the increased catchability of coastal species, such as, silver biddy (*Gerres subfasciatus*) and yellowfin bream (*Acanthopagrus australis*) during drought.

This study incorporated various assumptions regarding the operational characteristics of commercial fishing businesses. Firstly, determining the costs of businesses that operated in multiple fisheries 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 that depended on fishing effort. Fishers' labour costs, however, can fluctuate as a function of income (Charles 1989). This may have inhibited the analyses given that no information on the relationship between fishers' labour costs and income existed. In many cases, the costs were likely to have been lower (and profits higher) due to fishers paying themselves less during periods of low revenue. Thirdly, the analyses solely focused on the economic characteristics of fishing businesses. Harvesting behaviour, however, represents a dynamic combination of socio-economic factors in the commercial fishing industry (Salas and Gaertner 2004). Information on social patterns of harvesting behaviour may have improved our understanding of business responses to drought events not explained by economics. Fishers often forgo income for lifestyle and autonomy (Dominion Consulting Pty Ltd 2001; 2002a; 2002b; 2004; 2006). Fourthly, fishing can be associated with intangible demographic factors (e.g. age, educational status and housing tenure) not considered here. Determining these social and demographic characteristics of fishing operations were beyond the scope of this study.

These additional dimensions to the characteristics of commercial fishing operations could generate results that contrasted to those presented here. Despite the various assumptions, this study provided a relative indication of the economic impacts of drought events on commercial fishing businesses and revealed the economic role of fishing method diversity under circumstances of climatic variability.

4.1. Revenue between non-drought and drought conditions

Mean monthly revenue was significantly lower during drought (Figure 3). 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 commercial catches 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 ocean prawn trawling and estuarine prawn trawling during drought resulted from decreased landings of penaeid prawns rather than market price fluctuations.

Variation in the market price of eastern king prawns and school prawns was relatively low (CV ≥ 19%) compared to landings (CV ≥ 55%) from ocean prawn trawling and estuarine prawn trawling. Drought-induced low flows can reduce the economic productivity of penaeid prawn fisheries by decreasing commercial landings (All 2006). Future reductions in rainfall and freshwater flow due to drought events are likely to result in decreased landings of penaeid prawns in eastern Australia (Ives *et al.* 2009). Results from this study indicated that decreased landings of penaeid prawns during drought events reduced revenue generation from commercial fishing businesses that operated with ocean prawn trawling and estuarine prawn trawling.

Gillnets and hauling nets provided a relatively smaller contribution to decreased revenue during drought. Sea mullet dominated revenue generation from gillnets (≥ 45%) and hauling nets (≥ 65%) providing the greatest contribution to decreased revenue from these methods during drought. Positive relationships between commercial catches of sea mullet and freshwater flow 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. Decreased landings of sea mullet during drought primarily reduced revenue generation from commercial fishing businesses that operated with gillnets and hauling nets.

Reductions in landings and revenue during drought can, to some extent, be compensated by diversifying harvesting behaviour to increase revenue generation (Figure 4). 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). Commercial fishers recognise that diverse harvesting strategies result in increased revenue generation due to extensive practical experience. A bet-hedging component to harvesting strategies was indicated by high Shannon index values. Fishers may employ bet-hedging harvesting strategies to minimise fishing effort and maximise revenue generation. Detection of diminishing returns indicated that diverse harvesting strategies only maximised revenue generation to an extent. Rates of revenue generation decreased when businesses operated beyond a certain number of methods. The number of methods required to saturate revenue generation was five or less in the estuarine and coastal fisheries associated with the Clarence River and two or less in the estuarine and coastal fisheries associated with the Hunter and Hawkesbury Rivers.

4.2. Profit between non-drought and drought conditions

Many businesses exhibited losses due to costs frequently exceeding revenue (Figure 5). Businesses were not expected to generate large profits given that the estuary general, estuarine prawn trawl and the ocean trap and line fisheries frequently operate at a loss (Dominion Consulting Pty Ltd 2001; 2002a; 2002b; 2004; 2006). Modelled estimates of losses under alternative cost-variability scenarios were consistently greater (≥ 5%) during drought (Figure 6). Increased cost-variability was associated with decreased mean losses. Only costs with a 75% coefficient of variation were associated with increased mean losses, when compared to alternative cost-variability scenarios, in the estuarine and coastal systems associated with the Clarence and Hawkesbury Rivers. The highest cost-variability scenario resulted in increased mean losses due to costs more frequently exceeding revenues.

Sensitivity analyses indicated that increased market prices of seafood and decreased costs reduced losses during non-drought and drought (Figure 7). Businesses generated profit when market prices and costs were increased or decreased, respectively, by ≥ 80%. 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 businesses into profit models to provide a better understanding of the economic impacts of drought on commercial fishing businesses.

Diversification of harvesting behaviour decreased profitability due to businesses incurring higher costs with increased fishing method diversity (Figure 8). Harvesting strategies represent an economic trade-off between revenue generation and the cost of fishing activities (Sampson 1991). Businesses that operated with multiple fishing methods employed an economic risk-reduction strategy that was compromised by higher costs. A bet-hedging component to harvesting strategies was indicated by high Shannon index values. Fishers may adopt bet-hedging harvesting strategies to minimise costs and maximise revenue generation. Increased cost variance was associated with decreasingly negative coefficients for the relationship between profit and fishing method diversity (Table 6). Increased cost variance reduced losses associated with the diversification of harvesting behaviour by decreasing the frequency that costs exceeded revenue. Significant interaction terms between the Shannon index and drought declaration revealed that interpretation of the relationship between profit and drought changed with fishing method diversity in the estuarine and coastal fisheries associated with the Clarence River. This result indicated that freshwater flows, method diversification and economic factors all need to be considered to better understand the possible impact of climate change on the economic performance of commercial fishing businesses.

