FISH KILL DYNAMICS – WHAT CAN WE LEARN FROM RECENT EVENTS AT SALTY LAGOON, EVANS HEAD?

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Abstract

What can we learn from fish kills? How can they help us understand the dynamics of aquatic ecosystems? What triggers them and what are the long term effects?

There are a wide range of factors leading to fish kills in our coastal systems and unfortunately fish kills are far more prevalent than we would like. Consequently, there is significant public interest in the topic and increasing discussion, although not always awareness or agreement on the main causes. Despite this, what is becoming increasingly apparent is that no two fish kills are the same and we cannot always rely on our previous understanding to explain future events.

This paper explores three fish kills within the Salty Lagoon system that were captured during the comprehensive ecosystem monitoring program being conducted at this site. Although a hydrodynamically complex waterbody, the majority of the catchment is contained within the Broadwater National Park and the main anthropogenic influences are easily identifiable. We aim to provide additional insights into fish kill dynamics in coastal systems and discuss the interplay between water quality, fish behaviour, habitat availability and hydrodynamics within the system. We identify the key risk factors leading up to a fish kill in this waterbody as well as the long term implications of these events.

Introduction

Salty Lagoon is a shallow coastal lagoon located within Broadwater National Park just north of Evans Head on the north coast of NSW. Salty Lagoon is connected to Salty Creek via a man-made channel. Salty Creek intermittently opens to the sea, thereby leading to periodic draining and salt water intrusion to both the creek and the lagoon system. Due to the artificial connection, the Lagoon functions as an ICOLL (intermittently opening and closing coastal lagoon), however prior to connection it would have functioned as a freshwater lagoon, only connected to Salty Creek during extreme weather events and king tides. A draining event in December 2005 created significant environmental issues including a large scale fish kill associated with poor water quality. This raised concerns regarding the on-going sustainability of the system, and in particular the effects of sewage effluent discharge to Salty Lagoon via a short wetland creek system. In August 2007, Richmond Valley Council (RVC) switched over to the upgraded Evans Head Sewage Treatment Plant (STP), replacing the existing plant that had been treating Evans Head sewage for over 60 years. The history of STP discharges has left a legacy of high nutrient and organic matter load in the system, however, since the opening of the new plant, there has been considerable improvement in the quality of effluent discharged.

As part of the wastewater system upgrade strategy, RVC initiated the design and implementation of a detailed monitoring program and rehabilitation plan for the Salty Lagoon system. The objectives of the Salty Lagoon Ecosystem Monitoring and Rehabilitation Program are to:

- Monitor the ecological health of the system in response to decreasing sewage effluent pollutant loads over time;
- Document the status of the key ecosystem components in order to inform the development of a detailed recovery plan for the system;
- Collect data that can assist in the evaluation of the broad level rehabilitation strategy prior to the production of the detailed rehabilitation plan;
- Determine the response of the system to significant events such as the lagoon draining.

During the scoping and design stages of the monitoring program a stakeholder group was formed comprising relevant government departments and community representatives. It was acknowledged that in order to adequately assess improvements in the system over time, it would be necessary to implement a 'whole of ecosystem' approach to monitoring that encompassed not only water quality and hydrological assessment, but also incorporated monitoring of selected flora and fauna in response to improvements at the STP. A key component coming out of the design and consultation stage was the need to implement an early warning system and be able to initiate timely response to any high risk events such as lagoon draining events and poor water quality conditions likely to result in fish and/or fauna kills. This was also an integral part of the monitoring program as it enabled collection of event observations and data during or soon after the event, a vital window of time that is often missed in most monitoring programs simply because events are only known about after the fact.

The resulting monitoring program includes automatic water quality monitoring, where data loggers are installed in-situ at sites in the lagoon and creek. The loggers continuously record water quality and water level information which is telemeted to a central database on a daily basis. Alarm triggers have been programmed to automatically send SMS notification to Hydrosphere Consulting staff when one or more triggers have been exceeded. The alarm system allows for rapid response to draining events and for valuable event-based data to be collected as soon as possible. In addition to event based sampling, monthly water quality sampling is conducted to assess ambient trends over time. The monitoring program also includes comprehensive monitoring of frogs, waterbirds, fish, vegetation, macroinvertebrates, and diatoms as indicator species.

