Major Fish Kills in the Northern Rivers of NSW in 2001: Causes, Impacts & Responses

Simon Walsh, Craig Copeland and Megan Westlake

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EXECUTIVE SUMMARY

Following major flooding in early February 2001 in the upper reaches of the Richmond River catchment, a major fish kill occurred in the Richmond River. Fish kills were also recorded at this time in tributaries of the Tweed and Brunswick Rivers. Subsequent flooding in March 2001 resulted in a major fish kill in the Macleay River and minor fish kills in the Clarence River (see Figure 1).

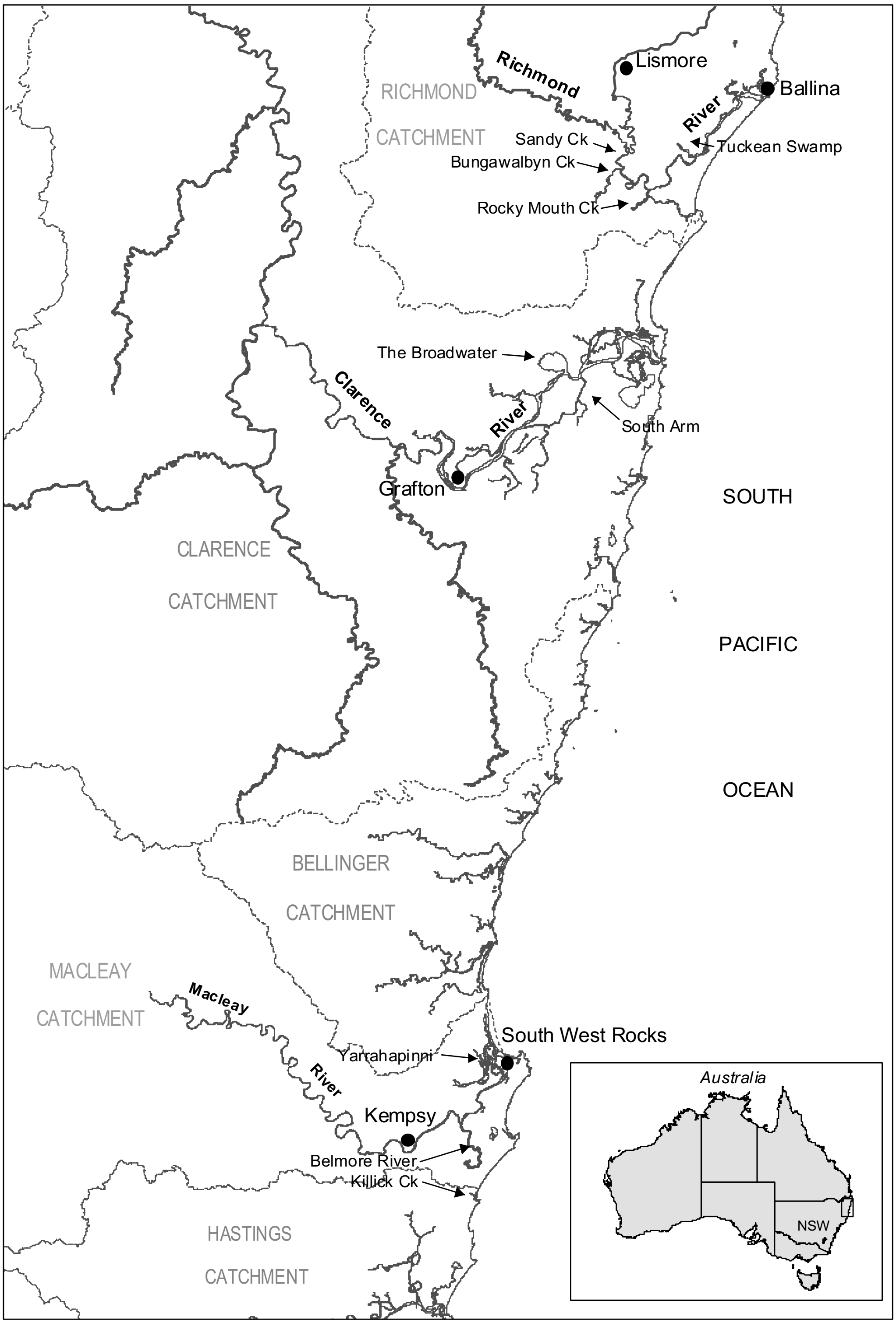
The cause of the fish kills was extremely low dissolved oxygen levels in the rivers; most were below 1 mg/L (well below the limit required for survival by fish of approximately 4 mg/L). This most likely resulted from the death of pasture grasses inundated by floods which removes oxygen from the water and the rapid drainage of this floodplain water into the river. Also acid sulphate soil-derived drainage sediments were also a likely contributor of low dissolved oxygen in the water. Key sources of low oxygen to the system were all areas that were formerly important fish habitats primarily Tuckean Swamp, Rocky Mouth Creek and Bungawalbyn Swamp in the Richmond; Everlasting Swamp, Shark Creek and Coldstream wetlands in the Clarence; and Yarrahapinni, Belmore Swamp, Swan Pool and Seven Oaks wetlands in the Macleay. All these wetlands have been extensively drained and floodgated.

As a response to the fish kills, NSW Fisheries closed the Richmond River and near shore areas to all forms of fishing for three weeks initially and then extended this closure a further three months. A closure to all forms of fishing was placed on the Macleay River for 3 months on 20 March 2001. Despite the economic impact on the community, this action received widespread industry and community support. This was facilitated by the appointment of Recovery Committees to the Richmond and Macleay river systems that consisted of stakeholders from commercial and recreational fisheries, indigenous representatives, tourism and accommodation outlets and bait and tackle shops. These Committees provided local advice on the timing and conditions applying to the re-opening of the rivers, in addition to valuable reviews of the scientific data gathered by NSW Fisheries' scientists.

The fish kill and river closures caused a range of socio-economic impacts on the local community, especially at Ballina and South-West Rocks. These impacts particularly lost revenue from cancelled visits by tourists, affected bait and tackle stores in particular and other businesses such as motels, caravan parks, service stations, seafood outlets, Fishermen's Co-operatives, boat-hire and maintenance businesses.

The closures to fishing in the rivers were modified following consultation with the Recovery Committees, analysis of scientific data and community input that occurred after a general call for submissions. The total closures were replaced with less restrictive recreational and commercial fishing closures on the Richmond and Macleay Rivers. These included daylight fishing hours only, restricted total bag limits and limits on the available fishing area. These new restrictions lasted for a period of 3 months in both rivers.

The partial river closures were lifted on 28 September 2001, following positive results from the scientific surveys, allowing for the resumption of 'normal' commercial and recreational fishing.


Lismore
Richmond
Ballina
River
RICHMOND
CATCHMENT
Sandy Ck
Bungawalbyn Ck
Tuckean Swamp
Rocky Mouth Ck
The Broadwater
Clarence
River
South Arm
Grafton
SOUTH
PACIFIC
OCEAN
CLARENCE
CATCHMENT
BELLINGER
CATCHMENT
MACLEAY
CATCHMENT
Macleay
River
South West Rocks
Yarrahapinni
Kempsy
Belmore River
Killick Ck
HASTINGS
CATCHMENT
Australia
NSW

1. BACKGROUND

Large scale fish kills are a worldwide phenomenon which have been reported in the published literature as occurring because of a variety of factors. These include blooms of toxic dinoflagellates (Heil et al., 2001), toxic algae (Lindholm et al., 1999), low and high pH (Leivestad and Muniz, 1976; Kann and Smith, 1999), low water temperatures (Cyrus and McLean, 1996), pesticides (Clark, 1974), cyanide (Gabor et al., 2000) and carbon monoxide (Kempinger et al., 1998). Another very important factor in causing large fish kills is low dissolved oxygen (DO). Attributes that contribute to low DO concentrations include: low rates of water flow, high water temperatures, upwelling of nutrient laden sediments (Barica, 1974), excess nutrients from anthropogenic and/or natural sources (Venugopalan et al., 1998) or a combination of these attributes leading to algal blooms (Paffoni and Krier, 1996). Natural fish kills have occurred in Australian coastal rivers since before European settlement, although most recent kills have largely been attributed to human-related factors (NSW Fisheries, 2001a). The occurrence of fish kills due to low DO and low pH is commonly attributed to land use practices in surrounding catchments, in particular changes to floodplain hydrology as a result of a significant increase in drainage density and drain depth. In this scenario, drains and their associated floodgates act to lower surface water and groundwater levels thereby oxidising acid sulfate soils. The acid produced is mobilised during subsequent rainfall and carried through the drainage network to adjacent rivers and creeks (see Sammut et al., 1996)

During early 2001, the northern rivers region of NSW experienced widespread severe flooding followed by the death of millions of fish of various species. Fish kills of this scale have not been documented previously in Australia, with the exception of the massive pilchard kills which occurred in southern Australian oceans during 1995 and 1998, as a result of a herpesvirus (see Gaughan et al., 2000).

The key catchments affected by the fish kills were the Richmond, Clarence and Macleay valleys (see Table 1 for general catchment description).

Fish kill at low tide, Richmond River (NSW Fisheries)

Table 1. Characteristics of the Richmond, Clarence and Macleay River Catchments relevant to the present study.

Characteristics	**River System**		
	Richmond	**Clarence**	**Macleay**
Area	6 864 km^2	19 800 km^2	11500 km^2
Mean annual rainfall	1650 – 1025 mm	1074 mm	1221 mm
Maximum tidal influence	58 km from mouth	Approx. 60 km from mouth	Approx. 55 km from mouth
Extent of high risk ASS	34000 ha on the entire Richmond system (DCLM 1995)	53000 ha of floodplain below Grafton (DCLM 1995)	31000 ha of floodplain below Kempsey (DCLM 1995)
No. floodgated systems	240(NSW Fisheries 2001b)	186 (NSW Fisheries 2001b)	180 (NSW Fisheries 2001b)
Land use	mostly sugarcane and cattle grazing; also dairy, beef, timber, tourism, tea-tree plantations	mostly sugarcane, plus dairy, beef also cropping, forestry, tourism, tea-tree plantations, aquaculture and coffee	mostly beef, dairy
Fishery	• commercial landings grossing over $704,000 (1998/99) • landings from the nearby ocean fishery grossing over $5million (1998/99) • est. mean number of fish recreationally harvested 1988/89 over 220,000,	• commercial landings grossing over $4.5 million (1998/99) (largest in NSW) • landings from the nearby ocean fishery grossing over $9.5 million (1998/99) (largest in state) • est. mean number of fish recreationally harvested in 1988/89 nearly 40,000	• commercial landings grossed just under $300,000 (1998/99) • landings from the nearby ocean fishery grossing over $109,000 (1998/99) • estimates of recreational catch not available

Species	**Estimated numbers of each species killed over a 20km long stretch of the Lower Richmond River**							
	<2000	<5000	<10000	<30000	<150000	<300000	<500000	1000000+
Prawn (*Metapenaeus macleayi*)								✔
Worm (*Australonereis ehleersii*)							✔	
Bream (*Acanthopagrus australis*)						✔		
Flathead (*Platycephalus fuscus*)					✔			
Herring (*Herklotsicht Castelnaui*)				✔				
Bass (*Macquaria novemaculeata*)			✔					
Eels (*Anguilla reinhardtii*)			✔					
Mudcrab (*Scylla serrata*)			✔					
Mullett (*Mugil cephalus*)			✔					
Whiting (*Sillago cilata*)			✔					
Sole (*Achlyopa nigra*)		✔						
Luderick (*Girella tricuspidata*)		✔						
Catfish (*Tandanus tandanus*)		✔						
Bullrout (*Centropogon marmoratus*)	✔							
Catfish (*Arius graeffi*)	✔							

1.1. Richmond

Between 30 January and 5 February 2001, regional centres within the Richmond catchment experienced up to 410 mm of rainfall, with the flood reaching 10.40 A.H.D. (Australian Height Datum) at Lismore. A major fish kill occurred in the lower reaches of the Richmond River approximately a week later, peaking on or about 9 February. Minor fish kills during this period were recorded in tributaries of the Tweed, Macleay and Brunswick Rivers. Although flooding and subsequent fish kills are relatively common occurrences in the northern rivers region, the fish kills that occurred in early 2001 were particularly severe with significant ecological, social and economic impacts.