If drought conditions are so severe and protracted that they are considered beyond the bounds of normal risk management, then the Australian Federal Government may declare an area as experiencing “drought exceptional circumstances” (White and O'Meagher 1995; White and Karssies 1999; Botterill 2003). Declaration of drought exceptional circumstances qualifies agricultural producers in these areas to apply for financial assistance. Commercial fisheries that operate in estuarine and coastal systems, however, are rarely eligible for financial assistance given that businesses cannot readily demonstrate that drought results in an economic downturn. The findings presented here indicate that the commercial fishing sector is a drought-affected industry.

Climatic variability caused commercial fishing businesses to experience variable economic conditions in eastern Australia. Future climatic projections for this region predict greater hydrological extremes with increased variability in rainfall and decreased freshwater flow (Hennessy *et al*. 2007). A climatic shift towards more extreme hydrological conditions is likely to result in commercial fishing businesses experiencing greater economic pressure. At present, variation in the economic performance of fishing businesses can be attributed to regional climatic variability but not to large-scale patterns of climate change. More detailed climatic projections are required to comprehensively examine the potential economic impacts of climate change on commercial fisheries.

5. Conclusions

Drought events redistributed revenue and profit among fishing methods, modifying the economic performance of commercial fishing businesses. Reductions in revenue and profit were most pronounced for businesses that operated with ocean prawn trawling and estuarine prawn trawling during drought. Modelled estimates of profit were highly dependent on costs incurred by businesses that operated in multiple fisheries. 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 appeared to be compromised by decreased profitability due to businesses incurring higher costs with increased fishing method diversity. Commercial fishers would benefit from diversifying their employment outside the coastal fishing industry to maintain net incomes during drought. Alterations to the economic performance of commercial fishing businesses during drought have important implications for the management of multi-method inshore fisheries in a changing climate. Understanding the coupled socio-economic impacts of drought events on commercial fishing businesses is essential when considering the wider implications of climate change on coastal fisheries.

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Table 1. Regions selected to investigate the economic impacts of drought events on commercial fishing businesses that operate in adjacent estuarine and coastal systems in eastern Australia.

Region	Latitude and longitude	Bioregion	Fishing businesses	Mean landings (tonnes/month)	Percent of fisheries harvest	Mean effort (days/month)	Mean revenue (AU$000/month)
Clarence River	29°25'37.20" S, 153°22'19.20" E	Northern	191	149	16	1160	522.9
Hunter River	32°54'54.00" S, 151°48'03.59" E	Central	91	79	9	444	167.9
Hawkesbury River	33°34'10.20" S, 151°18'32.40" E	Central	86	62	7	478	113.9

Bioregion refers to defined latitudinal estuarine regions (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$000/month) refer to mean landings in tonnes per month, the percentage contribution of all fisheries to commercial fisheries harvest per month, mean effort in days per month and mean revenue in AU$ 000's per month respectively between July 1997 and June 2007.

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

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

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. Landings and revenue information presented for species groups that provided the dominant contribution (≥ 95%) to commercial fisheries harvest.

Table 3. Summary of selected fishing methods used to investigate the economic impacts of drought events on commercial fishing businesses that operate in adjacent estuarine and coastal systems in eastern Australia.

System	Fishing method	Method abbreviation	Fishery	Gear	Mean landings (tonnes/ month)	Mean effort (days/ month)	Mean revenue (AU$000/ month)
Estuarine	Bait net	BN	EG	Active	3.4	12	8.9
Estuarine	Bullringing	BU	EG	Active	0.5	10	1.9
Estuarine	Crab pot	CP	EG	Passive	2.3	89	33.8
Estuarine	Eel trap	EE	EG	Passive	3.8	127	12.3
Estuarine	Fish trap	FT	EG	Passive	0.8	51	6.1
Estuarine	Gillnets	GI	EG	Passive	61.4	711	155.7
Estuarine	Handline	LI	EG	Active	1.1	72	8.6
Estuarine	Hauling net	HN	EG	Active	32.1	276	85.0
Estuarine	Prawn set pocket net	PN	EG	Passive	4.7	69	34.6
Estuarine	Estuarine prawn trawl	EP	EPT	Active	37.1	854	255.7
Coastal	Bait net	BN	OH	Active	3.2	7	9.6
Coastal	Fish trap	FT	OT&L	Passive	6.7	337	31.0
Coastal	Fish trawl	FW	OT	Active	14.8	196	44.6
Coastal	Handline	LI	OT&L	Active	5.7	355	27.1
Coastal	Hauling net	HN	OH	Active	62.6	244	123.9
Coastal	Ocean prawn trawl	OP	OT	Active	49.5	779	772.7
Coastal	Purse seine net	PS	OH	Active	5.7	17	15.7

Fishing method describes the methods. Fishery represents Estuary General (EG), Estuary Prawn Trawl (EPT), Ocean Hauling (OH), Ocean Trawl (OT) and Ocean Trap & Line (OT&L). Gear indicates whether fishing equipment is active or passive. 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. Landings, effort and revenue information presented for fishing methods that provided the dominant contribution (≥ 95%) to commercial fisheries harvest.