This paper explores three fish kill events captured by the Salty Lagoon Ecosystem Response Monitoring Program. The aims of this discussion are to:

- provide insights into fish kill dynamics in coastal systems and discuss the interplay between water quality, fish behaviour, habitat availability and hydrodynamics within the system;
- discuss the key risk factors leading up to a fish kill in this waterbody as well as the long term implications of these events; and
- discuss what we have learnt about fish kill events in Salty Lagoon that may improve understanding about these events in similar coastal environments.

History of Fish Kills

A number of fish kill events are known to have occurred within the Salty Lagoon system in recent years. Event based monitoring incorporating automatic event notification has been operating since mid-2008 and prior to this the historical record of fish kills is unclear. The only documented fish kill prior to the monitoring program was in relation to the major event in December 2005. The fish kill events documented then and during he monitoring program are briefly summarised below.

December 2005

This event occurred following an entrance opening event in the early hours of the 8th December 2005. According to observations of locals prior to the opening event, the lagoon had been filling for some time and the opening event was triggered by significant rainfall in the hours preceding the event. A large number (thousands to tens of thousands) of aquatic organisms were observed either dead or dying throughout the system during the following day. The majority of fish species were small to medium sized and comprised common estuarine species (mullet, flathead, bream etc.). Other species included a significant number of eels and smaller numbers of crustaceans and prawns. Many species appeared to have become stranded by the quickly receding waters and water quality in the remaining pools and channel was very poor. In-situ water quality measurements revealed that water temperatures ranged from 30-38°C; dissolved oxygen was in the range of 0.5-1.2 mg/L which is not sufficient to sustain aquatic life; the water was highly turbid and generally acidic (RVC, 2005).

Recent Events

Three fish kill events have been recorded by the Salty Lagoon Ecosystem Response Monitoring Program since its inception in March 2008. All fish kills have been associated with the opening of Salty Creek mouth to the ocean and subsequent draining of Salty Lagoon, although there have been a number of opening events when fish kills did not occur. Table 1 provides details of all entrance opening events recorded by the program thus far and indicates the major fish kill events.

Table 1: Entrance opening events from inception of monitoring program in 2008 (all water level information sourced from Salty Lagoon logger)

Date and Time	Fish Kill?	Water level at time of opening (mAHD)	Opening duration (days)	Days since last open	Tide State	Rate of water level decrease during draining (m/hr)		Rainfall (mm)	
						Average	Peak	Week prior	24h prior
18May08 12:00	No	1.59	1.7	>13	dropping	0.04	0.10	0	0
29May08 06:45	No	1.55	9.6	10.0	dropping	0.02	0.12	41	11
23Jun08 09:30	Yes	1.89	3.5	14.0	rising	0.04	0.27	17	0
01Jul08 10:15	No	1.36	24.8	4.0	dropping	0.02	0.09	0	0
25Jul08 00:30	No	1.55	7.7	2.2	dropping (high)	0.01	0.07	110	70
04Aug08 08:45	No	1.43	11.3	2.6	rising (almost high)	0.01	0.02	0	0
05Sep08 20:15	No	1.84	11.5	21.2	Rising (almost high)	0.01	0.10	40	35
23Sep08 13:15	No	1.23	1.5	6.2	Rising (almost high)	0.01	0.06	4	4
27Nov08 23:00	Yes	1.83	28.3	72.0	Dropping (mid tide)	0.02	0.16	110	76
27Mar09 21:00	Yes	1.99	131.0	118.0	rising (almost high)	0.09	0.26	54	32

June 2008

In the weeks leading up the June 2008 event, heavy seas and high tides hve introduced large amounts of seawater into the system resulting in highly saline conditions and high water levels also influenced by minor catchment inflows to the system. There was some decline in Salty Creek water quality during this time, however the primary concern was the rapid stagnation of Salty Lagoon which becomes largely anoxic by the 20th June 2008. Water temperature during this time is static around 19.5°C. The dissolved oxygen in Salty Lagoon is consistently below 1 mg/L (Figure 1). Salty Creek mouth opened to the sea on 23rd June 2008 and the entire system was drained to very low levels in approximately 10 hours.

