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Effects of freshwater flow on the year-class strength of a non-diadromous estuarine finfish, king threadfin (*Polydactylus macrochir*), in a dry-tropical estuary

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Abstract. The year-class strength of the commercial catch of king threadfin (*Polydactylus macrochir* (Gunther, 1876)) was correlated with freshwater flows into a dry-tropical estuary over five consecutive years. The year-class strength of king threadfin, a non-diadromous estuarine species, fluctuated and correlated significantly with freshwater flow and coastal rainfall in spring and summer; a result similar to that found for the catadromous barramundi (*Lates calcarifer*) within the same estuarine system. All sub-sets general linear models were used to screen relationships between year-class strength and freshwater variables. King threadfin spawn from spring to summer in north-eastern Australia, when hydrological conditions adjacent to estuaries have high salinities and are optimal for egg and post-larval survival. Young-of-the-year enter estuaries during the wet season, enabling them to take advantage of salinity gradients and the seasonal blooms in prey species such as *Acetes* spp. and juvenile penaeids that are accentuated in wet years. Freshwater flows in spring and summer are important drivers of the year-class strength of estuarine finfish, and reduction in these flows, through the development of water infrastructure and abstraction or long-term climate change, will potentially reduce the size of the population of estuarine fish available for human harvest.

Additional keywords: environmental flows, fish recruitment, otoliths, year-class strength (YCS).

Introduction

Worldwide, fresh water resources are increasingly in demand as a result of increased human development (and use), and in some areas, such as Australia, reduced rainfall and associated run-off are increasingly predicted as a consequence of climate change (Hughes 2003). The general response to increased freshwater demand has been the construction of dams and, more recently, recognition of the need to use water efficiently, which includes recycling where suitable and reducing consumption where possible. Despite the continued use of freshwater resources and subsequent alteration of the quantity and quality of freshwater flowing down rivers to estuaries, there is limited understanding of the impacts of such changes on estuarine flora and fauna. To understand the impact of changed flow, we need first to understand and quantify the role of freshwater on populations of estuarine-dependent species.

Numerous correlative studies support speculation that the fishery catch (an index of population abundance) of some estuarine and marine finfish and shellfish is strongly linked to freshwater flows in tropical, sub-tropical and temperate areas (see Drinkwater and Frank 1994; Gillanders and Kingsford 2002; Robins *et al*. 2005; Whitfield 2005). Possible mechanisms for these relationships include that freshwater flowing to estuaries: (*i*) enhances the overall biological productivity of estuaries by providing an input of organic and inorganic matter (including nutrients), driving the lower end of the food chain (e.g. phytoplankton and bacteria) and having flow-on effects for the survival and growth of species at higher trophic levels; (*ii*) alters the accessibility of important nursery habitats such as coastal lagoons and floodplains, thereby improving recruitment (and subsequent abundance) of estuarine species; and (*iii*) affects catch rates in estuarine and coastal fisheries by triggering behavioural responses (e.g. movement and spawning) in some species (Copeland 1966; Aleem 1972; Peters 1982; Drinkwater 1986; Drinkwater and Frank 1994; Loneragan and Bunn 1999; Livingston *et al*. 2000; Gillanders and Kingsford 2002; Sobrino *et al*. 2002; Staunton-Smith *et al*. 2004; Robins *et al*. 2006). Mechanisms (*i*) and (*ii*) above potentially affect the number of fish that survive, particularly during their first year of life, and then contribute to the fished or reproductive population.

The number of fish that survive the first year of life is often referred to as year-class strength (Maceina 1997) and can be influenced by density-dependent factors (e.g. competition, predation, disease and fishing pressure) as well as density-independent environmental factors. Staunton-Smith *et al*. (2004) reported significant positive relationships between seasonal

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freshwater flows and the year-class strength of barramundi (*Lates calcarifer*) in northern Australia, while Bonvechio and Allen (2005) report positive and negative relationships between seasonal flow rates and the year-class strength of black bass (*Micropterus* spp.) and *Lepomis* spp. in Florida, USA. It is not surprising that the year-class strength of freshwater fish (e.g. black bass and *Lepomis* spp.) and diadromous fish (e.g. barramundi) should be linked to freshwater flows, particularly for species that take advantage of habitats inundated by such flows.