Table 4. Average 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

Average 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, 2002b, 2004, 2006). Values presented to the nearest AU$100.

Table 5. Fitted coefficients for model terms that incorporated $R_t \sim \overline{H'}_t + D_t$ for the estuarine and coastal fisheries associated with the Clarence (CRF), Hunter (HUF) and Hawkesbury (HKF) Rivers.

Region	Term	Estimate of coefficient	SE	P(t)
CRF	Intercept	3.77	0.03	<0.001
	$\overline{H'}_t$	0.83	0.28	<0.01
	D_t	-0.09	0.02	<0.001
	$\overline{H'}_t \times D_t$	0.76	0.56	**>0.05**
HUF	Intercept	3.38	0.04	<0.001
	$\overline{H'}_t$	3.57	0.54	<0.001
	D_t	-0.11	0.04	<0.01
	$\overline{H'}_t \times D_t$	2.01	1.09	**>0.05**
HKF	Intercept	3.14	0.04	<0.001
	$\overline{H'}_t$	4.53	0.51	<0.001
	D_t	-0.10	0.03	<0.01
	$\overline{H'}_t \times D_t$	0.07	1.26	**>0.05**

Coefficient details provided for $\log_{10}$ transformed data; n = 120; $\alpha < 0.05$.
R_t, $\overline{H'}_t$ and D_t refer to the mean revenue in month *t*, mean Shannon index in month *t* and drought declaration in month *t*, respectively. Non-significant model terms (P > 0.05) shown in bold.

Table 6. Fitted coefficients for model terms that incorporated $\pi_t \sim \overline{H'}_t + D_t$ for the estuarine and coastal fisheries associated with the Clarence (CRF), Hunter (HUF) and Hawkesbury (HKF) Rivers.

Region	CV model	Term	Estimate of coefficient	SE	P(t)
CRF	25%	Intercept	-6.73	0.62	<0.001
		$\overline{H'}_t$	-21.71	6.06	<0.001
		D_t	-3.60	1.03	<0.001
		$\overline{H'}_t \times D_t$	15.90	10.52	**>0.05**
	50%	Intercept	-5.61	0.57	<0.001
		$\overline{H'}_t$	-27.75	5.56	<0.001
		D_t	-2.86	0.95	<0.01
		$\overline{H'}_t \times D_t$	19.98	9.65	<0.05
	75%	Intercept	-4.77	1.05	<0.001
		$\overline{H'}_t$	-10.39	10.28	<0.01
		D_t	-2.62	1.75	<0.01
		$\overline{H'}_t \times D_t$	-50.15	17.83	<0.05
HUF	25%	Intercept	-8.50	0.40	<0.001
		$\overline{H'}_t$	-33.74	5.40	<0.001
		D_t	-2.43	0.38	<0.01
		$\overline{H'}_t \times D_t$	15.06	10.83	**>0.05**
	50%	Intercept	-7.19	0.41	<0.001
		$\overline{H'}_t$	-55.72	5.64	<0.001
		D_t	-2.02	0.40	<0.05
		$\overline{H'}_t \times D_t$	16.44	11.30	**>0.05**
	75%	Intercept	-4.63	1.09	<0.001
		$\overline{H'}_t$	-89.92	14.87	<0.001
		D_t	-2.54	1.06	<0.01
		$\overline{H'}_t \times D_t$	6.01	30.07	**>0.05**
HKF	25%	Intercept	-7.58	0.40	<0.001
		$\overline{H'}_t$	-24.43	4.67	<0.001
		D_t	-2.85	0.28	<0.01
		$\overline{H'}_t \times D_t$	-6.85	11.07	**>0.05**
	50%	Intercept	-6.13	0.47	<0.001
		$\overline{H'}_t$	-45.22	5.50	<0.001
		D_t	-2.98	0.33	<0.01
		$\overline{H'}_t \times D_t$	5.59	13.06	**>0.05**
	75%	Intercept	-2.36	1.32	<0.01
		$\overline{H'}_t$	-122.20	15.60	<0.001
		D_t	-2.60	0.94	<0.01
		$\overline{H'}_t \times D_t$	-9.21	37.04	**>0.05**

Coefficient details provided for untransformed data; n = 120; α <0.05. CV model indicates the alternative cost-variability scenarios examined. π_t, $\overline{H'}_t$ and D_t refer to the mean profit in month *t*, mean Shannon index in month *t* and drought declaration in month *t*, respectively. Non-significant model terms (P > 0.05) shown in bold.