A small number of native aquatic organisms were found dead during site inspection following the entrance opening. Other evidence of fish stranding was also observed with a small long-finned eel being located alive on the mudflats in lower Salty Lagoon. Automatic alarming was not operational at the time of the event and it is estimated that inspection took place approximately 24 hours after the commencement of the draining event. It was noted that abundant birdlife was present foraging on the exposed mudflats and it was suspected that a higher number of stranded fish would have been observed if the site inspection was undertaken closer to or during the draining event. Mosquitofish (*Gambusia holbrooki*) were observed in the small creek lines within the drained Salty Lagoon. These fish are highly tolerant of poor water quality, and were the only small fish observed during the site visit.

On the basis of the water quality information, fish sampling and post-draining site inspection, it was clear that Salty Lagoon had very low suitability for native freshwater fish species during late June. This was due to the combination of low dissolved oxygen which prevented colonisation by marine species, and excluded freshwater species due to the combination of moderate to high salinity and low dissolved oxygen. It is likely that the native freshwater fish retreated to small pockets of suitable water within the margins of Salty Lagoon, found passage to the more acceptable reaches within Salty Creek or simply died over this time period. Conversely, these conditions are highly suitable for Mosquitofish which are very tolerant of low dissolved conditions and are adapted to brackish or fresh waters. Episodes of water quality similar to observed in late June provide Mosquitofish with a competitive advantage over the native species in the system.

Whilst the water quality in Salty Creek remained at more acceptable levels than Salty Lagoon, dissolved oxygen had declined below 6 mg/L which is generally regarded as a threshold beyond which some effects are likely to be observed in fish populations. It is not clear whether the deoxygenating processes that were operating in Salty Lagoon were also occurring (albeit at a lesser rate) in Salty Creek, or whether exchange of water between the two waterbodies via the artificial channel was leading to this decline. In any case, if the stagnation event had persisted for a significant length of time, it is considered that water quality within the Creek would also have reached concerning levels.