An initial survey (see section 1.4) revealed that school prawns (*Metapenaeus macleayi*) and worms (*Australonereis ehlersii*) were affected in the fish kill in the greatest numbers, with yellowfin bream (*Acanthopagrus australis*), dusky and sand flathead (*Platycephalus fuscus* and *P. arenarius*), southern herring (*Herklotsichthys castelnaui*), Australian bass (*Macquaria novemaculeata*), longfinned eels (*Anguilla reinhardtii*), mudcrabs (*Scylla serrata*), sea mullet (*Mugil cephalus*), and school whiting (*Sillago ciliata*) also affected in large numbers (Table 2). A total estimate of fish, crustaceans and worms killed over the 20 km stretch of river most affected was at least 2 million.

1.2. Macleay

Just before the middle of March 2001, the Macleay River system also experienced a flood event. Crescent Head, in the Macleay catchment, received 234 mm of rainfall in February and 317 mm over March. This was almost double the average annual rainfall for this region during February. In the Macleay, minor fish kills occurred in the upper estuarine reaches at the time of the flooding, with up to 1000 mullet and eels being reported dead in Killick Creek. Approximately a week later the major kill occurred, with an estimate of the fish affected at South West Rocks (one of the areas worst affected) of over 180 000 within a 1.5 km long river stretch. Over 1000 fish of various species were also killed in the Belmore River (Macleay River System) around this time, and thousands of sea mullet in the Yarrahapinni Broadwater (P. Haskins pers. comm.).

1.3. Clarence

The Clarence catchment was also subject to heavy flooding during mid March 2001 with fish kills reported between the 10th to the 19th of March 2001. The regional centre of Grafton, situated within the Clarence floodplain, received over 234 and 449 mm of rainfall for February and March respectively, which was almost double the region's average for February (165 mm) and over two and a half times the average for March (169 mm).

Fish kills reported for the Clarence were relatively minor compared to those for the other two systems. This may be attributed to the larger flow in the river and therefore its enhanced buffering capability and the opportunity for fish to escape into the two large water bodies in the system, the Broadwater and Lake Wooloweyah. Not all areas of the river were equally affected, with the South Arm being more affected than other sections.

1.4. NSW Fisheries initial response and the involvement of others

Reports of fish kills were investigated by NSW Fisheries staff and the locations, numbers of fish, species affected and other observations were estimated and recorded via a rapid initial survey. Where possible, water quality parameters were measured. A broad survey was conducted at the time of the kill in the Richmond River to establish the relative quantities of each species affected and to provide an indication of the total number of fish killed. Boat based surveys were undertaken on 9 February by three NSW Fisheries staff, with the aid of staff from the Ballina Jet Rescue Boat, Ballina Shire Council and Volunteer Coast Guard. Eleven locations were examined between North Creek and Wardell, in an attempt to encompass most of the lower reaches of the Richmond River where the bulk of the fish kills had occurred. Observations were restricted to the lower reaches of the river due to time and staffing constraints.

NSW Fisheries water quality sampling

At each survey location, a ~ 5 km long stretch of river was examined. Six x 20 m transects were surveyed: 2 at the upper, 2 at the middle and 2 at the lower reaches of each of these 5-km long stretches. The transects were surveyed along the shoreline at each reach on either side of the river. The numbers of each fish or crustacean species washed up on or floating near the shoreline were visually estimated. Individual estimates were combined to give overall estimates of the numbers of each species killed along those stretches and the data converted to give an indication of numbers of each species that were present over a 20 km long stretch.

There is no widely accepted technique for estimating the number of fish affected by a fish kill. Very seldom will the counts represent more than a modest fraction of the fish actually killed; counts can only be based on fish actually seen once during what is actually a very dynamic, ongoing process (American Fisheries Society, 1992). Visual estimates of the total numbers of fish affected are usually a gross underestimate of actual numbers, given that dead fish are often made inconspicuous by riparian vegetation, and that large numbers of dead fish would have sunk, been eaten by birds, or swept away with the tide/river flow.

The Richmond River is a large system subject to considerable tidal (~2 m at the time of surveying) and flood related flow. It also supports many natural fish predators such as ospreys, pelicans, cormorants and gulls. This, combined with the fact that species counts were extremely large, extensive numbers of cryptic juveniles and small species (prawns, worms, etc.) were present, dense riparian vegetation made individuals inconspicuous and the short survey period (restricted by tides) made identification success very low. Studies of dead fish after a fish kill reveal low identification rates were influenced by the timing of the counts after the fish kills. Identification rates were in the order of 8% successful (1 day post-kill, Hayne *et al.*, 1980), 10% (1-3 days post-kill, Krumholz, 1944), 15% (4 – 10 days post-kill, Krumholz, 1944), and 39% (1 day post-kill, Labay and Buzan, 1999) of the total numbers of dead fish originally present. These significant underestimates of fish numbers imply the need to multiply identification counts by a factor relevant to the system type, species type, prevailing conditions and visual techniques used to give a more accurate estimate.

The fish kills observed in the northern rivers of NSW during February–March 2001 were on a scale rarely documented in Australia. The Richmond River was particularly impacted and, although the number of organisms inhabiting the river is unknown, it appeared that very large numbers of almost every aquatic animal species present were killed in some reaches with millions of fish, crustacean and worms affected. There is no documented evidence of kills of this scale occurring as a result of low dissolved oxygen elsewhere in Australian estuaries.

In a similar situation in the United States, however, thousands of fish were killed in North Carolina after the region experienced two hurricanes and associated flooding (Mallin et al., 1999). The kills occurred after millions of litres of raw and partially treated human waste and large quantities of concentrated swine waste, were diverted into the river. The fish kills in the Richmond River were an order of magnitude greater than those recorded in North Carolina even though this region did not experience inputs of sewerage and wastewater.

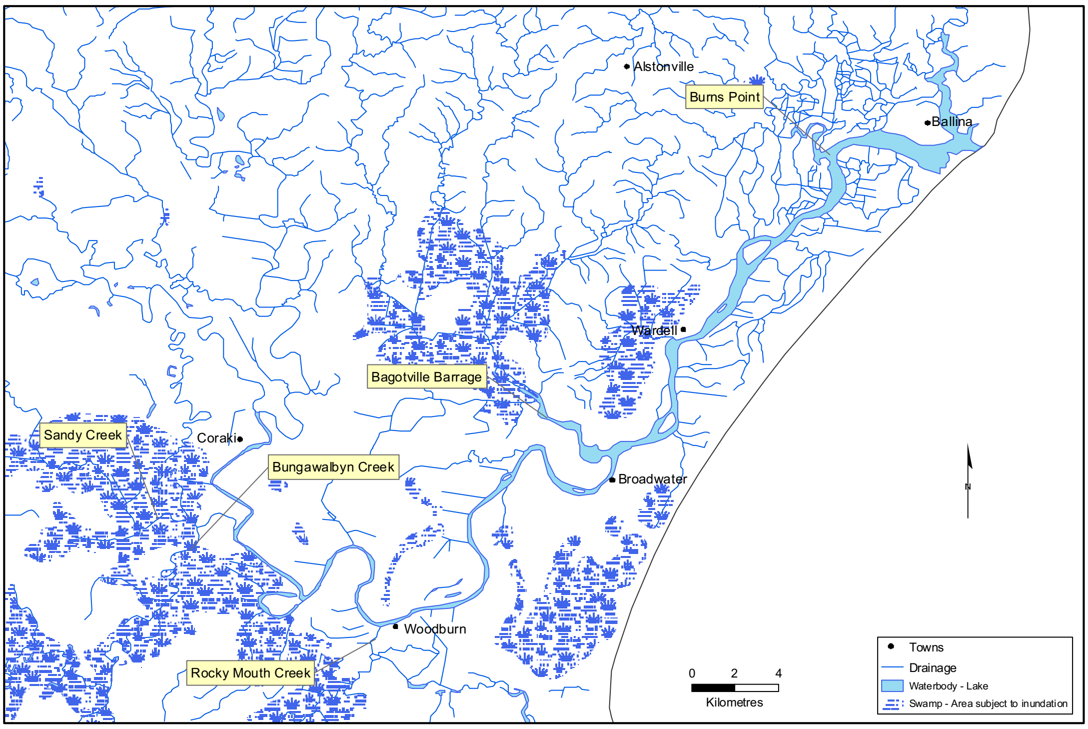
2. MONITORING

2.1. Water Quality

Measurements of water quality were made in the Clarence, Richmond and Macleay rivers and tributaries. Recordings were made using a Horiba U-10 Water Quality Meter in surface waters on the outgoing tide (0.5 – 3 m depth) to obtain dissolved oxygen (mg/L), pH (a measure of acidity/alkalinity), conductivity (mS/cm), salinity (%), turbidity (NTU) and water temperature (^{o}C) readings. Water quality in the Richmond River system were collected by NSW Fisheries, Richmond River County Council and Ballina Shire Council. Those taken in the Clarence were taken by NSW Fisheries and Maclean Shire Council. Macleay water quality information was provided by Kempsey Shire Council and the Department of Land and Water Conservation.

2.2. Richmond River

Figure 2 **Richmond Catchment Sample Sites**



NSW Fisheries recorded water quality in the lower reaches of the Richmond at the time of the kill, and later established a sampling program recording water quality throughout the lower reaches initially every 2/3 days, then weekly (Tables 3 and 4). The program commenced on 19 February 2001. Richmond River County Council conducted a parallel program for the upper reaches of the Richmond system. Ballina Shire Council (BSC) recorded water quality on a monthly basis, incorporating the dates of 9 and 28 February.

Water quality assessment at the beginning of the fish kills (7 - 9 February) was restricted to opportunistic recordings in the lower reaches of the Richmond River at sites where large numbers of dead fish were reported, and readings provided by Ballina Shire Council. All of the nine opportunistic readings taken in the main channel between Burns Point and Wardell were below 1.5

mg/L Dissolved Oxygen (DO), with most below 0.5 mg/L DO. Monitoring in the lower tributaries by BSC found DO between 0.95 – 6.81 mg/L. Further recordings were not available until the establishment of the water quality monitoring program on 19 February. Ongoing monitoring of water quality after this time showed variability throughout the catchment.

Within a month of the major flooding (1 March), DO in the lower-main channel had resumed to the level recommended for healthy estuarine systems of around 5 mg/L (ANZECC 1999) and was found to be at similar levels one month later. DO in the mid-upper main channel was monitored more regularly, and revealed fluctuating DO levels over time. DO in the mid-region, recorded at Woodburn and Wardell (see Figure 2), was more variable than that further upstream at Coraki. DO at Woodburn and Wardell took longer to recover and did not reach recommended levels until almost one month after the fish kill.

On 21 February, 48 sites throughout the broader Richmond Catchment were analysed for the water quality parameters mentioned previously, using a Horiba U-10. Sites included drains, river and tributary (creeks and streams) waters. Water samples were also collected from 15 sites for Southern Cross University laboratory analysis of conductivity, dissolved solids, biochemical oxygen demand, chemical oxygen demand, total phosphorous, phosphate, total nitrogen, nitrate, nitrite, ammonia, total aluminium, dissolved aluminium, total iron and dissolved iron.

Many of these water quality parameters were higher than recommended ANZECC (1999) levels for lowland rivers and estuaries (Table 5). Total aluminium and iron levels were higher than recommended throughout the entire catchment. Chemical Oxygen Demand (COD) and pH was outside recommended levels at 74% of sites. Ammonia was above recommended levels at 67% of sites. Nitrogen levels were acceptable at the majority of sites with 27% of sites above recommended levels, as were Biological Oxygen Demand (BOD) levels, with only 13% of sites above recommended levels.

There was large spatial variability among readings for the various parameters measured, with some sites possessing water of worse quality than others. Problem areas included Sandy Creek, Bagotville Barrage, Rocky Mouth Creek and Bungawalbyn Creek. Exceptionally poor water quality values worth noting included: COD levels of 123 mg/L at Rocky Mouth and 156 mg/L at Sandy Creek. These were 3 times greater than the recommended levels. Total nitrogen levels at Rocky Mouth Creek (2.36 mg/L), Bungawalbyn Creek (2.23 mg/L) and Sandy Creek (4.68 mg/L). The former two locations were one and a half times the recommended levels, with Sandy Creek almost 3 times higher. Total iron was 1900 times higher than recommended at Rocky Mouth Creek, and almost 40 times higher at all other sites. BOD was almost double recommended levels at Sandy Creek (28.5 mg/L). Total phosphorous was almost 15 times higher than recommended at Sandy Creek (0.588 mg/L). Total aluminium levels were 94 times above the recommended level at Bagotville Barrage (2.82 mg/L). Ammonia levels were over 7 times recommended levels at Bagotville Barrage (0.143 mg/L).