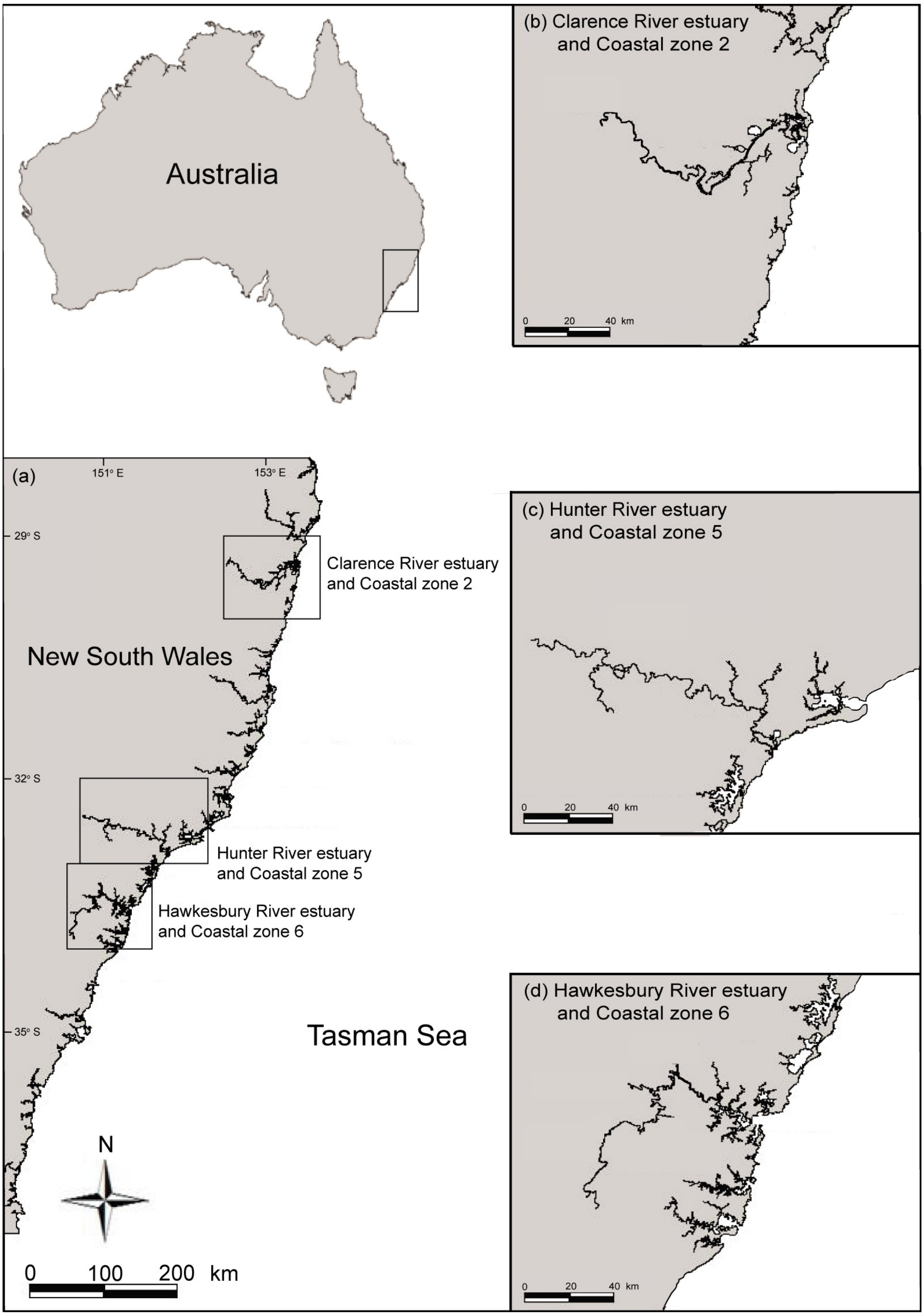

Figure 1. Location of three adjacent estuarine and coastal systems selected to investigate the economic impacts of drought events on commercial fishing businesses in eastern Australia (a). Estuarine and coastal reaches shown in relation to the Clarence (b), Hunter (c) and Hawkesbury (d) River systems.