We tested the hypothesis that variations in freshwater flows influence the number of juveniles that survive the first year of life of a non-diadromous estuarine-dependent finfish species and these patterns are reflected in the population years later. This was done by: (*i*) estimating the annual year-class strength (YCS) of a non-diadromous finfish (king threadfin, *Polydactylus macrochir*) in a dry-tropical Australian estuary; (*ii*) correlating YCS with seasonal patterns of freshwater flowing into the estuary; (*iii*) identifying possible causal mechanisms for the observed relationships; and (*iv*) comparing the results with those reported for barramundi (Staunton-Smith *et al.* 2004).

Materials and methods

Study area

King threadfin were sourced from the Fitzroy River estuary, as described in detail in Staunton-Smith *et al.* (2004) and Robins *et al.* (2005). This river is on the east coast of Queensland, Australia, and straddles the Tropic of Capricorn. A barrage delineates the upper limit of the estuary, ~50 km from the river mouth. The Fitzroy River estuary has many islands and channels in the delta, with extensive areas of mangrove, intertidal salt marshes and extensive salt pans (Long and McKinnon 2002). Freshwater flows to the estuary occur from rainfall run-off in the river's 142 537 km^2 catchment and are highly variable between years. The mean annual (i.e. September to August) freshwater flow is 5.2×10^6 ML (164.8 m^3 s^{-1}), with a minimum annual freshwater flow of 0.08×10^6 ML (2.5 m^3 s^{-1}) and a maximum annual flow of 37.3×10^6 ML (1182.7 m^3 s^{-1}). Additional run-off from coastal rainfall occurs in the estuary via several small- to medium-sized creeks that connect to the Fitzroy River estuary downstream of the barrage.

Study species

King threadfin (previously *Polydactylus sheridani*) are endemic to the estuaries of northern Australia and southern Papua New Guinea (Motomura *et al.* 2000). Although *Polydactylus* spp. are widely distributed and important fishery species in many countries adjoining the Pacific, Atlantic and Indian Oceans (FishBase 2006), no published papers deal with the ecology of king threadfin and the majority of the recorded accounts are from general sources. King threadfin have a complex life history, being protandrous hermaphrodites (i.e. males first then females, Russell 1988), utilising estuarine and associated coastal foreshore waters. They do not use freshwater during any life history stage, although adults can be found in the upper estuary during winter, as saline waters intrude (I. Halliday, pers. obs.). Adults spawn in inshore, coastal waters away from river mouths (Russell 1988) and the length of the spawning season and month(s) of peak spawning vary between areas. For the east coast of Queensland, spawning occurs between spring and summer (i.e. October to January, Russell 1988), but for stocks in the Gulf of Carpentaria spawning occurs between late winter and spring (Garrett 1997), whereas those in the Northern Territory spawn from October to March, with a peak in December (Kailola *et al.* 1993). Spawning is thought to occur in high salinity water (>32 on the practical salinity scale; R. Garrett, pers. comm.) and the pelagic eggs probably require salinities near that of seawater for high survival rates. The early life history of king threadfin is poorly quantified, although juvenile king threadfin are thought to exploit shallow, inshore nursery areas, where the salinity is less than that of seawater (Kailola *et al.* 1993; Williams 2002). Young-of-the-year juveniles (30–100 mm fork length (FL)) occur in estuaries of the Queensland east coast between December and May, in salinities ranging from 2.0 to 37.8 (I. Halliday, unpubl. data). King threadfin do not occur in temporary supra-littoral pools in the Gulf of Carpentaria (Russell and Garrett 1983), suggesting that this species restricts its use of estuarine habitats to permanent water areas in the main channels and tributaries of creeks and rivers.

Estimating year-class strength

Year-class strength (YCS) was estimated from population age-structure using catch-curve regressions (i.e. regression of the natural log of the number of fish in each year-class against age) as per Maceina (1997). We assumed that deviation from the expected abundance of each year-class, given its age and the catch-curve regression equation is a reflection of variable recruitment (as per Staunton-Smith *et al.* 2004). Residuals from the catch-curve regressions were used as an index of YCS, with large positive and negative residuals representing strong and weak year-classes respectively.