Table 3. Dissolved oxygen levels (mg/L) in the Richmond, Clarence and Macleay Rivers following the fish kills (*number of sites analysed in each region is given in brackets, NA = not assessed).*

	Approximate time of reading following the main fish kills in the region							
Region	**Time of kill**	**1 week after**	**2 weeks after**	**3 weeks after**	**1 month after**	**2 months after**	**3 months after**	**4 months after**
<u>Richmond</u>								
Lower main channel (3 sites)	Highly spatially variable (1.4–6.5)	NA	NA	Within recommended levels (5.1–6.1)	NA	Still within recommended levels (5.1-5.8)		
Lower tributaries (8 sites)	NA	Spatially variable (1.3-5.2)	Spatially variable (1.3-5.7)	Slightly recovered (4.3-5.1)	Slightly recovered, but spatially variable (3.6-8.8)	Similar to 1 month (4.93 – 7.15)	All within recommended levels (6.1-6.6)	All within recommended levels (6.92-8.27)
Upper main channel (3 sites)	Very low (all <1)	NA	Marginally higher (all <1.23)	Within recommended levels (5.3-7.6)	Dropped and variable (1-4.5)	Within recommended levels (6.5-6.9)		
Upper tributaries (3 sites)	NA	Very low (all <0.1)		Low and spatially variable (<0.1-2.07)	NA	Slightly improved (1.1-3.7)		

Table 3. Continued

Region	Approximate time of reading following the main fish kills in the region							
	Time of kill	**1 week after**	**2 weeks after**	**3 weeks after**	**1 month after**	**2 months after**	**3 months after**	**4 months after**
Clarence								
Main channel (7 sites)	Variable 1.7-4.1	Spatially variable (<.1-4)	Slightly improved (2-5.1)	NA	Within recommended levels (6.9-7.6)	NA	NA	NA
Broadwater (1 site)	Close to recommended levels (4.8)	Low (1.8)	Close to recommended levels (4.8)	NA	Within recommended levels (7.3)	NA	NA	NA
South Arm (4 sites)	Low (<1.3)	Very low (<0.1)	Very low (<0.1)	NA	Within recommended levels (5.1-7.25)			
Macleay								
Main channel (2 sites)	NA	Moderate (3.4-4.6)	Slight recovery (4.9 – 5.8)	Within recommended levels (5.2-5.3)	Within recommended levels (5.9-6.3)			
Tributaries (4 sites)	Very low (<0.2)	Low (<1.4)	Low (<1.95)	Slightly recovered (1.5-4.3)	Regionally variable (1.3-7.5)			

Table 4. pH levels in the Richmond, Clarence and Macleay Rivers following the fish kills (number of sites analysed in each region is given in brackets. NA = not assessed).

Region	**Approximate time of reading following the main kill events in the region**							
	Time of kill	1 week after	2 weeks after	3 weeks after	1 month after	2 months after	3 months after	4 months after
Richmond								
Lower main channel (3 sites)	Close to recommended levels (6.3 – 8.1)	NA	NA	Within recommended levels (7.5-8.7)	NA	Within recommended levels (7.8-7.9)	NA	NA
Lower tributaries (8 sites)	NA	Spatially variable (4.5-7.7)	Spatially variable (4.4-7.8)	Spatially variable (5.5-8.3)	Spatially variable (5.4-7.3)	Spatially variable (4.3-7.6)	Close to recommended levels (6.0-8.1)	Spatially variable (4.2-7.5)
Upper main channel (3 sites)	NA	Within recommended levels (6.6-7.1)	Within recommended levels (6.6-7.5)	Close to recommended levels (6.3-7.2)	NA	Close to recommended levels (6.4-7.7)	NA	NA
Upper Tributaries (3 sites)	NA	Below recommended levels (4.1-6.6)	Low (3.9-6.6)	Below recommended levels (3.9-6.6)	NA	Below recommended levels (4.1-4.5)	NA	NA

Table 4. Continued

Region	**Approximate time of reading following the main kill events in the region**							
	Time of kill	1 week after	2 weeks after	3 weeks after	1 month after	2 months after	3 months after	4 months after
<u>Clarence</u>								
Main channel (7 sites)	Close to recommended levels (6.3-6.9)	Spatially variable (5.6-6.8)	Within recommended levels (7.1-7.4)	NA	Within recommended levels (7.5-8.0)	NA	NA	NA
Broadwater (1 site)	Within recommended levels (6.9)	Within recommended levels (7.0)	Within recommended levels (6.9)	NA	Within recommended levels (7.3)	NA	NA	NA
South Arm (4 sites)	Below recommended levels (5.9-6.3)	Below recommended levels (5.7-6.1)	Close to recommended levels (6.5-7.1)	NA	Within recommended levels (6.6-7.3)	NA	NA	NA
<u>Macleay</u>								
Main channel (2 sites)	NA	Close to recommended levels (6.4,6.5)	Close to recommended levels (6.5,6.7)	Within recommended levels (6.8,6.9)	Within recommended levels (6.6,6.9)	NA	NA	NA
Tributaries (4 sites)	Below recommended levels (5.9-6.2)	Below recommended levels (6.0-6.1)	Below recommended levels (6.2-6.5)	Below recommended levels (6.1-6.4)	Close to recommended levels (5.5-6.9)	NA	NA	NA

Table 5. Average (± 1 standard deviation) water quality parameters analysed from tributaries (natural and constructed) throughout the lower–mid Richmond catchment, and percentage of sites outside recommended levels (n = 15). (*Relevant levels for a "healthy" system as recommended by ANZECC (1999) are given)*.

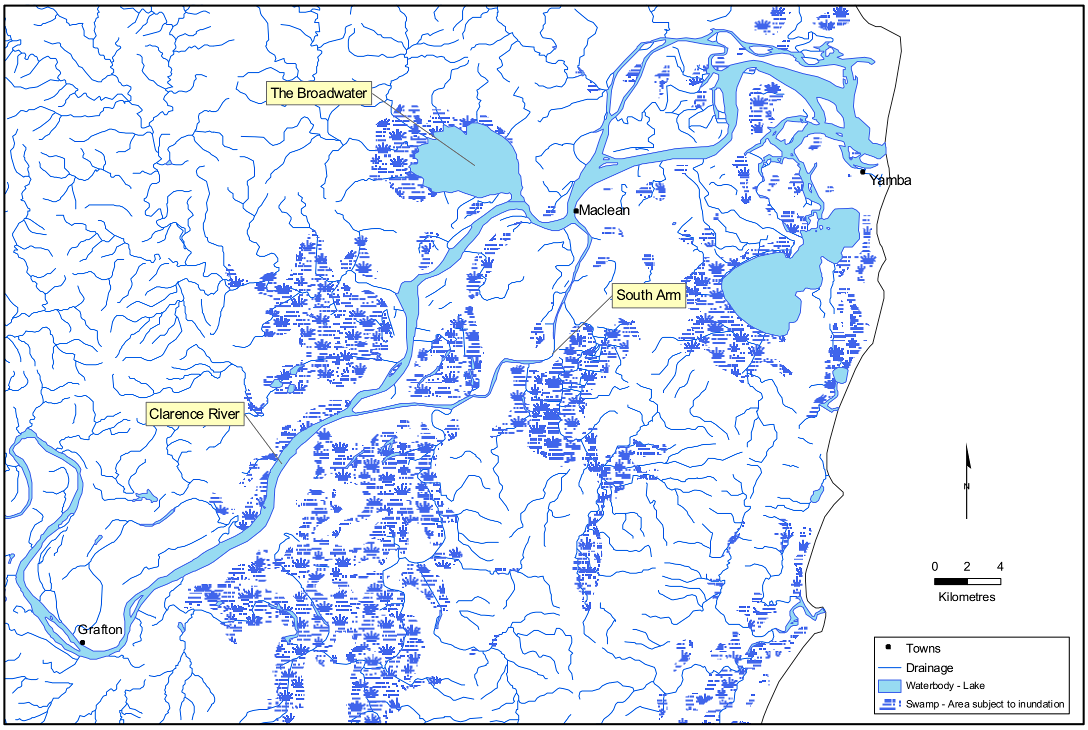
Parameter	Average (± St.dev.)	% sites outside recommended levels	Guideline Level[*1]	
			Fresh water	Salt water
Biochemical Oxygen Demand (mg/L)	7.11 ± 7.31	13	<15	<15
Total Nitrogen (mg/L)	1.501 ± 1.028	27	1.6 (lowland rivers)	0.08 (estuaries)
Ammonia (mg/L)	0.045 ± 0.040	62	0.02	0.02
pH	6.106 ± 0.94	74	6.6 – 8 (lowland rivers)	7.5 – 8.5 (estuaries)
Chemical Oxygen Demand (mg/L)	71.5 ± 35.47	74	<40	<40
Total Phosphorous (mg/L)	0.150 ± 0.137	97	0.037 (lowland rivers)	0.045 (estuaries)
Total Alluminium (mg/L)	0.497 ± 0.681	100	<0.03	<0.01
Total Iron (mg/L)	3.395 ± 4.88	100	<0.01	<0.01

[*1] Recommended levels referred to are those provided by ANZECC (1999) for either lowland rivers or estuaries, depending on which value was the least conservative.

2.3. Clarence River

Water quality in the Clarence was recorded by NSW Fisheries with a U-10 Horiba meter just after the peak of the kills every several days for almost two weeks, and again one month later (Tables 3 and 4).

Figure 3 Clarence Catchment Sample Sites



The Clarence River system DO levels displayed a high level of spatial and temporal variability, with the South Arm (see Figure 3) showing exceptionally low levels. Soon after the initial fish kills (16 March 2001), the South Arm had an average DO of 1.2 mg/L, after which DO levels dropped further to an average of 0.06 mg/L for the following 10 days while recording occurred. The main channel maintained higher DO levels averaging around 2.5 mg/L, with the exception of 19 March 2001, when average DO dropped to 0.5 mg/L.

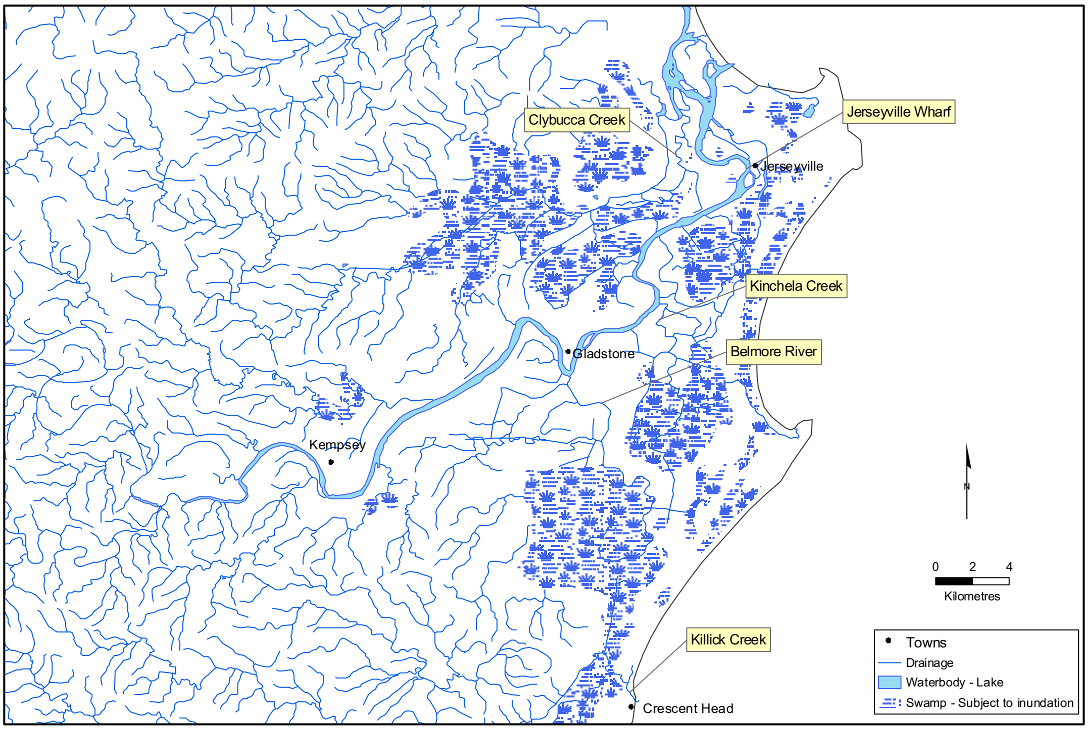
It was suspected that Lake Wooloweyah and the Broadwater given their size and position off the main channel would provide refugia for fish still within the river. Levels of DO in the Broadwater exhibited the widest fluctuation, being as high as 5.9 on 19 March, then declining rapidly to 1.4 on 21 March, and increasing to 4.7 by 26 March. Water quality testing approximately one month after initial sampling had ceased (19 April) revealed that DO had returned to acceptable levels in all regions.