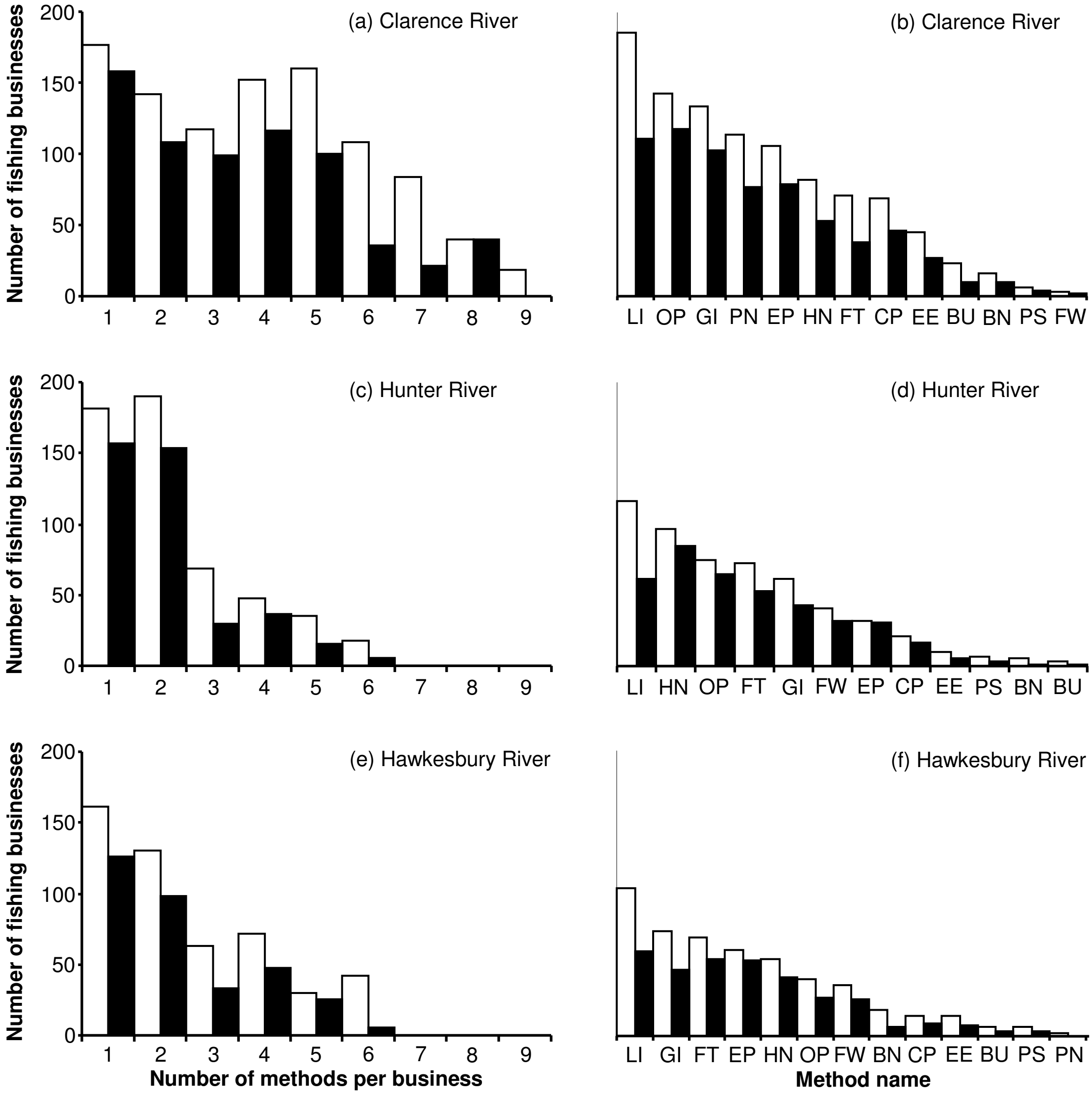

Figure 2. Number of fishing businesses operating with different fishing methods during non-drought (white) and drought (black) conditions for the estuarine and coastal fisheries associated with the Clarence, Hunter and Hawkesbury Rivers from July 1997 to June 2007. See Table 3 for details of fishing method abbreviations. Monthly periods of drought declaration for the Clarence River were 38 out of 120 considered, Hunter River 31/120 and Hawkesbury River 29/120.

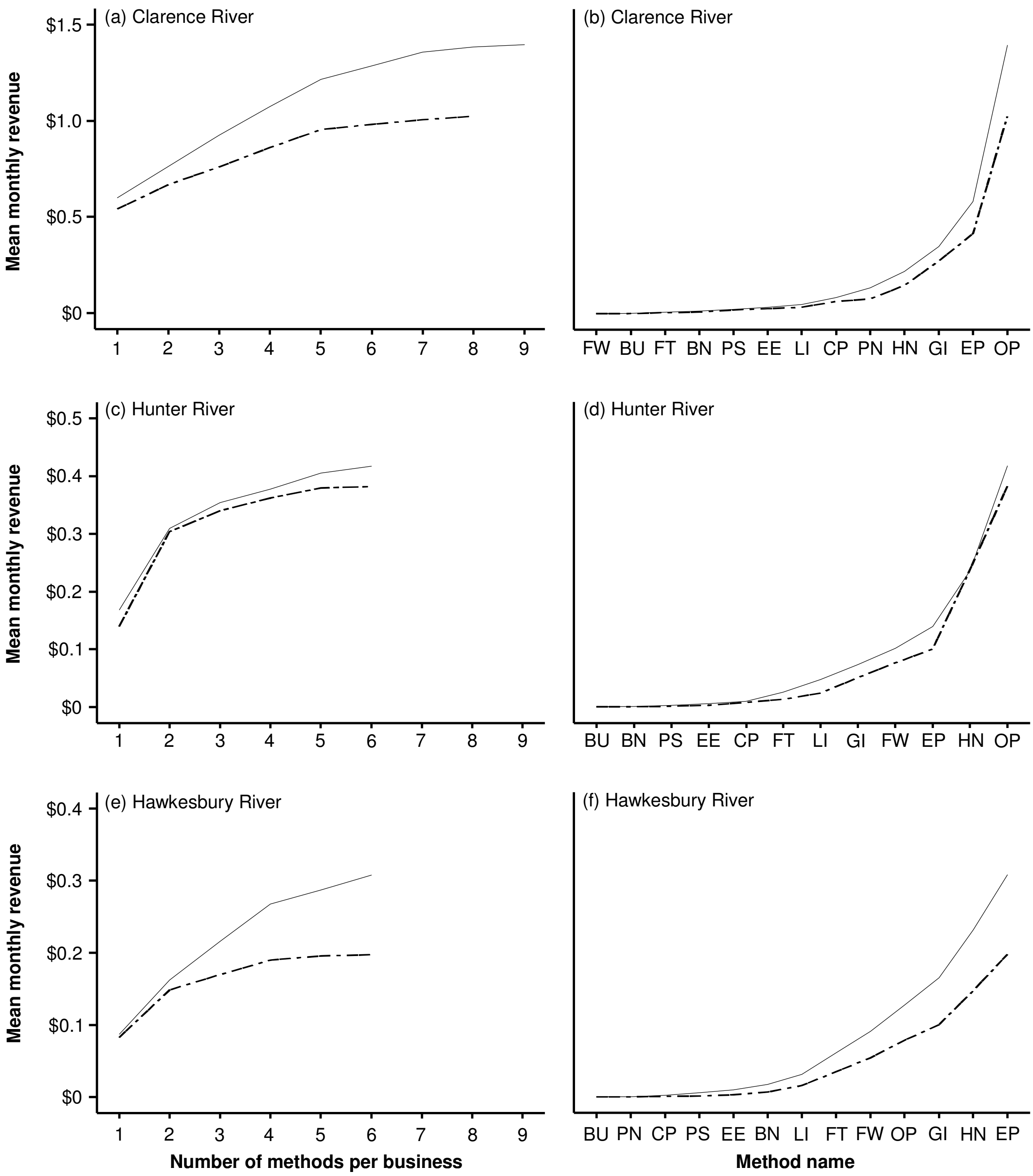

Figure 3. Cumulative mean revenue per month in millions of Australian dollars generated from different fishing methods during non-drought (solid line) and drought (dotted line) conditions for the estuarine and coastal fisheries associated with the Clarence, Hunter and Hawkesbury Rivers from July 1997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