The population age-structure of king threadfin was estimated following the methods of Staunton-Smith *et al.* (2004), but are briefly re-described here. Otoliths were sampled from the commercial net fishing catch of the Fitzroy River estuary in the week(s) preceding and following the annual seasonal closure for barramundi on the Queensland east coast, which occurs between 1 November and 31 January. Sampling occurred at three seafood processors who consistently purchased most of the commercially caught estuarine fish in the Fitzroy River region. The king threadfin purchased by the processors during the sampling period were measured as fork length (FL ± 10 mm) and sagital otoliths removed from as many fish as time permitted. Samples were collected over five consecutive 'sampling years': Year 1 = October 2000–February 2001; Year 2 = October 2001–February 2002; Year 3 = October 2002–February 2003; Year 4 = October 2003–February 2004; and Year 5 = October 2004–February 2005.

Otoliths were blocked in resin, sectioned at 300 μm, mounted on microscope slides and viewed using a microscope and reflected light. King threadfin otoliths had distinct banding similar to that of barramundi in the same estuary (Stuart and McKillup 2002; Staunton-Smith *et al.* 2004), having narrow, opaque and broad, translucent growth bands. Narrow, opaque increments were assumed to be laid down annually and used as an estimate of fish age. An extra year was added to fish caught in October if an opaque band was not visible on the otolith's edge

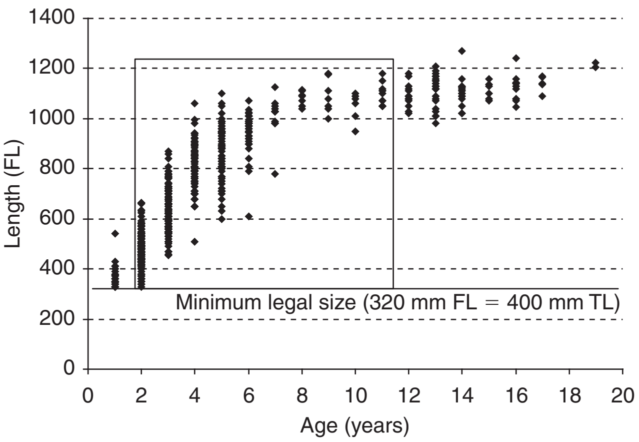

Fig. 1. Length-at-age plots for king threadfin sampled from commercial catches in the Fitzroy River estuary. Boxed area indicates data used in the analyses of year-class strength (ages two- to eleven-years-old).

(i.e. if they had a wide translucent margin) as per Staunton-Smith *et al.* (2004).

Age estimates were used to construct age-length keys, which were used to convert length-frequencies into age-frequencies. Age-length keys and length-frequency distributions were constructed for each sampling trip (i.e. two trips per sampling year). From these, a single age-structure was constructed for each sampling year. Year-classes were assigned on the basis of spawning year with an allocated 1 January birthday (i.e. fish born between October 1990 and January 1991 are in the 1991 year-class).

Despite being present in the commercial catch, the one-year-old age-class was probably not fully recruited to the fishery, with 54% being within 20 mm of the minimum legal size of 400 mm total length (TL) and were not included in the analysis. Of the 176 two-year-old king threadfin sampled, 98% were over 420 mm and were considered to be fully recruited to the fishery (Fig. 1). Likewise, we considered that king threadfin older than 11 years were probably not adequately sampled by the net fishery, as a consequence of the restricted mesh sizes used in the fishery (i.e. 135 mm to 180 mm stretch mesh size). King threadfin do not have a maximum size limit and are caught in the same fishery as barramundi, which has a maximum size limit of 1200 mm TL.

Correlating year-class strength with freshwater variables

Correlation analyses and all sub-sets general linear modelling (Genstat 2006) were used to examine relationships between the individual YCS estimates and freshwater flow and coastal rainfall. Age and sample year were forced into the general linear models because the abundance of individual age-classes is not comparable between years (Staunton Smith *et al.* 2004). The regression residuals were examined for serial auto-correlation using residual maximum likelihood (REML) (Genstat 2006) to check whether indices of year-class strength were auto-correlated. Ridge regression (Genstat 2006) was used to investigate the effects of co-linearity between terms in the fitted model (i.e. flow and rainfall).