The pH in the Clarence River system also varied widely, ranging between 5.7 – 7.2. In the lower main channel and the Broadwater, pH was within the ANZECC (1999) recommended levels, with the exception of 21 March where pH in the Broadwater fell to 6.2. pH in the main channel was, on average, below recommended levels from the time sampling commenced (16 March) until 21 March, after which it increased to recommended levels. In the South Arm, average pH levels were below those recommended between 16 March – 26 March, after which it increased to recommended levels. Sampling approximately one month (19 March) after initial sampling ceased revealed that average pH in each of the regions had reached recommended levels.

Being a very large river system, the Clarence contains several deep 'holes' where water quality was potentially different from surface waters, leading to the hypothesis that such holes may have been providing a refuge of better quality water for fish reducing the extent of the fish kills. However, none of the samples of DO taken at depth on 22 March were within the recommended guideline levels. In nearly all cases, DO readings of water taken from deep holes (>15m) were higher than those taken at the surface, which lends support to the hypothesis, though the difference between DO readings taken at surface (<1m), mid depth (10m) and deep holes (>15 m) was not statistically significant (ANOVA, df = 30, P = 0.51, F = 0.69, F Crit = 3.34). The greatest difference in DO levels between surface waters and waters at depth occurred at one site where DO was seven times greater at depth. pH was also higher in the deep holes although, again, the differences between readings taken at surface (<1m), mid depth (10m) and deep holes (>15 m) was not statistically significant (ANOVA, df = 31, P = 0.77, F = 0.27, F Crit = 3.33).

2.4. Macleay River

Figure 3 Macleay Catchment Sample Sites



Water quality measurements commenced several days after the fish kills were reported in the Macleay system. Water quality in the Macleay was recorded every several days by the Kempsey Shire Council via in-stream probes, commencing during the peak of the kills for a period of almost one month (Tables 3 and 4).

At the commencement of recording, DO in the tributaries was low, down to 0.18 mg/L at Kinchela Creek (see Figure 4), after which DO generally increased to peak at 6.02 mg/L on 4 April (Kinchela Ck). After this time DO became more variable between sites, ranging between 7.45 mg/L (Belmore, 9 April 2001) to 1.28 (Killick Ck, 9 April). Dissolved oxygen in the main channel was higher than in the tributaries. The lowest DO reading occurred at the start of sampling when it was

0.98 mg/L (Jerseyville Wharf, 23 March), after which DO levels increased to reach ANZECC (1999) recommended levels on 4 April and remained at this level throughout the rest of the sampling period.

The pH in recorded tributaries was below recommended levels for 97% of recordings. pH in most tributaries was lowest after the fish kill, and generally increased over time. Kinchela Creek and Clybucca generally had the lowest pH. The main channel had a much higher pH than the tributaries, with all readings except one being above recommended levels. pH in the main channel also increased over time, with Jerseyville generally having higher values than Gladstone.

2.5. General trends

In all three river systems DO was exceptionally low at the time of the fish kills, and these low levels persisted for many days. In general the upper and mid-reaches of the estuary were most affected and for the longest time period. The main channels and larger water bodies contained better water quality than smaller tributaries. pH values were mostly greater than 6 indicating that acidity was not a severe problem at the time of flooding.

Water Quality Recommendations

The above work provided some useful lessons if in the future more of these events occur. In particular

- The Richmond catchment has established a standardised protocol for both ongoing and event-based sampling of water quality. The Richmond Estuary Ecological Health Management Study (REEHMS) was established to develop a flood response strategy in collecting representative water quality samples.
- REEHMS coordinates the efforts of various local and State government agencies to avoid duplication of sampling locations and times.
- Other catchments could benefit in improved data collation from cooperation through a similar process.

3. CAUSES

Autopsies indicated the most likely cause of the fish kills in these 3 rivers was low dissolved oxygen (DO) (Dr R. Callinan, NSW Fisheries Veterinary Scientist *pers. comm*.). A diagnosis of exclusion was made in the absence of a specific test for oxygen deprivation. Fish exhibited classic symptoms of oxygen deprivation: gasping at the surface/edges of the water with gills extended, and many species were affected at a similar time. Autopsies revealed the absence of parasites, bacteria or fungal infections. This diagnosis is in accordance with water quality data gathered at the time of the fish kills which recorded DO levels well below the critical thresholds for many fish species (generally set at ~4 mg/L) and commonly below 1 mg/L in large areas of all three river systems. pH was commonly around 5-6, which is potentially lethal, but not likely to be directly responsible for the widespread and rapid fish kills observed. Thus, the inflow from the floodplains of acidic water (although implicated in previous fish kills in this area) did not appear to be a significant cause of the fish kills in these cases.

3.1. Wollongbar workshop executive summary

The following information was based on the Fish Kill Workshop held at Alstonville on 15 May 2001, to discuss the causes of the event and provide recommendations for future management. This summary of the workshop findings was provided by Dr Peter Slavich, Director, Wollongbar Agricultural Institute (Slavich, 2001).

3.1.1. Introduction

Major flooding on the Richmond in February 2001 caused extremely poor water quality and massive fish kills. Similar effects also occurred on the Clarence and Macleay Rivers. Whilst this workshop focused on the Richmond River, information from the Clarence and Macleay catchments were also presented to help gain a more complete understanding of the processes involved.

Various State agencies, councils and researchers had actively collected information on these floods. NSW Agriculture convened a workshop at Alstonville on 15 May to review the collected information, identify the contributing factors and evaluate the implications for land and water management. The meeting was attended by 40 invited participants selected for their local and industry knowledge, technical expertise and roles in land and water management.

Presentations were made on the climatic conditions, the movement of floodwaters, water quality data and fishery impact. The flood impacts were compared to those of previous floods and estuary recovery processes were outlined. The review enabled a time-line of the main processes to be constructed and presentation of sufficient information to enable a reasoned identification of the dominant causative processes.

3.1.2. Time line of rainfall, flood, fish kill and black water

1 February

Major rainfall (200-400mm) occurred over the upper catchment, particularly in the northern and western areas. Less rain fell on the coast and the southern Bungawalbyn sub-catchment. The intense upper catchment rainfall mobilised large amounts of sediment from the upper catchment and stripped the banks of vegetation.

2 February

Further rain (<100 mm), Lismore flooded.

3 – 4 February

River flows peaked in lower Richmond. Clear, sunny weather.

5 February

Smell (methane / sulfidic) from floodplain pervaded Alstonville Plateau.

6 February

Major floodgated systems begin to discharge into the lower Richmond River. Drainage waters 22 – 24 deg C.

7 – 9 February

Major fish kill evident in lower Richmond River. Water entering the river had very low dissolved oxygen.

10 February – March

'Black water' drainage discharge and rotting fish fouls Richmond River. Drainage waters become more acid with time.

3.1.3. Impacts of the flood on the lower Richmond River

The February flood resulted in at least two major impacts on the lower Richmond River:

1. Major death of aquatic organisms in lower reaches of the Richmond River. This had direct effects on commercial and recreational fishing.
2. An extensive period of extremely poor water quality in the river. This had direct impacts on river amenity and tourism.

The workshop agreed that very low dissolved oxygen was the primary cause of the extensive fish kill.

3.1.4. Contributing factors to loss of dissolved oxygen and development of 'black water'

The heavy sediment loads in the river have the potential to remove approximately half the dissolved oxygen through oxidation of reduced compounds in soil sediments and organic detritus. These effects have also been identified in previous floods. The flood immediately placed the river in a sensitive condition in relation to its oxygen balance as the turbid waters also reduce the potential for photosynthesising bacteria to oxygenate the water.

The falling river level in the lower reaches of the river coincided with rising water levels behind floodgated drainage systems on the 6 February and caused the major floodgated drainage systems (Tuckean Swamp, Rocky Mouth Creek, Bungawalbyn) to begin discharging to the river at about the same time. Evidence was presented to show that this water started to deoxygenate once discharge flows commenced and became completely deoxygenated within 1 – 3 days, depending on site conditions. This initial period of deoxygenation coincided with the reports of major fish kills.

Evidence was presented to show that large quantities of mono-sulphide rich black ooze, which is a gel-like sludge common in drains leading from acid sulphate soil areas, was mobilised as the drains began to discharge. Data was also received to show that drainage water quality deteriorated greatly in the weeks after the fish kill. This water remained devoid of oxygen, increased in dissolved organic carbon and iron content, the black water became more anaerobic, and its capacity to deplete oxygen from river water increased. Observations were presented which indicated this water could cause skin and eye irritation on contact. The dominant process determining the composition of this water would have been microbial breakdown of vegetation killed by floodwaters combined with the mobilisation of iron mono-sulfides, which consumes dissolved oxygen very efficiently through a catalytic feed-back process. This would have maintained low levels of dissolved oxygen for many weeks.

Data were presented that demonstrated that the majority of the flux of oxygen-depleting contaminants discharged after drain water levels reached about mean local high water. Under natural, undrained conditions very little drainage of backswamps would have occurred beyond this level. Thus the majority of oxygen-depleting contaminants entering the river from the lower floodplain backswamps was due to induced drainage. The oxygen depletion capacity of this drainage water exceeded the assimilative capacity of the estuary.

3.1.5. Implications for land and water management

The extent to which the water quality impacts of major floods can be controlled by changes to land and water management remains uncertain. However, the analysis of this flood has revealed significant new processes and understanding that will assist in the management of drainage water quality resulting from at least normal or average rainfall events.

Whilst the fish kill and black water were associated with very low dissolved oxygen, it was clear that the causes of low dissolved oxygen were associated with drainage from acid sulphate soils (ASS) as well as vegetation decomposition. The drains which exported the largest amounts of black water and Mono-sulfidic Black Ooze (MBO) are also known to export significant amounts of acid. The drainage waters become highly anaerobic due to oxidation / reduction interactions between soluble iron and organic matter decomposition products.

It seems that drainage of floodplain ASS backswamps has changed the natural organic matter cycling processes occurring on the floodplain. Drainage both enables inundation-intolerant vegetation to establish in backswamps and, most importantly, enables rapid transport of highly anaerobic backswamp water to the estuary. Without drainage, this water would have completed decomposition processes within the backswamp.

Whilst sediment loads from the upper catchment contributed to the deoxygenation, these effects were much less severe than the deoxygenation that arises from either MBO's or iron and organic matter interactions on the floodplain. That is, it is likely that the fish kill and subsequent discharges of black water would have occurred even if the upper catchment water was not turbid.

The workshop suggests that the most strategic remediation approach to improving drainage water quality would be to slow the rate at which mobilised iron and dissolved organic carbon enter the drainage system from the floodplain. Drainage of acid sulphate soils has enabled oxidation of pyrite to release acid and soluble forms of iron. Soluble iron enters the drainage system mainly from groundwater seepage and from surface water flow. Rainfall run off becomes acidified partly by acid produced by the hydrolysis of soluble forms of iron within the drainage system. The oxidation of reduced soluble iron and of mobilised mono-sulfidic black ooze can initially deoxygenate and also later acidify drainage water.

Recommendations

Management practices, which will improve the quality of water entering creek and estuary system, in order of strategic importance, are:

1. Retaining rainfall run-off and encouraging inundation-tolerant vegetation on very low, highly acidic, low-value grazing land. This is likely to favour the transformation of surface oxidised iron to less soluble iron sulphides and enable a buildup of a thick organic surface mat. These mats reduce transport of acidic products to the soil surface by reducing groundwater evaporation. This will not completely prevent iron export but is likely to reduce greatly the amount, rate and frequency of export.
2. Shallowing and reducing the density of drainage systems so they intercept less iron and aluminium rich groundwater and do not store water during dry periods.
3. Managed opening of floodgates. This is likely to reduce the extent of accumulation of mono-sulfidic black ooze behind the gates.
4. Drain bank management by regular liming and not disturbing the limed zone. This is likely to cause soluble iron in groundwater to precipitate in the drain bank rather than enter the drainage water.