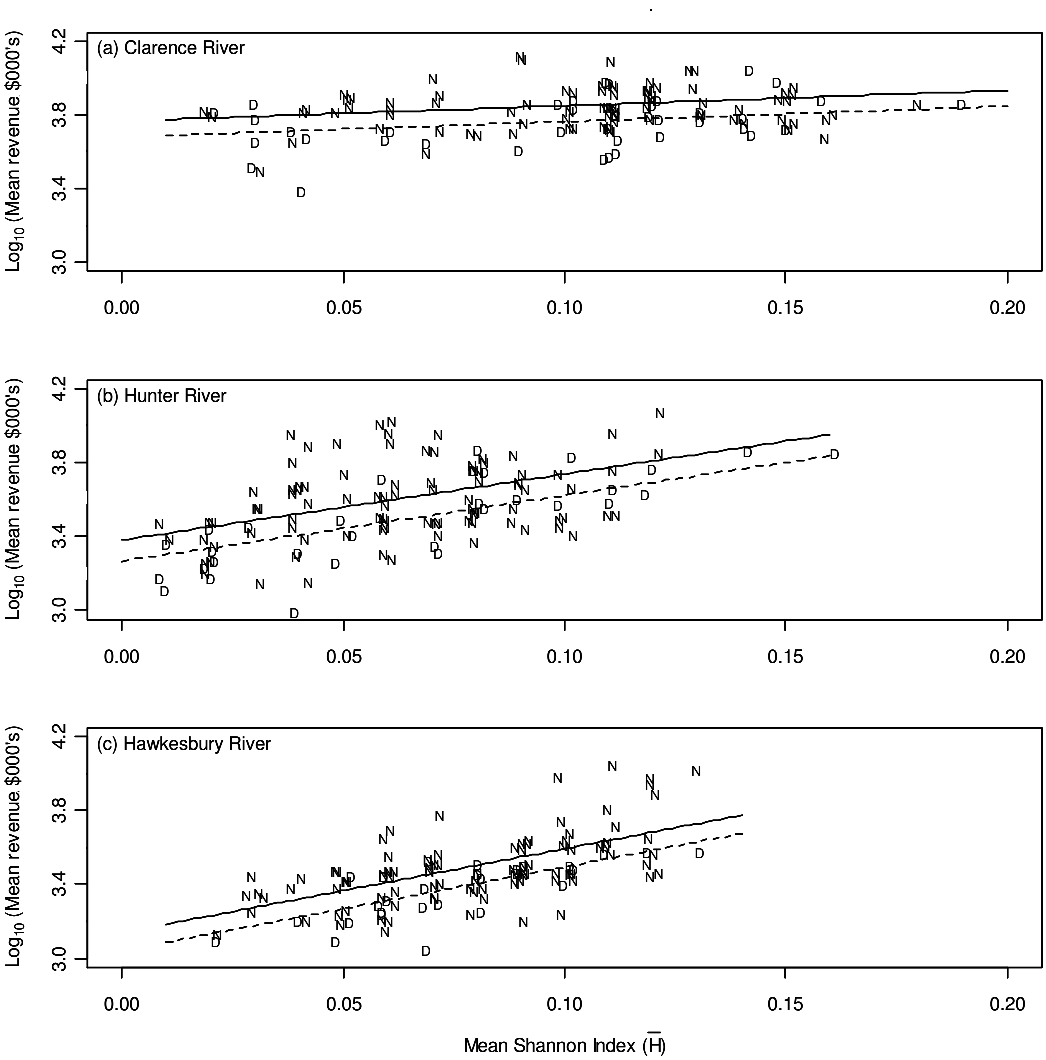

Figure 4. Regression models predicting mean monthly revenue per business from the mean monthly Shannon index during non-drought (solid line) and drought (dotted line) conditions for estuarine and coastal fisheries associated with the Clarence, Hunter and Hawkesbury Rivers (statistics for the regression models presented in Table 5). Note that data points associated with non-drought (N) and drought (D) periods have been jittered on the linear plots to improve clarity.

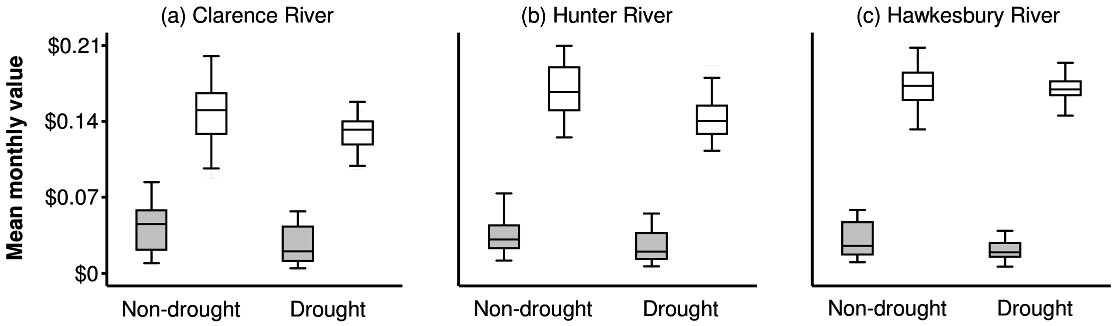

Figure 5. Box and whisker plots illustrating differences between mean monthly revenue (grey) and costs (white) in thousands of Australian dollars during non-drought and drought conditions for the estuarine and coastal fisheries associated with the Clarence, Hunter and Hawkesbury Rivers. Mean monthly revenue per business was calculated from catch-return records and mean monthly costs per business were obtained from a cost model based upon economic analyses undertaken by Dominion consulting for the 1999-2000 fiscal period.