Freshwater flow to the estuary was calculated as gauged flow at the most downstream gauging station (i.e. at 'The Gap', 142.1 km adopted middle thread distance), minus the estimated downstream extractive use. Gauged data and estimated extractive use were obtained from the Department of Natural Resources, Mines and Water Queensland and Fitzroy River Water. Freshwater flow was aggregated into seasonal totals where spring = September to November; summer = December to February; autumn = March to May; and winter = June to August; as well as 'spawning season' = September to February inclusive. Coastal rainfall was also included in the analyses because in the Fitzroy River estuary, heavy coastal rainfall can cause significant flooding in the estuary without increasing freshwater flow through the barrage. Rainfall data were averaged for the nine coastal rainfall stations within 50 km of the coast and on the seaward side of the coastal mountain ranges. Rainfall data were obtained from *Rainman StreamFlow 4.3* (Queensland Department of Primary Industries and Fisheries, Brisbane) (Clewett *et al.* 2003) and aggregated into seasonal totals, as per freshwater flow. Freshwater flow and coastal rainfall variables were transformed ($\log_{10}x + 1$) before analyses to normalise data and stabilise variances.

Assumptions and limitations

The following assumptions were made: (*i*) that observed age-structure was determined mainly by recruitment (i.e. in the first year of life); (*ii*) that migration rates between estuaries were low; (*iii*) that narrow, opaque bands on the otoliths of king threadfin in the Fitzroy River estuary were annual in periodicity; and (*iv*) that the age-structure of the adult population of king threadfin was estimated accurately. The validity of assumptions (*i*) and (*iv*) are discussed in Staunton-Smith *et al.* (2004).

The current analyses assumed that migration of king threadfin between estuaries was low. Individual king threadfin can move large distances along the coastline (e.g. 550 km Kailola *et al.* 1993), potentially confounding relationships between freshwater flow and the abundance of king threadfin. However, the frequency of these movements and proportion of the population that moves such large distances is unknown. Tag–recapture data from the Suntag Program of the Australian National Sport Fishing Association Queensland Inc. (ANSQ Qld) was examined for evidence of king threadfin migration. In the Fitzroy River region, 148 king threadfin were tagged and recaptured between 1986 and 2005, being at liberty for between 0 and 2599 days (median = 227 days), at sizes between 340 and 1424 mm FL. Although individuals had moved within the Fitzroy River estuary and adjacent surrounds, none had been recaptured more than 68 km from their release location, supporting our assumption that that migration rates between estuaries were low.

The method also assumed that opaque bands on the otoliths of king threadfin from the Fitzroy River estuary are laid down annually. There are no published ageing studies on king threadfin, nor any known-age individuals. However, otoliths of king threadfin sampled from the Fitzroy River estuary had clearly defined opaque and translucent bands (Fig. 2). Over the five years of sampling, consistent differences were observed in the marginal increment of king threadfin otoliths collected in the October to those collected in following February (Table 1). Therefore, it was assumed that like barramundi (see Staunton-Smith *et al.* 2004), opaque bands of king threadfin in the Fitzroy River estuary were laid annually and that the first increment could be accurately

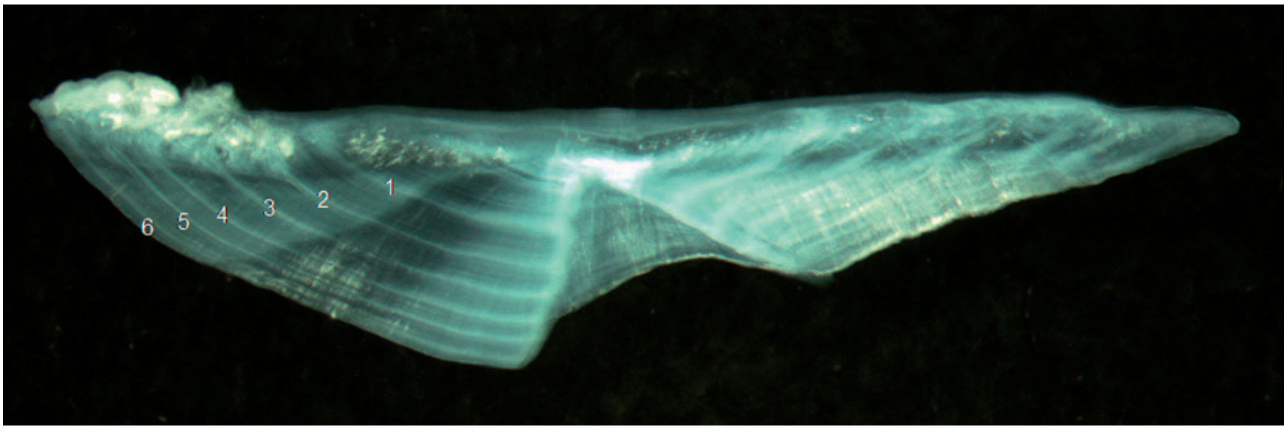

Fig. 2. Transverse section of an otolith from a six-year-old king threadfin sampled from the commercial catch of the Fitzroy River estuary.