Dissolved organic carbon increases as a result of the decomposition of algae, aquatic vegetation and flooding of inundation-intolerant vegetation. Floodgate opening will reduce algal blooms in drainage systems and reduce the build up of many aquatic weeds. Replacement of inundation-intolerant pastures with water-tolerant species in low acidic backswamps, will also reduce the export of dissolved organic carbon.

There is a further water quality strategy that could be used for flood drainage to prevent anaerobic water and decomposition processes overloading the estuary. This strategy would be to retain major and / or minor flood waters in low lying ASS backswamps to approximately local mean high water level (about 0.5 m on 0 m AHD backswamps) for several weeks until the biological decomposition processes were largely completed, then allow slow release of residual waters and dissipation by evaporation. Whilst this strategy is likely to give very effective water quality outcomes, its feasibility at a particular site needs to be carefully assessed.

4. NSW FISHERIES SCIENTIFIC SURVEY SUMMARIES

Complete reports on the scientific surveys (using a combination of fishery – independent & departmental, observer and creel surveys) of recovering fish stocks in the Richmond and Macleay Rivers are available in Kennelly and McVea (2002). Key findings from this report are outlined below.

4.1. Research team monitoring

Following the initial closure in the Richmond River, NSW Fisheries coordinated a survey of the area with a rapid-response research team seconded from Sydney.

Issues faced by the research team were:

- An unprecedented fish kill had wiped out most fish, of most size classes, from the estuary.
- There was no data indicating 'natural' fish stocks prior to the kill.
- A sampling methodology needed to be designed very quickly, with whatever resources were close to hand.

The basic methodology used in this survey was to assess the state of the fisheries resources in the lower Richmond and Macleay river systems by using commercial fishing gear normally employed in the river at this time of year. To this end, an experienced local commercial fishing crew was chartered to undertake prawn hauling, fish meshing, fish hauling and crab trapping at sites normally fished by these methods. Scientific seining using a small mesh haul net was also done. All catches were identified, counted, measured and weighed by NSW Fisheries staff working with the commercial fishermen.

The team used a commercial fishing vessel to sample popular commercial fishing areas for a two-week period. This survey also included twice-daily water quality monitoring and detailed discussions with recreational and commercial fishers, who indicated the river system would take some time to recover.

Extensive recreational creel surveys were also undertaken in both the Richmond and Macleay Rivers after the rivers were re-opened to recreational fishing, to determine the level of recreational take in these systems. Key results are detailed below.

4.2. Prawn trawl survey

As a component of the overall surveys done by NSW Fisheries to examine the recovery of the river after such a large kill, investigations into the abundances of recreational and commercial species in the offshore fishing closure outside the mouth of the estuary were done using an ocean prawn trawler during the months of April, June and July (Miller, 2002).

Survey sites were chosen throughout the entire closure area, with the results indicating high by-catch to school prawn ratios. The main recreational and commercial species observed in high numbers were juvenile mulloway with lesser numbers of juvenile and small adults of tarwhine, silver biddy and large-toothed flounder.

Overall, there were limited proportions of estuarine fish species captured at these sites during each of the months surveyed, but the closure did seem to be beneficial in protecting juvenile mulloway after the flood and for the spawning of school prawns before they migrated away from the system and became susceptible to capture outside the closure.

It appeared that the oceanic closure subsequent to the fish kill may have had benefits to future stocks of mulloway and school prawns in the region (Miller, 2002).

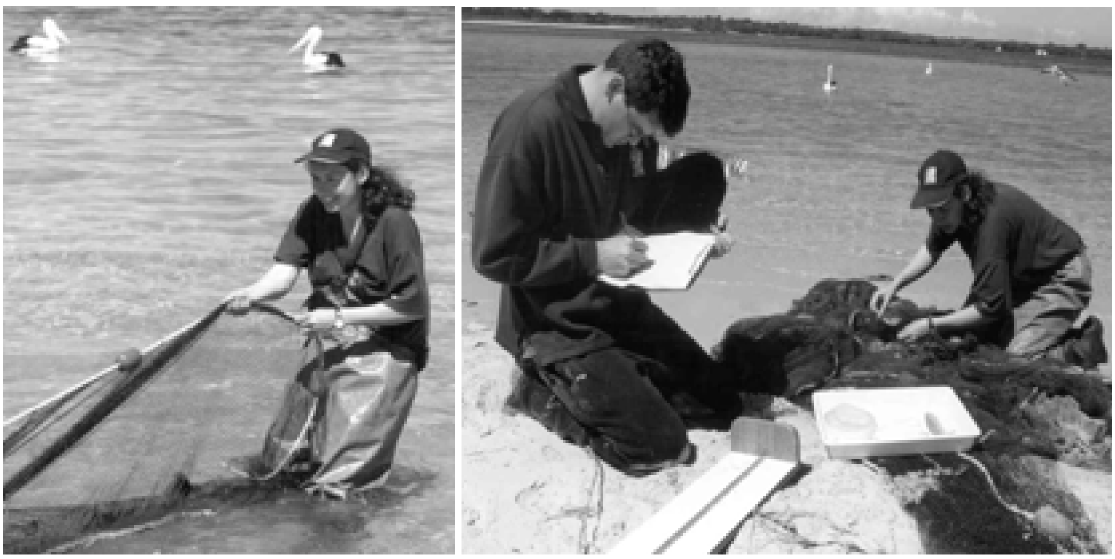
4.3. Richmond Scientific Survey

The executive summary from the scientific report of this survey (Macbeth *et al.* 2002a) is reproduced in full below.

In summary, there were three main objectives of the sampling surveys of the fish and crustacean populations in the river done as part of the post-fish kill monitoring program:

1. to provide the necessary biological and water quality information required to make fisheries management decisions as to if, when and how the fishing closures in the river should be lifted;
2. to monitor for any possible deleterious effects relating to the resumption of fishing activities once these closures were lifted; and
3. to contribute useful information regarding the "normal" state of stocks in the river for the purpose of comparisons with data collected during the initial surveys conducted immediately after the fish kill.

A regular, structured sampling regime was designed and implemented with the help of local commercial fishers and interest groups in order to monitor the recovery of the fish and crustacean populations in the river immediately following the fish kill. These four-weekly sampling surveys incorporated the use of three commercial fishing methods to regularly sample the biota in the river – prawn hauling, mesh netting and crab trapping. Regular scientific seining involving the use of small-mesh seine nets was also done, as was the collection of water quality information.



Richmond River scientific survey, 2001

The question of whether the stocks of fish and crustaceans had recovered to pre-fish kill levels cannot be answered directly because we did not have detailed information describing the precise status of these fish and crustacean stocks in the Richmond River immediately before the fish-kill event. We also did not have comparable detailed information about fish and crustacean communities in other non-impacted estuaries in the region that could be used as controls or reference sites. Therefore, we were primarily restricted to making inferences about the recovery of the fish and crustacean populations by interpreting spatial and temporal trends in the distribution and abundance of fish and crustaceans that are apparent in the data collected as part of this monitoring program.

In general, by the time the fishing restrictions were lifted, the populations of fish and crustaceans in the Richmond River had recovered to levels that could sustain normal commercial and recreational fishing practices, comparable to the levels during the months immediately prior to the fish kill. Some species appeared to recover relatively quickly in the main river channel to levels that have been more or less maintained since (e.g. school prawn, mud crab, sea mullet, yellowfin bream and juvenile mulloway), while some other species took much longer to recover (e.g. sand whiting and silver biddy). In contrast, some species recovered in the lower part of the estuary (i.e. downstream of Burns Point Ferry) quite quickly, but were quite slow to recolonise the main river channel (e.g. luderick).

4.4. Macleay Scientific Survey

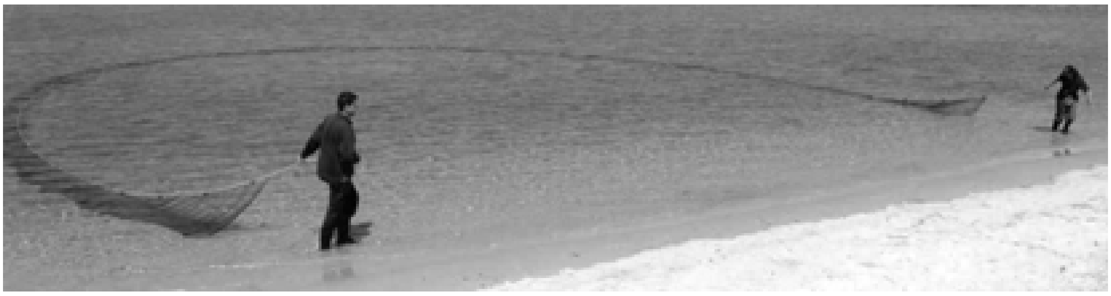
The executive summary from the scientific report of this survey (Macbeth *et al.* 2002b) is reproduced in full below.

In summary, there were three main objectives of the sampling surveys of the fish and crustacean populations in the river done as part of the post-fish kill monitoring program:

1. to provide the necessary biological and water quality information required to make fisheries management decisions as to if, when and how the fishing closures in the river should be lifted;
2. to monitor for any possible deleterious effects relating to the resumption of fishing activities once these closures were lifted; and
3. to contribute useful information regarding the "normal" state of stocks in the river for the purpose of comparisons with data collected during the initial surveys conducted immediately after the fish kill.

A regular, structured sampling regime was designed and implemented with the help of local commercial fishers and other stakeholder groups in order to monitor the recovery of the fish and crustacean populations in the river immediately following the fish kill. These four-weekly sampling surveys incorporated the use of three commercial fishing methods to regularly sample the biota in the river – mesh netting, crab trapping and eel trapping. Regular scientific seining involving the use of small-mesh seine nets was also done, as was the collection of water quality information.

The question of whether the stocks of fish and crustaceans had recovered to pre-fish kill levels could not be answered directly because we did not have detailed information describing the precise status of these fish and crustacean stocks in the Macleay River immediately before the fish-kill event. We also don't have comparable detailed information about fish and crustacean communities in other non-impacted estuaries in the region that could be used as controls or reference sites. Therefore, we were thus primarily restricted to making inferences about the recovery of the fish and crustacean populations by interpreting spatial and temporal trends in the distribution and abundance of fish and crustaceans that were apparent in the data collected as part of this monitoring program.



Scientific survey, 2001

In general, by the time the fishing restrictions were lifted, the populations of fish and crustaceans in the Macleay River had recovered to levels that could sustain normal commercial and recreational fishing practices, comparable to the levels during the months immediately prior to the fish kill. Some species appeared to recover relatively quickly in the main river channel to levels that have been more or less maintained since (e.g. mud crab, sea mullet, yellowfin bream, long-finned eel and pinkeye mullet), while some other species took longer to recover (e.g. luderick and sand whiting).

Further work should be undertaken to develop a standard sampling design protocol for use in similar monitoring programs that will probably be necessary in the future. This would require detailed review of the techniques used and analyses of the data collected during this present monitoring program. The development of robust and reliable sampling regimes would result in more accurate overall assessments of the status of populations of fish and crustaceans in any given river or estuary.

Fish monitoring recommendations

A debriefing session of staff involved in the Fish Kill Assessment was held in Cronulla on the 18th September 2001. It was recommended that, in an ideal situation it would be preferable to:

- Conduct research surveys in all NSW rivers for many years, perhaps alternating between areas over time,
- Make this type of regular sampling part of NSW Fisheries ‘core’ business,
- Establish suitable sampling methods for particular species that would allow for training of an ‘event-based ready response team’.
- Research is required to review the current situation concerning the relationship between degraded fish habitats and contribution of these areas to low dissolved oxygen levels following floods.
- Research is needed to facilitate the production of maps showing the location of key sites contributing high volumes of low dissolved oxygen following floods.

4.5. Richmond Recreational Fishing Survey

As stated in Steffe & Macbeth (2002a), "Recreational fishing surveys of sound statistical design are essential for the collection of statistically unbiased information. We used stratified random sampling procedures as the basis of the survey design and integrated many data quality checks into the survey. Complemented survey methods were used to estimate the fishing effort; harvest and discard rates; and total harvest and discard for both the boat-based and shore-based fisheries in the Richmond River over a four-month survey period (July to October 2001 inclusive). The successful planning, organisation and execution of a large on-site survey of recreational fishing is a demanding and costly task. A community-based approach to the survey work, relying heavily on the support and involvement of local interest groups during all phases of the survey, proved highly successful.