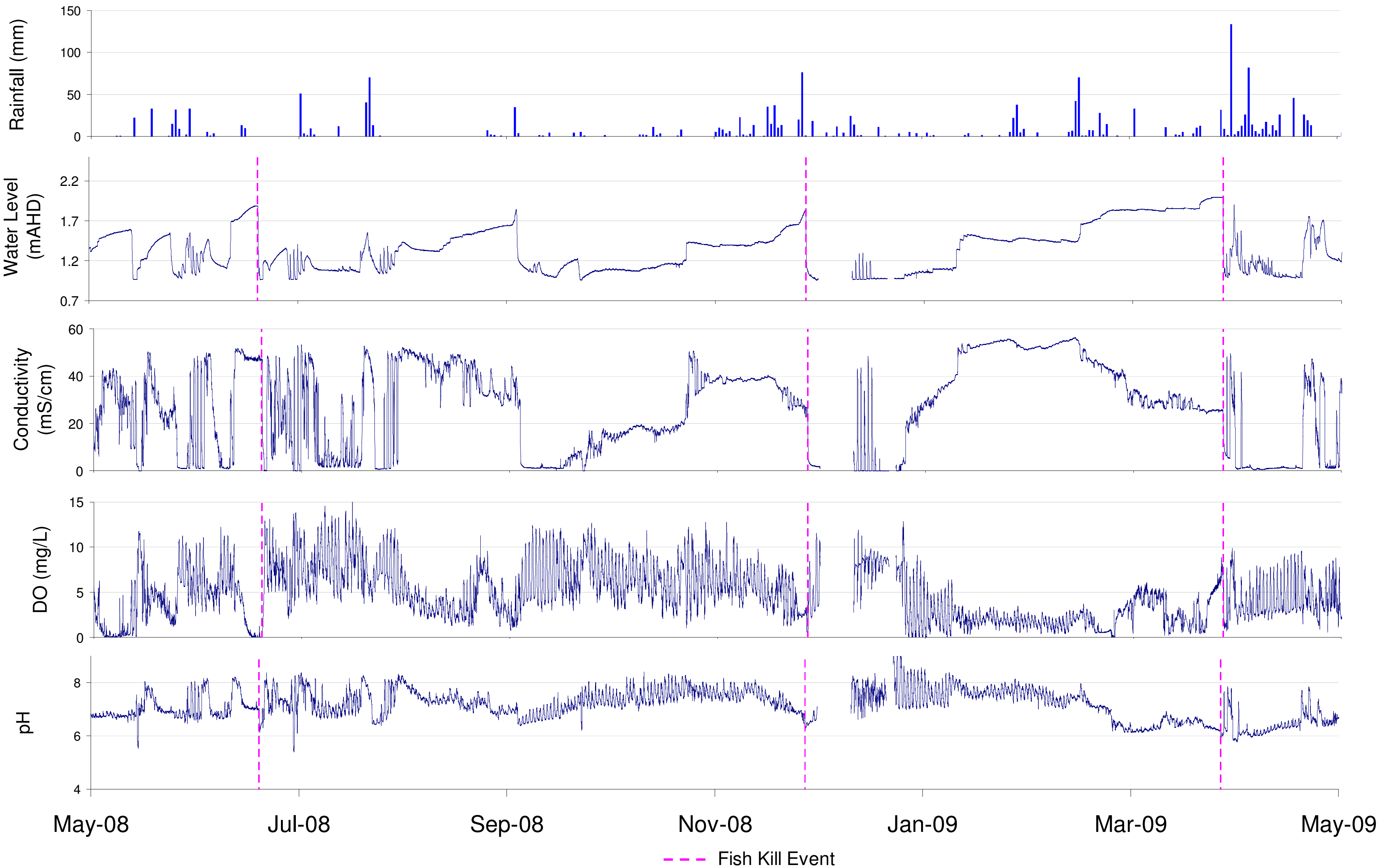

Figure 1: Salty Lagoon water quality data showing entrance opening and fish kill events as vertical dashed lines (gaps in graph represent times when sensors were exposure to air during extreme low water levels)

November 2008

Corresponding to what was observed in the June 2008 event, the weeks leading up to the November 2008 fish kill saw waves on the high tide washing over the sand berm at the entrance to Salty Creek introducing seawater to the system in mid-October creating saline conditions (Figure 1). Water level remained relatively constant until mid November when a period of significant rainfall (over 100mm in one week) caused water level to increase further and coincided with a decrease in the levels of dissolved oxygen. By the 27th of November daily DO is averaging about 2mg/L in both systems, which is generally considered to be unsuitable levels for sustaining aquatic life. Further rainfall triggered entrance opening late in the evening of the 27th November 2008 and the entire system is drained by lunch time the following day.

Site inspection conducted on the 28th November reported a number of dead juvenile fish, eels, prawns and crustaceans observed on the banks and in the shallows of Salty Creek. There were also a greater number of small dead fish (gobies, gudgeons) observed during the inspection of the lagoon. These fish were largely hidden under the water surface. There were a great number of birds throughout the system foraging the dewatered areas.

Although DO dropped to critical levels (<1mg/L) immediately prior to the opening event, levels quickly recovers following the opening, with both Salty Lagoon and Creek returning to conditions similar to early November, mostly likely due to flushing off deoxygenated waters. pH drops in Salty Creek to between pH 4 - 5 immediately following entrance opening, which is likely to be indicative of the runoff of naturally acidic water from the Salty Creek catchment. A spike in turbidity was observed at the time of entrance opening, which is likely to be a result of increased turbulence and mixing.