Table 1. Marginal increment assessment of king threadfin in the Fitzroy River region

Marginal increments defined as: 'New': when the opaque increment was on the margin; 'Plus': when the opaque increment was separated from the margin by a narrow translucent increment; 'Due': when the distance from the outer opaque increment to the margin was almost equal to the width of the previous translucent increment

Sample time	Marginal increment			Total
	New	Plus	Due	
Year 1				
October 2000	47	–	–	47
February 2001	–	133	–	133
Year 2				
October 2001	95	–	1	96
February 2002	1	141	1	143
Year 3				
October 2002	45	–	2	47
February 2003	–	4	–	4
Year 4				
October 2003	45	–	–	45
February 2004		8	–	8
Year 5				
October 2004	82	–	1	83
February 2005	–	110	–	110

identified. The Fitzroy River estuary is towards the southern limit of the distribution of king threadfin in Australia, and water temperatures (and food availability) drop considerably over winter. The assumption that opaque bands are laid down annually may not be valid throughout the distribution of king threadfin, but appears to be reasonable for the Fitzroy River estuary, until otolith annuli can be validated in known-age fish.

Results

Length-frequencies and age-structure of samples

Table 2. Age and proportion of king threadfin sampled from the commercial catch in the Fitzroy River estuary

Year 1: 2000–2001; Year 2: 2001–2002; Year 3: 2002–2003; Year 4: 2003–2004; and Year 5: 2004–2005

Sample year	No. measured	No. aged
Year 1	207	180
Year 2	680	239
Year 3	52	51
Year 4	53	53
Year 5	193	193
Total	1185	716

A total of 1185 king threadfin from the Fitzroy River estuary were measured during the five 'sample years', with age estimated for 716 individuals (Table 2). The king threadfin sampled ranged in length from the minimum legal size of 320 mm FL (= 400 mm TL) to 1270 mm FL (= 1500 mm TL). King threadfin ranged in estimated age from one-year-old (23 individuals, ranging in size from 330 to 540 mm FL) to 19-years-old (two individuals, size 1205 and 1225 mm FL). Within the sample, there were 19 individuals >15-years-old, and 24 individuals 14- or 15-years-old.

There was large variation in the length-at-age of king threadfin (Fig. 1), indicating that length is not a reliable indicator of age for this species. For example, three-year-old king threadfin may range in length from 500 mm to 850 mm FL, whereas a 1000 mm FL king threadfin can be between four- and 16-years-old.

The proportional age-structure of king threadfin progressively changed from Year 1 to Year 5 (Fig. 3). In Year 1, the two- and five-year-old age-classes were relatively more abundant than other age-classes and could be followed in the yearly age structures over the five sample years.

Residuals from the catch-curve regression as indices of year-class strength

The standardised residuals from the catch-curve regressions give an indication of relative YCS (Maceina 1997). King threadfin year-classes 'born' in 1996, 1999 and 2001 had large, positive residuals, indicative of strong recruitment, whereas those 'born' in 1992–1995, 1997, 1998 and 2000 had large negative residuals (Fig. 4), indicative of weak recruitment. The remaining years had residuals that were not large in either direction. King threadfin