Recreational Creel Survey, Richmond River, 2001.

We found that the recreational fishing population of the lower Richmond River was dominated by males - over 83% of both the boat-based fishers and shore-based fishers interviewed were male. We also found that the great majority of fishers interviewed were of local origin, ranging from 75% from the local area in the shore-based fishery to approximately 83% in the boat-based fishery.

We estimated that approximately 70,100 fisher hours of daytime recreational effort was expended in the lower Richmond River during the survey period - July to October 2001. The level of daytime recreational fishing effort showed a distinct monthly pattern with the highest level of effort in July, an intermediate level of effort in August and the lowest levels of effort in September and October. This monthly pattern of effort was similar to that recorded in a previous survey of a much larger area in the Richmond River, suggesting that these effort data are showing a seasonal trend.

We estimated that the daytime recreational harvest from the Richmond River fishery during the survey period consisted of approximately 29,800 fish, crabs and cephalopods from 26 taxa. The bulk of this harvest was made up of luderick (13,680 fish - 7.3 tonnes), yellowfin bream (7,700 - 3.8 tonnes), dusky flathead (3,430 - 2.2 tonnes), sand mullet (1,630 - 0.1 tonnes), tailor (1,270 - 0.4 tonnes), and sand whiting (1,260 - 0.3 tonnes). These six taxa, by number, accounted for 97.3% of the daytime recreational harvest during the survey period. Comparisons made between these data and those collected during a previous survey in the Richmond River (1988 – 1989) indicate that there have not been any major changes in the structure of the recreational fishery since that time. Recreational anglers are still targeting and harvesting much the same species in the river and the monthly patterns of targeting and harvesting that we have documented are consistent with normal seasonal changes in this fishery. The size of the recreational harvest taken during the four-month survey period can be put in context by comparing the size of the estimated recreational harvest to the estimates of total fish mortality associated with the fish-kill of February 2001. NSW Fisheries estimated that around 300,000 yellowfin bream, 150,000 dusky flathead, 10,000 sand whiting and 5,000 luderick were killed in a 20 kilometre stretch of the lower Richmond River during the fish-kill event.

We estimated that recreational fishers (boat-based and shore-based) discarded approximately 50,900 fish, crabs and cephalopods (± 2,680 individuals - approximate SE) from 46 taxa whilst fishing in the lower Richmond River during the survey period. The six most commonly discarded taxa, by number, during the survey period were yellowfin bream (30,060), dusky flathead (5,950), luderick (5,560), tailor (3,940), sand whiting (2,520) and southern herring (600). These six taxa, by number, accounted for 95.4% of the total daytime recreational discard. Recreational fishers indicated that the great majority (>90%) of discarded yellowfin bream, dusky flathead, luderick, tailor and sand whiting were below the legal minimum length. Although these discard data should be viewed with some caution because they are self-reported and less accurate than harvest data (which are collected by direct observation), they show that recreational fishers were catching and returning to the water large numbers of juvenile fish.

The four indicators of recreational fishing quality considered in this study were the proportion of unsuccessful fishing parties, non-directed harvest rates for the boat-based and shore-based fisheries, non-directed discard rates for the boat-based and shore-based fisheries and size-frequency distributions for some important taxa harvested by the recreational sector. The proportion of unsuccessful boat-based fishing parties ranged from approximately 31% to 59% on a monthly basis whilst the proportion of unsuccessful shore-based fishing parties was relatively higher ranging from approximately 61% to 80% on a monthly basis. In both fisheries the lowest proportion of unsuccessful fishing trips was recorded during July, immediately after the river was re-opened to recreational fishing, and progressively higher proportions of unsuccessful fishing parties were recorded in the following months. These data suggest that the quality of recreational fishing was best in July after the river had been re-opened to recreational fishing and that there had been a gradual decline in fishing quality in the following months. The reason for these trends in the boat and shore fisheries was probably a combination of seasonal fish abundances and the large amount of fishing effort that occurred immediately after the fishery was re-opened.

The harvest rates and discard rates we calculated and presented are based on the total non-directed fishing effort. The harvest rates observed during this four month survey are similar to comparable harvest rate data collected in other estuarine fisheries in NSW. These similarities suggest that the quality of recreational fishing was quite good for boat-based and shore-based fishers during the survey period in the lower Richmond River. A similar conclusion is reached when examining discard rate data. High rates of discard were reported for the main species of recreational interest during the survey period indicating that juvenile fish were abundant in the lower Richmond River during the survey period.

The size-frequency distributions presented are important baseline indicators that can be used to monitor future changes (if any) in the size structure of these species in the fishery. Overall, the proportions of undersized fish retained by recreational fishers in the lower Richmond River fishery (boat and shore-based) were comparable to rates measured in some other estuarine fisheries in NSW, suggesting a comparable availability of legal-sized fish in the population in the Richmond River. In addition, large individuals that were highly-prized by fishers were common in the recreational harvests, indicating that the quality of recreational fishing opportunities in this fishery were quite good.

In summary, the question of whether the recreational fishery (shore and boat-based) in the Richmond River has recovered from the impact of the February fish-kill event cannot be answered directly because we do not have any detailed information describing the status of riverine fish stocks or the recreational boat and shore fisheries in the Richmond River immediately before the fish-kill event nor do we have information about other non-impacted estuarine recreational fisheries in the region that could be used as controls or reference sites. Therefore, we are restricted to making inferences about the recovery of estuarine fish stocks and the status of the recreational fisheries from limited comparisons with previous studies and by examining a number of indicators of recreational fishing quality that have been derived from the current survey. The interpretation of the available evidence strongly suggests that the recreational fisheries in the lower Richmond River are still productive and providing quality recreational fishing opportunities despite the adverse impacts of the February 2001 fish-kill event."

4.6. Macleay Recreational Fishing Survey

Steffe & Macbeth (2002b) summarise that "Recreational fishing surveys of sound statistical design are essential for the collection of statistically unbiased information. We used stratified random sampling procedures as the basis of the survey design and integrated many data quality checks into the survey. Complemented survey methods were used to estimate the fishing effort; harvest and discard rates; and total harvest and discard for both the boat-based and shore-based fisheries in the Macleay River over a four-month survey period (July to October 2001 inclusive). The successful planning, organisation and execution of a large on-site survey of recreational fishing is a demanding and costly task. A community-based approach to the survey work, relying heavily on the support and involvement of local interest groups during all phases of the survey, proved highly successful.

We found that the recreational fishing population of the lower Macleay River was dominated by males - 82% of the boat-based fishers and 79% of the shore-based fishers interviewed were male. We also found that approximately 48% of the fishers interviewed were of local origin, ranging from approximately 43% from the local area in the boat-based fishery to approximately 51% in the shore-based fishery.

We estimated that approximately 78,800 fisher hours of daytime recreational effort was expended in the lower Macleay River during the survey period - July to October 2001 inclusive. The level of daytime recreational fishing effort showed a distinct monthly pattern with the highest levels of effort recorded during July and August, and the lowest levels of effort recorded during September and October. This monthly pattern of effort was similar to that recorded in the Richmond River, suggesting that these effort data are showing a seasonal trend.

We estimated that the daytime recreational harvest from the Macleay River fishery during the survey period consisted of approximately 45,300 fish and crabs from 16 taxa. The bulk of this harvest was made up of luderick (29,110 fish - 16.5 tonnes), yellowfin bream (9,250 - 4.7 tonnes), dusky flathead (3,760 - 1.9 tonnes), striped seapike (1,220 - 0.1 tonnes), tailor (670 - 0.3 tonnes), and sand mullet (600 - 0.1 tonnes). These six taxa, by number, accounted for 98.5% of the daytime recreational harvest during the survey period. A limited comparison made between these data and a summary of information collected during a five month recreational fishing survey in 1990 in the lower Macleay River indicated that there have not been any major changes in the structure of the recreational fishery since that time. Recreational anglers are still targeting and harvesting much the same species in the river. Further comparisons made between this study, a concurrent survey in the lower Richmond River and data collected during 1988-1989 from the Richmond River suggest strongly that the monthly patterns of targeting and harvesting that we have documented are consistent with normal seasonal changes in this fishery.

The size of the recreational harvest taken during the four-month survey period can be put in context by considering the relative sizes of the estimated recreational harvest with respect to the relative magnitude of the fish mortality caused by the fish-kill event of March 2001.

NSW Fisheries have estimated the number of dead fish in a 1.5 km stretch of the lower Macleay River, near the town of South West Rocks, at approximately 180,000 individual fish of various species. In comparison, the number of fish and crabs harvested by recreational fishers during the survey period were estimated as approximately 45,300 individuals that is approximately one quarter of the size of the estimated mortality for a 1.5 km stretch of the lower Macleay River during the mid-March fish-kill event.

We estimated that daytime recreational fishers (boat-based and shore-based) discarded approximately 34,310 fish and crabs from 26 taxa whilst fishing in the lower Macleay River during the survey period. The six most commonly discarded taxa, by number, during the survey period were yellowfin bream (22,260 - 64.8%), luderick (5,200 - 15.2%), dusky flathead (3,590 - 10.5%), sand whiting (1,250 – 3.6%), tailor (1,040 – 3.0%), and silver batfish (470 - 1.4%) - (Table 23). These six taxa, by number, accounted for 98.5% of the total daytime recreational discard. Recreational fishers indicated that the great majority of discarded yellowfin bream (94.7%), sand whiting (97.6%), luderick (82.9%), dusky flathead (76.7%) and tailor (75.0%) were below the legal minimum length. Although these discard data should be viewed with some caution because they are self-reported and less accurate than harvest data (which are collected by direct observation), they show that recreational fishers were catching and returning to the water large numbers of juvenile fish.

The four indicators of recreational fishing quality considered in this study were the proportion of unsuccessful fishing parties, non-directed harvest rates for the boat-based and shore-based fisheries, non-directed discard rates for the boat-based and shore-based fisheries and size-frequency distributions for some important taxa harvested by the recreational sector. The proportion of unsuccessful boat-based fishing parties ranged from approximately 22% to 51% on a monthly basis whilst the proportion of unsuccessful shore-based fishing parties was relatively higher ranging from approximately 54% to 74% on a monthly basis. In both fisheries the lowest proportion of unsuccessful fishing trips was recorded during July, immediately after the river was re-opened to recreational fishing, and higher proportions of unsuccessful fishing parties were recorded in the following months. These data suggest that the quality of recreational fishing was best in July after the river had been re-opened to recreational fishing and that there had been a gradual decline in fishing quality in the following months. The reason for these trends in the boat and shore fisheries was probably a combination of seasonal fish abundances and the large amount of fishing effort that occurred immediately after the fishery was re-opened.

The harvest rates and discard rates we calculated and presented are based on the total non-directed fishing effort. The harvest rates of the main angling species measured during this four month survey were similar, and in some cases higher, than comparable harvest rate data collected in other estuarine fisheries in NSW. These findings suggest that the quality of recreational fishing was quite good for boat-based and shore-based fishers during the survey period in the lower Macleay River. A similar conclusion is reached when examining discard rate data. High rates of discard were reported for the main species of recreational interest during the survey period indicating that juvenile fish were abundant in the lower Macleay River during the survey period.

The size-frequency distributions presented are important baseline indicators that can be used to monitor future changes (if any) in the size structure of these species in the fishery. Overall, the proportions of undersized fish retained by recreational fishers in the lower Macleay River fishery (boat and shore-based) were comparable to rates measured in some other estuarine fisheries in

NSW, suggesting a comparable availability of legal-sized fish in the population in the Macleay River. In addition, large individuals that were highly prized by fishers were common in the recreational harvests, indicating that the quality of recreational fishing opportunities in this fishery were quite good.

In summary, the question of whether the recreational fishery (shore and boat-based) in the Macleay River has recovered from the impact of the March fish-kill event cannot be answered directly because we do not have any detailed information describing the status of riverine fish stocks or the recreational boat and shore fisheries in the Macleay River immediately before the fish-kill event nor do we have information about other non-impacted estuarine recreational fisheries in the region that could be used as controls or reference sites. Therefore, we are restricted to making inferences about the recovery of estuarine fish stocks and the status of the recreational fisheries from limited comparisons with previous studies and by examining a number of indicators of recreational fishing quality that have been derived from the current survey. The interpretation of the available evidence strongly suggests that the recreational fisheries in the lower Macleay River are still productive and providing quality recreational fishing opportunities despite the adverse impacts of the March 2001 fish-kill event."