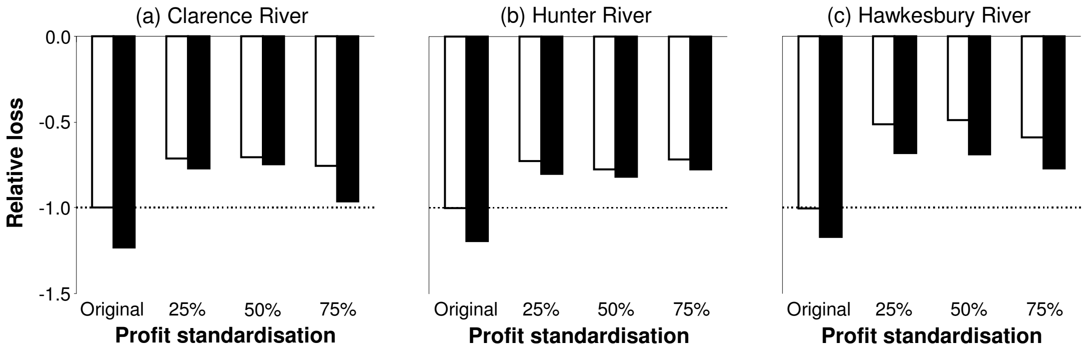

Figure 6. Sensitivity analyses indicating the effects of variability in monthly costs on profit during non-drought (white) and drought (black) conditions for the estuarine and coastal fisheries associated with the Clarence, Hunter and Hawkesbury Rivers. Subfigures illustrate the relative loss as the coefficient of variation of cost increases from the non-drought baseline (dotted line). Profit standardised by mean costs per fishing business with a fixed 25%, 50% and 75% coefficient of variation. Note that costs with a 75% coefficient of variation were attributed to increased losses due to businesses with high cost variance encountering decreased profitability in the estuarine and coastal fisheries associated with the Clarence and Hawkesbury Rivers.