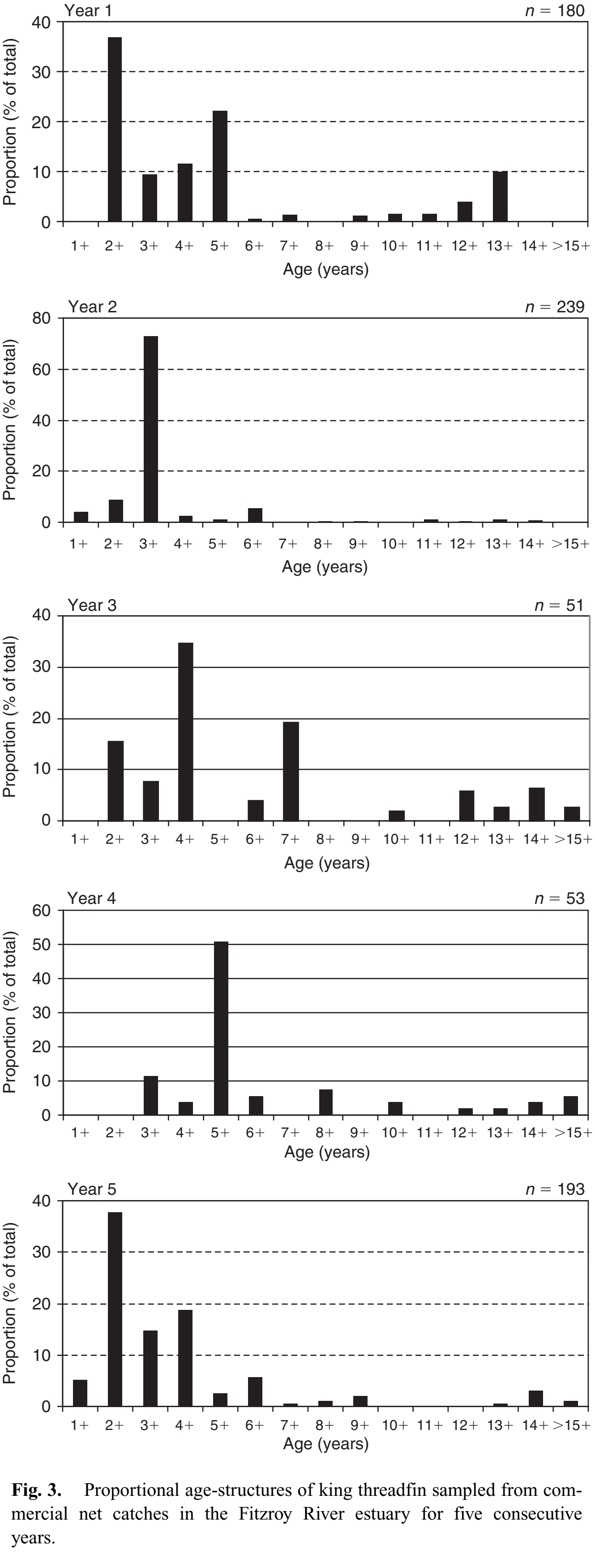

Fig. 3. Proportional age-structures of king threadfin sampled from commercial net catches in the Fitzroy River estuary for five consecutive years.

born in the high summer flow year of 1991 showed a mixed result. Of the two YCS estimates for 1991, one indicated a strong recruitment year and the other was neutral (Fig. 4).

Correlations between flow and year-class strength

Freshwater flow and coastal rainfall were significantly correlated in spring, summer and autumn ($r = 0.73$, 0.78 and 0.63, respectively, $P < 0.05$, $n = 14$), but not in winter. They were also significantly correlated during the spawning season (i.e. September to February inclusive). YCS of king threadfin was significantly and positively correlated with freshwater flow and coastal rainfall annual totals during spring and summer, as well as with the aggregate of spawning season (Table 3). YCS of king threadfin was not significantly correlated with freshwater flow or rainfall in autumn or winter. Correlation coefficients tended to be at least equal or of greater value for freshwater flow variables than for rainfall variables.

All sub-sets general linear modelling (GLM) identified several alternate models that explained significant variation in the abundance of YCS of king threadfin. The base model of age and sample year (i.e. forced variables) explained 54.6% of the variation in abundance of year-classes of king threadfin. The best final two term model of summer flow and spring flow ($r^2 = 74.6\%$) explained 44% of the residual variation from the base model. The only other significant two term model included summer flow and spring rain ($r^2 = 73.3\%$) explaining 42% of the residual variation from the base model. The relative influence of each term (summer flow and spring flow) was determined using the estimate from the table of effects multiplied by the flow range (summer flow = 2.46; spring flow = 1.38). This indicated that summer flow has an influence of approximately double that of spring flow on the abundance of any given year-class. Significant positive serial auto-correlation was found under an auto regressive process of order 1 (AR1) (i.e. a one year lag) (REML) (GENSTAT 2006), indicating that for king threadfin there is an increased likelihood of strong year-classes following strong year-classes and weak year-classes following weak year-classes. Coefficients adjusted for AR1 were not significantly different to those derived from the general linear modelling. Ridge regression correlations among the independent variables were not pronounced, averaging 0.26 with a maximum of 0.36. These values indicated a low adjustment factor (k-coefficient) for the ridge regressions, and in these ranges the ridge traces (or coefficient values for the independent variables) were stable. Therefore, the low degree of correlations among the independent variables was dismissed, and standard general linear models adopted throughout. Significant correlation of the YCS of king threadfin and barramundi ($r = 0.57$, $P < 0.05$) indicates that freshwater flows influence the YCS of both species in a similar way.