Recreational Creel Survey, 2001.

Recommendations

Detailed information is required that indicates levels of estuarine fish stocks and the status of estuarine fisheries, before fish kill events.

1. Recreational fishing surveys of sound statistical design are essential for the collection of statistically unbiased information,
2. A community based survey aids in minimising costs and maximises opportunities for the community to become actively involved in the recovery process.

4.7. Other Wildlife

During the period of fish kills and subsequent river recovery, most of the larger bird species, like pelicans, naturally migrated inland for breeding purposes and so were believed to have been unaffected by the lack of fish (Lance Ferris, pers. comm.) The pelicans returned in late May 2001. Lance Ferris of Australian Seabird Rescue states “not one bird was reported or located injured by fishing tackle during the five months of the closure of the river to fishing”. In contrast, “within seven days of the opening of the river to fishing, seven birds became entangled in fishing tackle”. Lance further attributed this to the concentration of fishers operating in the lower section of the estuary where many of the birds were actively feeding.

5. COMMUNICATIONS

5.1. External – Media releases / articles

The NSW Fisheries Media Unit have copies of all available media releases and articles on the Northern Rivers fish kills.

5.2. River closures / Compliance Strategy

(NB. See Appendix 1 for detailed river closure time-line).

Closures:

On 9 February 2001, the Richmond River estuary was temporarily closed to all fishing for 3 weeks, and later extended a further 3 months ending on 30 May 2001, pending a positive review of fish and water quality recovery. This closure extended from the river mouth, upstream for 30 kilometres to Coraki and also applied to commercial trawling and haul net fishing in ocean waters adjacent to the river.

On 20 March 2001, the Macleay River was also closed to all fishing for three months. The closure applied to the whole of the tidal waters of Macleay River and tributaries and soon after included adjacent ocean waters to a depth of 10 fathoms in a line extending from 'Cheerio' wreck on Stewart's Beach south to Laggers Creek.

There were no closures placed on the Clarence River as it did not experience the massive fish kills of the other systems and as such its recovery was expected to be relatively rapid.

On 27 April 2001, special permits were issued (under Section 37 of the *Fisheries Management Act 1994*) to commercial fishers authorising the operation of a hauling crew in specified waters of the rivers. These allowed for the fishing of travelling sea mullet schools that entered the rivers and were issued to crews who did not have alternative endorsements to fish outside the rivers.

The river closures were renewed upon expiry on a month to month basis, with renewal dependent on a review of the water and fish sampling results by the respective River Recovery Committees. On 1 July 2001 both the Richmond and Macleay Rivers were reopened to limited recreational and commercial fishing for a period of 3 months.

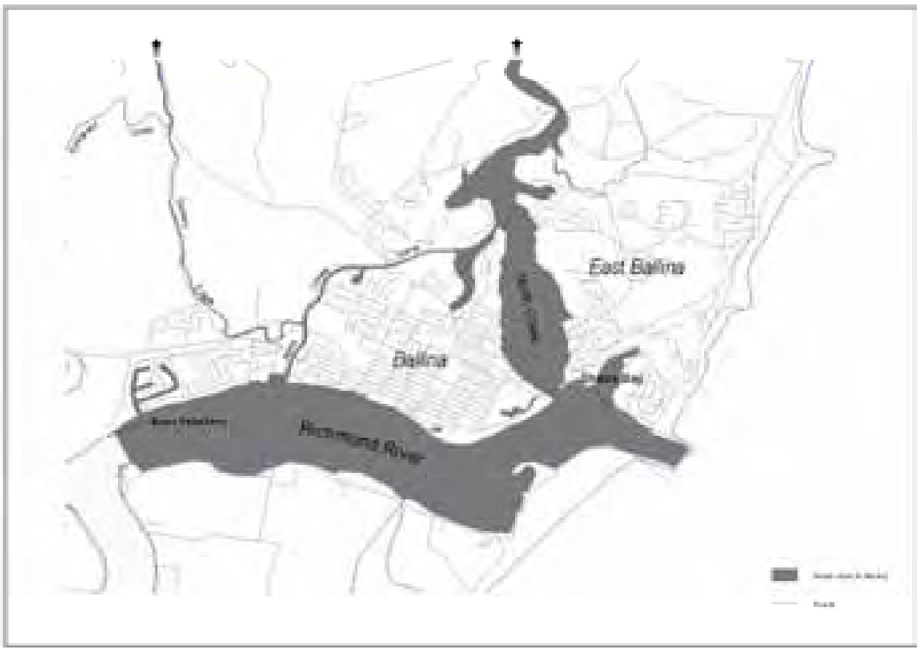
In the estuaries, recreational line fishing and crab and eel trapping was permitted with limited fishing hours, bag limits and fishing areas. Ocean beaches were opened to commercial hauling and recreational line fishing for travelling species only (mullet, pilchards).

Commercial fishing of mullet continued under the permit system and in the Macleay River, commercial fishers were also authorised to operate crab traps and 95 mm mesh netting (splash only) in the lower reaches of the river. Crab trapping was also authorised in the Richmond River.

River closures ended in both systems at 6 pm on Friday, 28 September with the resumption of normal recreational and commercial fishing activities.

Notification Example

Following the partial reopening of the Richmond River to limited commercial (crabs) and recreational fishing, this notice (overleaf) was erected at boat ramps and distributed to bait and tackle shops and other tourism outlets:



NOTICE

THE RICHMOND RIVER IS OPEN TO LIMITED FISHING ONLY, FROM SUNDAY 1ST JULY 2001 TO 30TH SEPTEMBER 2001

RE-OPENING OF THE RIVER IS SUBJECT TO THE FOLLOWING:

- FISHING HOURS ARE FROM **6 AM UNTIL 7 PM** DAILY
- WATERS **DOWNSTREAM** OF BURNS POINT FERRY (AS SHOWN ABOVE) ARE OPEN TO RECREATIONAL LINE FISHING AND BAIT GATHERING. FIVE HOOP NETS ARE PERMITTED.
- BAG LIMITS ARE RESTRICTED TO **TEN FISH**, WITH NO MORE THAN FIVE BREAM AND ONE MULLOWAY; NOT TO EXCEED EXISTING BAG LIMITS FOR ANY SPECIES.
  A LIVE BAIT BAG LIMIT OF 20 PODDY MULLET, LESS THAN 15 CM, IS PERMITTED.
- RECREATIONAL AND COMMERCIAL CRAB TRAPPING IS ALLOWED **UPSTREAM** OF BURNS POINT FERRY USING PRESCRIBED METHODS. ALL OTHER FISHING METHODS ARE PROHIBITED.
- **TRAPS** OF ALL DESCRIPTIONS ARE PROHIBITED DOWNSTREAM OF BURNS POINT FERRY EXCEPT FOR THE PRESCRIBED RECREATIONAL BAIT TRAP AND YABBY PUMPS

By Order,

NSW FISHERIES

5.3. Recovery Committees

Recovery Committees for the Richmond River and Macleay River were formed to provide advice to the Minister for Fisheries regarding possible actions to be taken in regard to the fish kills. Membership of these groups consisted of recreational and commercial fishers along with other stakeholders including some or all of the following:

- Chair – NSW Fisheries
- Charter boat operators
- Bait and Tackle businesses
- Sport fishing clubs
- Marine and Coastal Conservation groups
- Tourism operators
- Indigenous representatives
- Ocean beach haulers
- Chamber of Commerce
- Local Government
- Fishermen's Co-operatives

The surveys described in Section 4 were conducted in the rivers to monitor water quality and the recovery of fish stocks. The results of these surveys were collated over time and progress reports were tabled at Recovery Committee meetings, which met approximately once a month during the closure period.

5.4. Public Submissions

A proposal to re-open parts of the Richmond and Macleay rivers to limited recreational and commercial fishing was developed and released for two week's public comment on 1st June 2001.

Richmond River Proposed Re-opening

1. That the closure be lifted for crab trapping.

2. That the closure be lifted for recreational fishing between the river mouth and Burns Point Ferry, **in daylight hours only and at half bag limits.** That the catch and effort of recreational fishers be monitored. The reason for daylight hours only is to restrict total effort, allow compliance monitoring of half bag limits and allow creel surveys to be undertaken.

3. That the closure be lifted in adjacent ocean beaches for commercial hauling of mullet and pilchard species only.

4. All other current closures/restrictions to remain in place at this time.

Macleay River Proposed Re-opening

1. That the closure of adjacent ocean waters be lifted to all methods of fishing with the exception of prawn trawling.

2. That the closure be lifted from the township of Kinchela to the River entrance, for all methods of recreational fishing and for the commercial fishing methods of meshing (splash net only) using no less than 95mm (33/4) mesh, with the exception of Flathead.

3. That the closure be lifted for crab and eel trapping.

4. That anglers competing in the Bass Catch in September be given a permit to fish in the Macleay River at the time of competition if the closure is still in place.

Over 900 submissions comprising mostly form letters were received, principally from persons identifying themselves as recreational fishers. Recreational fishing clubs, commercial fishermen's Co-operatives and individual commercial fishers also made submissions.

Over 95 % of submissions called for some change to the existing closures. In contrast with the small proportion seeking maintenance of the status quo, almost 50 % of submissions for the Macleay River suggested complete lifting of the closure. For the Richmond River, this figure was closer to 5 %.

There was generally support for NSW Fisheries' proposals described above. Most submissions proposed alternatives focused on specific detail contained in NSW Fisheries proposals, rather than fundamental changes. A summary of the submissions is provided below.

5.5. Richmond River Public Submission Summary

Proposal	% Support
Richmond River Recovery Committee recommendation	83.2 %
Lift closure	7.0 %
Other	6.5 %
Fisheries proposal	2.0 %
Maintain closure	1.3 %

5.6. Macleay River Public Submission Summary

Proposal	% Support
Macleay River Recovery Committee recommendation	40.0 %
Lift closure	50.0 %
Other	5.0 %
Fisheries proposal	5.0 %
Maintain closure	0.0 %

On the basis of these submissions and the scientific reports, NSW Fisheries put forward a modified proposal for comment by the working groups. Principal changes related to the recreational bag limits, and period open to fishing and target species.

The Richmond River Recovery Committee met on 22nd June 2001. There was majority support for a revised proposal from NSW Fisheries, which in addition to the above, stipulated a total bag limit of 10 fish and specified that of these, only 5 bream and one mulloway would be allowed. Two members supported maintenance of existing closures on the basis of the scientific reports.

The Macleay River Recovery Working Group met on 24th June 2001 and also discussed a revised proposal from NSW Fisheries. This included daylight hour fishing only for recreational fishers, the same bag limits as for the Richmond River as well as opening the North arm of Clybucca Creek. The Committee suggested in addition that mesh of not less than 95mm be used by commercial mesh netters operating in the Macleay River, that flathead should not be retained by mesh netters, that ocean waters should be open to all species except prawns, and that recreational fishing should be permitted until 9 pm rather than 7 pm.

The revised proposals and the additional suggested changes in the Macleay River were incorporated into the new closure that came into force from the 1st of July 2001 until the 30th September 2001.

Although the scientific reports acknowledged slow recovery of fish stocks, the area proposed for opening was a relatively small part of the lower reaches of both rivers. It was concluded that an increase in fishing effort (closely monitored through ongoing research and creel surveys) was not likely to undermine the long-term recovery of the rivers. However, it was deemed possible that recovery may not have been as rapid, as would have been the case had the existing closures remained in force.

5.7. Compliance / Effectiveness

Advertising of river closures occurred in local, state and national newspapers following consultation with the NSW Fisheries Media Unit.

A3 laminated signs (closure notices) were erected in prominent locations along the waterways, as well as at boat ramps, tourist parks and bait and tackle shops in the local areas. Fisheries offices in the closure areas also had copies of the closure notices for handout.

NSW Fisheries on Patrol, Richmond River, 2001.

Research vessels were clearly identified by means of readily visible signage on the boats and any other vehicles used. This aimed to reduce the incidence of phone calls from the public regarding ‘illegal fishing during the closure’.