March 2009

Salty Creek entrance remains closed for a three month period from late December 2008 to the opening event in late March. During this time seawater has washed into the system during heavy seas and high tides on a number of occasions. There was a decline in Salty Creek water quality during this time but water quality remained moderate until mid-Feb. In contrast, Salty lagoon water quality was largely anoxic from the time of seawater intrusion on 10th Jan. Temperature was also high during this period ranging from 25-35^{o}C, creating conditions that were assessed as high risk of fish/fauna kill. Site inspections were carried out in mid-Feb to assess risk on-ground and there were no signs of dead or distressed fauna observed. Water quality data showed signs of improvement in the week leading up to the opening event, with dissolved oxygen levels increasing to 4-8mg/L in both creek and lagoon. Late in the evening on 27th March 2009 water level began to drop as Salty Creek mouth opened to the ocean draining to a base level in approximately 10 hours.

There were a significant number of dead aquatic fauna observed along the beach, at the entrance and in the lower sections of Salty Creek and in Salty Lagoon during event response inspections on 28th March 2009. The full suite of fish species of both freshwater and estuarine origin were observed including even the hardiest species such as *Gambusia* and eels. Fish were observed to be actively avoiding the main body of water and becoming stranded as a result. Freshwater fish species were observed well out of the water on the margins. It is important to note that there was likely to have been many fish not detected because they were either flushed out to sea or obscured by the dark water. Salty Creek upstream of the confluence seemed to be largely unaffected and many live fish were observed in the water. A variety of birds were observed in Salty Creek and Salty Lagoon foraging on the exposed mudflats.

DO levels in Salty Lagoon dropped off immediately following the entrance opening event to approx. 1mg/L, but recovered within 24 hours to moderate levels (3mg/L-8mg/L). pH levels dropped slightly following the entrance opening and this drop was more significant in Salty Creek indicating surface water runoff from surrounding wallum heath (naturally acidic) having more influence on Creek than lagoon. In both Salty Lagoon and Salty Creek conductivity dropped from fairly saline levels (approx. 25mS/cm) to brackish (approx 6mS/cm) following entrance opening, indicating freshwater inputs from rainfall and the catchment.

Water Quality and Environmental Factors Preceding Recent Fish Kills

Water quality in Salty Lagoon is highly variable and is influenced by three main sources:

- the majority of the catchment is contained within the Broadwater National Park and consists primarily of coastal heath and marsh lands. Water draining from these areas are typically tannin stained, acidic (as low as pH4) and fresh. During low rainfall periods the majority of water reaches the Salty Lagoon system via groundwater.
- The Evans Head STP which discharges a large proportion of the freshwater reaching the Lagoon. Water balance modelling has indicated that the STP frequently accounts for greater than half the freshwater flow to the system, with approximately 43% of the total flow in 2008/09 being attributed to the STP. Although improved significantly in 2007 with the upgrade of the STP, the effluent is characterised by relatively high nutrient concentrations and neutral pH.
- Sea water intrusion. The factor is largely unquantified to date, but is known to have an overwhelming influence under certain conditions High seas can overtop the beach berm, quickly filling the system with high salinity water. In other cases when the beach entrance is open, there is significant tidal exchange particularly during spring tides.

The influence of the STP is significant and has led to nutrient enrichment of the Drainage Channel between the STP and Salty Lagoon, as well as increasing the nutrient loads within Salty Lagoon itself. The increased nutrient status of the system predisposes Salty Lagoon to high levels of phytoplankton and macrophyte growth, and ultimately to periods of dissolved oxygen depletion. Such oxygen depletion will occur in association with relatively well understood ‘boom and bust’ cycles, but importantly, our data show that the key triggers are disruptive events such as salt water intrusion or lagoon draining and the advective flows from the Drainage Channel.