Discussion

Variation in year-class strength, as an indicator of the overall recruitment and survival of juvenile king threadfin, was consistently and positively related to the amount of freshwater flowing or coastal rainfall delivered into the Fitzroy River estuary during spring and summer. These results are the first to provide quantitative evidence in support of increased juvenile survival with increased wet season freshwater flow (or rainfall).

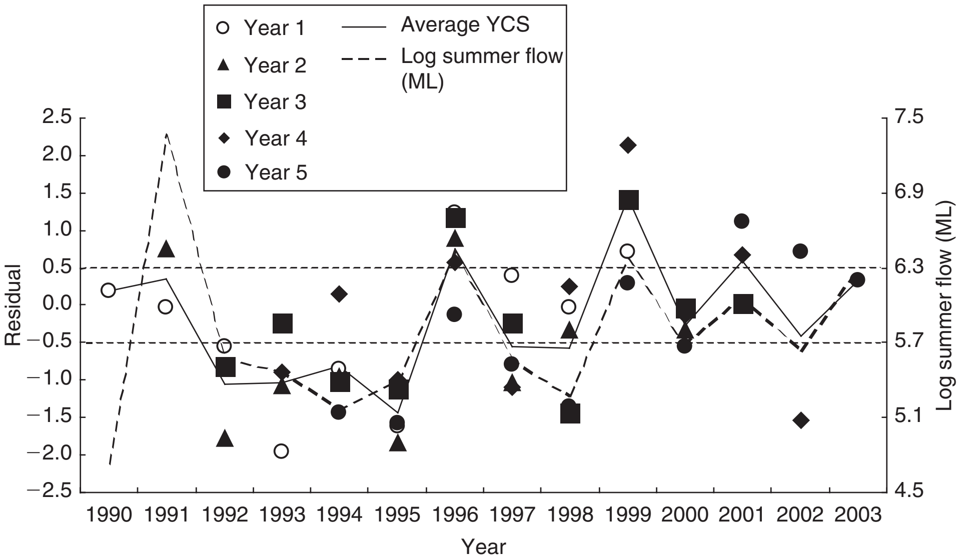

Fig. 4. Residuals from catch-curve regressions of king threadfin against summer freshwater flows from the Fitzroy River region. Dashed lines indicate the level at which the YCS was considered to be strong or weak.

Table 3. Correlation coefficients (*r*) between estimated year-class strength (YCS) and freshwater flow and coastal rainfall variables for king threadfin sampled from the Fitzroy River estuary

*: $P < 0.05$; ***: $P < 0.001$

Variable	King threadfin YCS
Annual flow	0.60***
Annual rain	0.60***
Spawning season flow	0.72***
Spawning season rain	0.60***
Spring flow	0.64***
Spring rain	0.44***
Summer flow	0.61***
Summer rain	0.32*
Autumn flow	0.21
Autumn rain	−0.06
Winter flow	0.03
Winter rain	−0.02

From the limited quantitative information available on the life history of king threadfin, it was hypothesised that freshwater flows may influence the survival of larval and/or juvenile king threadfin in estuarine habitats, leading to increased year-class strength by:

(a) enhancing the biological productivity of the estuary, thereby increasing the availability of food resulting in improved growth (Whitfield 2005; Robins *et al.* 2006)
(b) affecting the area of favourable habitat potentially through larger areas of decreased salinity, with lowered salinities affecting the energy budgets (Cardona 2000)
(c) creating turbid conditions reducing predation, enhancing survival rates (Hecht and van der Lingen 1992).