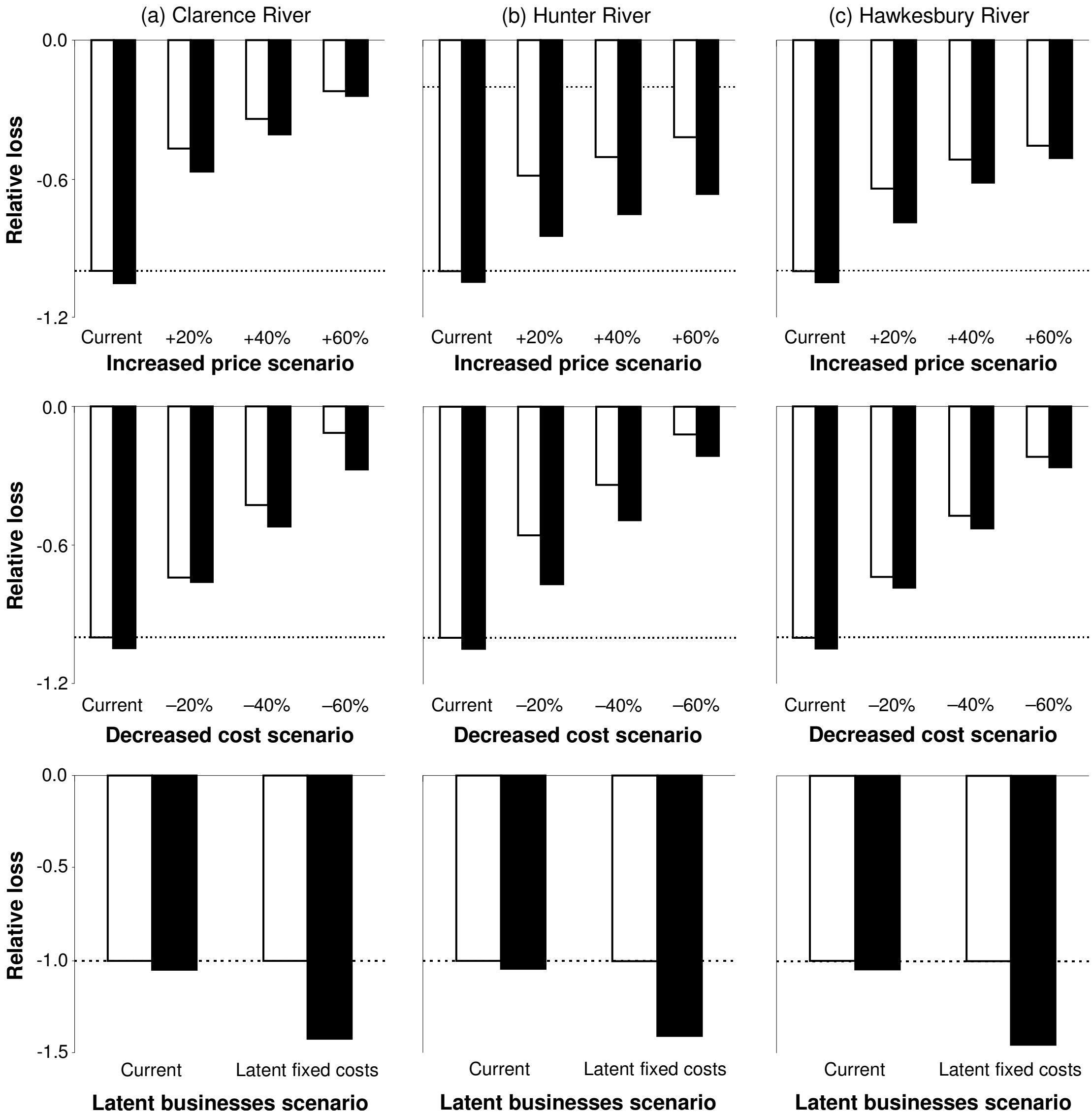

Figure 7. Sensitivity analyses indicating the effects of increased market price of seafood, decreased costs and the addition of fixed costs incurred by drought latent businesses on profit during non-drought (white) and drought (black) conditions for the estuarine and coastal fisheries associated with the Clarence, Hunter and Hawkesbury Rivers. 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 profit standardised by mean costs per business with a 50% coefficient of variation. Note that the addition of fixed costs incurred by latent businesses during drought resulted in increased loss.

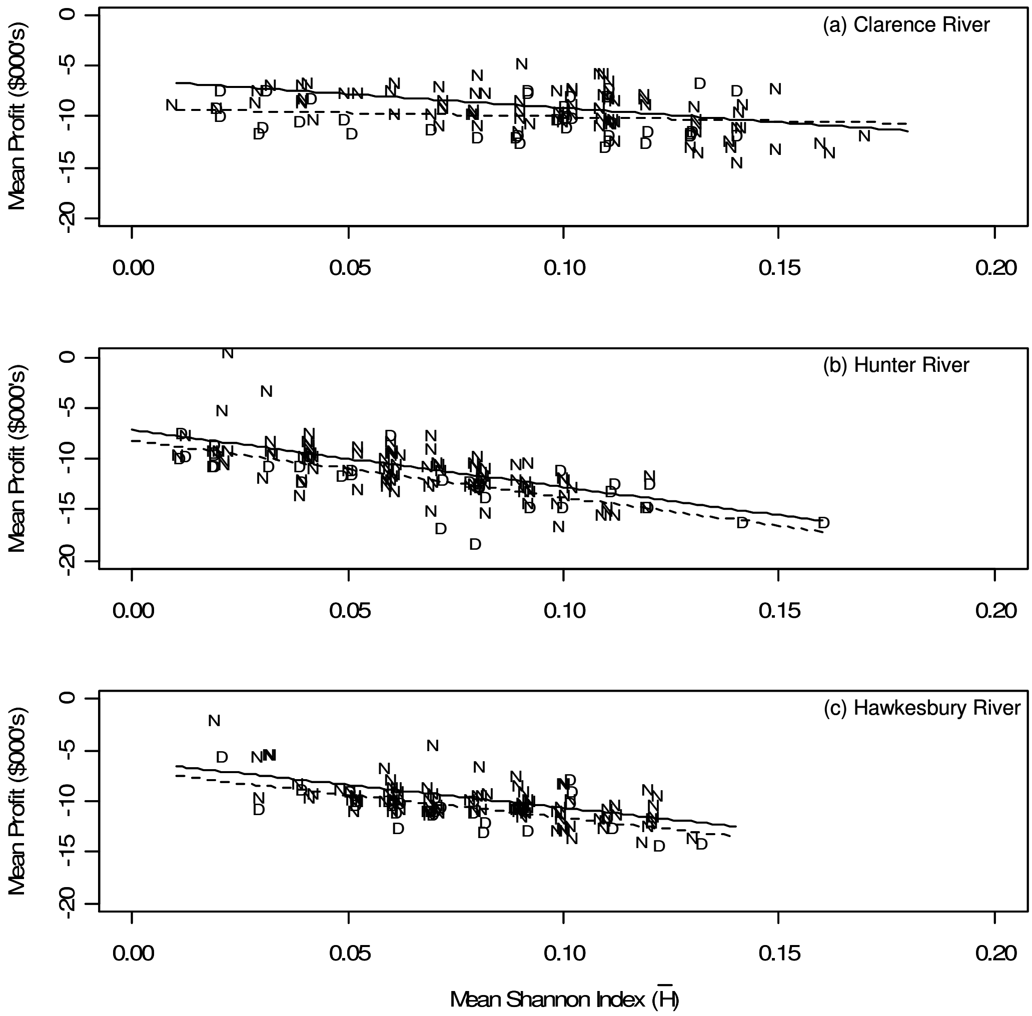

Figure 8. Regression models predicting mean monthly profit per business from the mean monthly Shannon index during non-drought (solid line) and drought (dotted line) conditions for the estuarine and coastal fisheries associated with the Clarence, Hunter and Hawkesbury Rivers (statistics for the regression models presented in Table 6). Results presented for mean monthly profit CV 50%. Note that data points associated with non-drought (N) and drought (D) periods have been jittered on the linear plots to improve clarity.