Extra staff were required at the Ballina Fisheries Office to deal with the huge volume of public interest in the fish kill event. Front counter duties were in great demand following the kills. A large number of phone calls were received each day inquiring about the fish kill causes, river closures and NSW Fisheries response to the event.

Staff were also needed to facilitate the coordination of the River Recovery Committees including organising meetings, keeping and publishing minutes, dealing with inquiries etc.

Recommendations

- River closures can be an effective management option following major fish kill events. The use of fishing closures at estuarine / oceanic interfaces can be also be a useful management option.
- An effective compliance and education program ensures the effectiveness of the closures.
- Modifications to the closure may be appropriate following scientific and community recommendations.

6. POTENTIAL SOLUTIONS TO FUTURE FISH KILL EVENTS

6.1. North Coast Regional Recovery Coordination Committee

NSW Fisheries was involved with the North Coast Regional Recovery Coordination Committee as an advisory member. The Committee was established to examine and assist in mitigating, the impacts of the 2001 floods that affected the North Coast region of NSW.

The direct involvement of NSW Fisheries with the Committee highlighted the extent of the impacts on commercial and recreational fishers associated with both flood events and the importance fishing has to the regional economy. This is through direct employment opportunities and also the flow-on values that fishing provides for tourism in the region. The attraction of Ballina as a fishing-based holiday destination provides additional economic opportunities to hotels, motels, service stations, bait and tackle shops, restaurants etc.

The North Coast Regional Recovery Coordination Committee identified a series of issues regarding flooding and flood recovery operations that will need longer-term management. One of the key recommendations arising from the Committee was that *"the cause of the fish kills should be thoroughly investigated and, where necessary, North Coast Floodplain Management plans should be reviewed in order to minimise the risk of de-oxygenated water killing fish populations during major flood events."*

6.2. Floodplain management

The only effective mechanism to prevent future large-scale fish kills occurring is through addressing floodplain management in an attempt to improve water quality throughout the catchment.

The Healthy Rivers Commission of NSW (1999) listed a number of possible technical responses that could be implemented to improve the health of coastal floodplains and estuaries. These responses include:

- Changing the drainage system by laser levelling of land, making drains shallower, reducing drainage density and relocating drains away from acid sulfate soil hotspots;
- Retaining aquatic vegetation in drains where their hydraulic capacity is sufficient and/or designing new drains to provide sufficient capacity;
- Modifying the opening and closing operation of floodgates to provide protection for farmers as well as benefits for river health, or removal of floodgates where possible;
- Reversal of the oxidation process of acid sulfate soils by applying organic matter;
- Rehabilitating key wetlands on the floodplain;
- Developing alternative farming techniques with fewer drainage requirements.

6.3. Current Initiatives

A number of projects are currently underway which are looking at providing some of the changes needed to facilitate improved floodplain management. These include:

- NSW Fisheries North Coast Floodgate Program (funded through the Environmental Trust) – aims to actively manage (open in non-flood periods) 50 floodgates to improve water quality and fish passage,
- Acid Sulfate Soil Hot Spot Program – aims to remediate identified areas of potential acid sulfate soil impacts,
- Richmond Floodplain Committee – aims to improve management of the Richmond river floodplain,
- Macleay Floodplain Project – aims to improve management of the Macleay river floodplain,
- Clarence Floodplain Project – aims to improve management of the Clarence river floodplain,
- NSW Sugar Industry review of Code of Practice – seeks to provide Best Practice guidelines for NSW sugar cane farmers,
- PhD research at Southern Cross University - examining the role of drain sludges and vegetation decomposition in aquatic deoxygenation events.

Recommendation

The above projects provide initiatives that could aid in addressing some of the causes and impacts of the 2001 fish kill events. Accelerating these programs, particularly in those floodplain areas where dissolved oxygen can become a critical issue during such events, would result in reduced likelihood of significant fish kills such as this one.

6.4. Suggested strategies to minimise future fish kill events

- Socially equitable incentive mechanisms be developed to accelerate adoption of the water retention in highly acidic backswamps and shallowing of drainage systems in hot spots.
- The interaction between deoxygenation and acidification processes be assessed during remediation of acid sulphate soil hot spots.
- An annual forum be established to facilitate communication of coastal floodplain research and management.
- A targeted monitoring strategy be developed for catchments likely to be affected by significant fish kills to increase understanding of interactions between estuarine health and land and water management.
- Further research on how management practices affect the accumulation and mobilisation of mono-sulfidic black ooze is a high priority.
- Best practice management documents be modified to reflect this new understanding.

- Coastal Catchment Management Authorities be informed of processes to assist allocation of resources.

7. SUMMARY OF RECOMMENDATIONS

Monitoring of water quality - Recommendations

- The Richmond catchment has established a standardised protocol for both ongoing and event-based sampling of water quality. The Richmond Estuary Ecological Health Management Study (REEHMS) was established to develop a flood response strategy in collecting representative water quality samples.
- REEHMS coordinates the efforts of various local and State government agencies to avoid duplication of sampling locations and times.
- Other catchments could benefit in improved data collation from cooperation through a similar process

Management of the causes of fish kills - Recommendations

- Retaining rainfall run-off and encouraging inundation-tolerant vegetation on very low, highly acidic, low-value grazing land. This is likely to favour the transformation of surface oxidised iron to less soluble iron sulphides and enable a build-up of a thick organic surface mat. These mats reduce transport of acidic products to the soil surface by reducing groundwater evaporation. This will not completely prevent iron export but is likely to reduce greatly the amount, rate and frequency of export.
- Shallowing and reducing the density of drainage systems so they intercept less iron and aluminium rich groundwater and do not store water during dry periods.
- Managed opening of floodgates. This is likely to reduce the extent of accumulation of mono-sulfidic black ooze behind the gates.
- Drain bank management by regular liming and not disturbing the limed zone. This is likely to cause soluble iron in groundwater to precipitate in the drain bank rather than enter the drainage water.
- Research is needed to facilitate the production of maps showing the location of key sites contributing high volumes of low dissolved oxygen following floods.

Monitoring of fish populations - Recommendations

- Conduct research surveys in all NSW rivers for many years, perhaps alternating between areas over time,
- Make this type of regular sampling part of NSW Fisheries ‘core’ business,
- Establish suitable sampling methods for particular species that would allow for training of an ‘event-based ready response team’.
- Research is required to review the current situation concerning the relationship between degraded fish habitats and contribution of these areas to low dissolved oxygen levels following floods.
- Detailed information is required that indicates levels of estuarine fish stocks and the status of estuarine fisheries, before fish kill events.
- Recreational fishing surveys of sound statistical design are essential for the collection of statistically unbiased information,

- A community based survey aids in minimising costs and maximises opportunities for the community to become actively involved in the recovery process.

Management of fish kills - Recommendations

- River closures can be an effective management option following major fish kill events. The use of fishing closures at estuarine / oceanic interfaces can be also be a useful management option
- An effective compliance and education program ensures the effectiveness of the closures.
- Modifications to the closure may be appropriate following scientific and community recommendations.

Suggested strategies to minimise future fish kill events

- Socially equitable incentive mechanisms be developed to accelerate adoption of the water retention in highly acidic backswamps and shallowing of drainage systems in hot spots.
- The interaction between deoxygenation and acidification processes be assessed during remediation of acid sulphate soil hot spots.
- An annual forum be established to facilitate communication of coastal floodplain research and management.
- A targeted monitoring strategy be developed for catchments likely to be affected by significant fish kills to increase understanding of interactions between estuarine health and land and water management.
- Further research on how management practices affect the accumulation and mobilisation of mono-sulfidic black ooze is a high priority.
- Best practice management documents be modified to reflect this new understanding.
- Coastal Catchment Management Authorities be informed of processes to assist allocation of resources.
- Accelerating existing programs (see Section 6.3) particularly in those floodplain areas where dissolved oxygen can become a critical issue during such events, would result in reduced likelihood of significant fish kills such as this one.

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APPENDIX 1: RIVER CLOSURES

NORTHERN NSW RIVER CLOSURES SUMMARY
(Extracted from Media Releases)

DATE (2001):	CLOSURE:	LOCATION:	PERIOD:
9 February	closed to all methods of fishing.	*Richmond River* - From Lennox Head, south to main bar; and the entire Richmond River estuary 30km upstream to Coraki.	3 weeks
1 March	closed to prawn trawling.	*Clarence River* - Ocean waters adjacent to the mouth of the Clarence River (1nm out from Barri Point, north to Iluka Bluff, then out to sea 2nm)	2 years
2 March	closed to trawling and hauling.	*Richmond River* - From Lennox Head to the Broadwater on South Ballina Beach.	3 months
	closed to all methods of fishing.	*Richmond River* - All of the Richmond River estuary 30km upstream to Coraki.	3 months
12 March	closed to prawn and fish trawling.	*Bellinger, Macleay and Hastings Rivers* - Ocean waters adjacent to the river mouths.	3 months
20 March	closed to all methods of fishing.	*Macleay River* - The whole of the estuary and in adjacent ocean waters to a depth of 10 fathoms in a line extending from the 'Cheerio' wreck on Stewart's Beach south to Back Creek.	3 months
23 March	closed to prawn and fish trawling.	*South West Rocks* - All ocean waters at South West Rocks which are bound by the southern training wall at Trial Bay, north to Grassy Head, and out to a depth of 10 fathoms.	1 month

DATE (2001):	CLOSURE:	LOCATION:	PERIOD:
23 March	closed to prawn and fish trawling.	*Nambucca River* - All ocean waters bound by the eastern extremity of the Nambucca River rock wall to Scotts Head, and out to a depth of 10 fathoms.	1 month
	closed to all methods of fishing.	*Macleay River* - All tidal waters of the Macleay River and tributaries, including adjacent ocean waters to a depth of 10 fathoms in a line extending from 'Cheerio' wreck on Stewart's Beach south to Laggers Creek.	3 months
10 April	amendment to closure of all fishing methods	*Macleay River* - All tidal waters of the Macleay River and tributaries, including adjacent ocean waters to a depth of 10 fathoms in a line extending from 'Cheerio' wreck on Stewart's Beach south to Laggers Point, then due west to the northern most part of Laggers Point	open
	opened to recreational fishing for bait species	a small area in Trial Bay	open
	opened to recreational fishing for all species	off the rocks at Laggers Point	open
12 April	opening of commercial sea mullet fishery	*South West Rocks* - From the beach between the southern end of Trial Bay near the historic jail, north to the National Park.	open (as per permit conditions)
30 April	Opening of commercial sea mullet fishery	*Richmond River* - Between the river mouth and Missingham Bridge.	open (as per permit conditions)

DATE (2001):	CLOSURE:	LOCATION:	PERIOD:
1 July	closed to all methods of commercial and recreational fishing with the following exceptions:	Richmond River - All waters of the Richmond River estuary and adjacent ocean waters.	3 months, until 30 September 2001.
	(i) recreational line fishing between 6am and 7pm, with a bag limit of 10 with no more than 5 bream and 1 mulloway;	All waters downstream of Burns Point Ferry to the river mouth, including North Creek and Fishery Creek.	
	(ii) commercial beach hauling for mullet	In waters adjacent to the beach of the northern bank immediately downstream of the Missingham Bridge.	
	(iii) recreational crab trapping (iv) commercial crab trapping	All of the Richmond River estuary from the river mouth, upstream 30 km to Coraki.	3 months, until 30 September 2001.
	(v) commercial fishing for travelling schools of mullet and pilchards.	Ocean beaches adjacent to the river mouth.	
1 July	closed to all commercial and recreational fishing with the following exceptions:	Macleay River – All the waters of the Macleay River estuary including tributaries upstream of the township of Kinchela and ocean beaches adjacent to the mouth of the river.	

DATE (2001):	CLOSURE:	LOCATION:	PERIOD:
	(i) recreational crab and eel fishing . (ii) commercial crab and eel trapping.	The whole of the waters of the Macleay River including its tributaries upstream of the township of Kinchela.	
	(iii) recreational line fishing, crab trapping, bait trapping, between the hours of 6am and 9pm, with a bag limit of 10 finfish with no more than 5 bream and 1 mulloway. (iv) commercial crab, eel and line fishing. (v) commercial mesh netting using splash net only, with mesh no less than 95mm, between 6pm and 6am, with no flathead to be retained.	The whole of the waters of the Macleay River, including all its tributaries, the Macleay Arm and Clybucca Creek, from the township of Kinchela downstream to where the eastern most extremity of both breakwaters meet the ocean.	

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