While none of these hypotheses have been directly addressed for king threadfin, the significant positive correlations between spring and summer freshwater flow and YCS provides evidence for the hypothesis that freshwater flows positively influence the survival of larval and juvenile king threadfin, which are reflected in the age structure of the commercial fishery years later.

Commonalities with barramundi, a catadromous species

Analysis of three years of data by Staunton-Smith *et al.* (2004) showed that the YCS of barramundi was highly correlated with spring and summer freshwater flow and coastal rainfall being delivered to the Fitzroy River estuary. Updated analysis of barramundi YCS using five years of data support this hypothesis (Halliday and Robins 2007), but indicate that some of the results were overestimates of the strength of particular year-classes. Significant correlation between the YCS of both king threadfin and barramundi indicate that each species is exhibiting similar survival in response to years of high and low spring and summer freshwater flows. The years identified as having strong (1996 and 1999) and weak YCS (1993–1995, 1997 and 1998) recruitment patterns were similar for both species. In 1992, the YCS of the two species are different, with king threadfin having a weak YCS and barramundi having a strong YCS. Coastal rainfall was above average but did not result in a major river flow. This was the only year when there was high coastal rainfall but low measured freshwater flow into the estuary. Overlap in recruitment variation would be expected as both species are carnivorous and would probably exploit any trophic blooms occurring in the estuary as a consequence of flow events. In addition, both species have a spawning season that extends over several months, thus allowing early life-history stages to exploit the benefits of freshwater flows that vary in timing from year to year in northern Australia.

The YCS of king threadfin and barramundi have the same positive response to spring and summer flows despite different tolerances to lower salinity that occur as a consequence of freshwater flows. The current paradigm suggests that juvenile barramundi access supra-littoral and freshwater wetlands where ever possible, whereas juvenile king threadfin occur in the estuary with adults leaving at the onset of a freshwater flow. King threadfin and barramundi are carnivorous, eating a variety of the seasonally available small fish species and crustaceans. Banana prawns (*Penaeus merguiensis*) are a major component in the diet of both species (Salini *et al.* 1990; Brewer *et al.* 1995), and variability in banana prawn abundance within the estuary may significantly affect the availability of prey for young-of-the-year king threadfin and barramundi. The abundance of juvenile banana prawns varies seasonally (Salini *et al.* 1990), generally peaking in autumn, and is related to the volume and timing of freshwater flows (Halliday and Robins 2007). *Acetes* spp. is another macro-crustacean whose population numbers are highly responsive to freshwater flows (I. Halliday, unpubl. data) and are a major prey item for juvenile king threadfin and barramundi.

Implications for fisheries and water management

Fisheries catch (commercial and recreational) is affected by the cumulative history of everything that has happened to all year-classes of the fished stock plus factors that affect fisheries, such as gear selectivity, effort and management restrictions. Understanding the factors other than fishing that influence the population size of fished species may enhance fisheries management (Shepherd *et al.* 1984; Hilborn and Walters 1992) and assist in moving towards a whole-of-ecosystem management approach. The large variability in YCS and the persistence of strong and weak year-classes in the barramundi and king threadfin populations of the Fitzroy River estuary over five consecutive years suggests that recruitment variability has the potential to influence adult stock size in at least these species. These results suggest that stock assessments should consider environmental influences, such as the impacts of freshwater flows (and/or coastal rainfall) on the annual recruitment of barramundi and king threadfin. Furthermore, because freshwater flows affect recruitment on a catchment basis, it is likely that stock assessments should be conducted regionally rather than at large spatial scales. This is particularly relevant when a significant proportion of regional populations do not undertake long-shore migration.

The YCS of two large, long-lived tropical estuarine species of commercial and recreational importance is significantly correlated with spring and summer flows. It is important that managers (and politicians and the general public) are made aware that freshwater flowing to estuaries is not wasted, but rather has a critical role in maintaining estuarine fish populations. Further research and numerical modelling is required before a robust estimate can be made of the extent to which the quantity, duration or frequency (e.g. number per decade) of freshwater flows could be modified and what effects these modified flows would subsequently have on estuarine fish populations. The aim of such work would be to achieve water efficiencies in environmental flow allocations; that is, how to achieve the same effect with less water. Whereas the underlying mechanisms for strong YCS in years of high spring and summer flows are yet to be determined, it appears likely that without freshwater flows there will be a reduction in the abundance of these fish species.

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