Naturally, Salty Creek would be subject to intermittent sea water intrusion and tidal effects, whereas Salty Lagoon would only be influenced when storm surges or king high tides were sufficient to overtop the natural connection between the two waterbodies. Even under these conditions the volume of salt water likely to enter Salty Lagoon would be a fraction of volume that is now facilitated by the ‘Artificial Channel’. Salty Lagoon, despite its name, was primarily a freshwater system. The influence of salt intrusion to the system are in some cases obvious (such as the establishment of mangroves in parts of the lagoon), but also underlie some of the less tangible factors that can lead to fish deaths in the system.

Each of the fish kills recorded during the monitoring program has been preceded by periods of high salinity. However, not all high salinity periods lead to fish kills in the Lagoon. Repeated saline intrusion modifies habitats and defines habitable zones for a range of species but as a general rule freshwater fish can escape or modify behaviour to avoid direct lethality due to seawater. At low water levels as may be experienced when the beach entrance is open to the sea, normal tidal exchange tends to maintain high dissolved oxygen levels. Under these conditions a suite of opportunistic estuarine and marine species will colonise Salty Lagoon and the freshwater species will retreat to the marshland area within the lagoon. In this state the system is relatively healthy and is characterised by reasonable D.O levels and high fish diversity.

In contrast to this, high water levels coupled with high salinity are disastrous for the Salty Lagoon fish community. This typically occurs either after beach berm overtopping during high seas. Under these conditions, dissolved oxygen levels quickly fall as freshwater benthic microalgae and bacterial processes are disrupted. Sustained high water levels occur when the creek entrance is closed at the beach and hence there is little flushing of the system. Freshwater entering the system is reduced by virtue of the reduced groundwater gradients and hence dilution is minimised. Dissolved oxygen in Salty Lagoon can fall to near anoxic levels within a matter of days.

The key risk factors preceding a fish kill in Salty Lagoon can be summarised as periods of sustained high salinity (e.g. E.C. >25mS/cm) when water levels are above 1.5 m AHD. These conditions are usually coupled with significant dissolved oxygen depletion and we have recorded periods where these conditions can persist for many weeks, however this alone is not enough to cause a fish kill. So what triggers a fish kill?

Influence of bathymetry, fish habitat, movement and spatial patterns in water quality

Fish kills are triggered when the risk factors described above are followed by a significant draining event. Draining events following periods of relatively good water quality do not give rise to large scale fish kills. Similarly, periods of poor water quality alone do not result in fish kills. It is the combination of these factors that inevitably leads to fish deaths in Salty Lagoon. The risk of a draining event is increased with higher water levels within the system and the resulting higher hydrostatic head across the beachface.

Although the dynamics of a fish kill are complex, our observations have shown that fish are still present within Salty Lagoon even during periods of stagnation. In these cases the fish are present in residual pockets of good quality water, along the margins and surface layers of the marshland. During a draining event, the marshland is dewatered and fish are forced to evacuate from these areas and in doing so are exposed to the poor water quality in the main body of the lagoon (Figure 2). Secondary effects such as stranding and predation are also high apparent during these times.

The influence of bathymetry, fish habitat use, behavioural response in fish and spatial patterns in water quality that determine the severity and in some cases the selectivity of fish kill events.

Salty Lagoon is a shallow basin whereas Salty Creek is highly channelised. During draining events, Salty Lagoon empties almost entirely via the Artificial Channel into the middle reaches of Salty Creek. Salty Creek empties to the same water level, but retains a far larger residual aquatic habitat by virtue of its relatively deep channel. Figure 3 demonstrates the dramatic change in inundation that occurs during a draining event. When the water level is at 2.3m AHD (the highest recorded to date) the wetland areas surrounding Salty Lagoon and Salty Creek are inundated. Below 1.9m, Salty Lagoon in the south separates from Salty Creek in the north with the only surface water connection via the narrow Artificial Channel. At 0.8m AHD (lowest level recorded to date), Salty Lagoon has virtually no water except remnants of a small residual drainage line leading to the Artificial Channel.

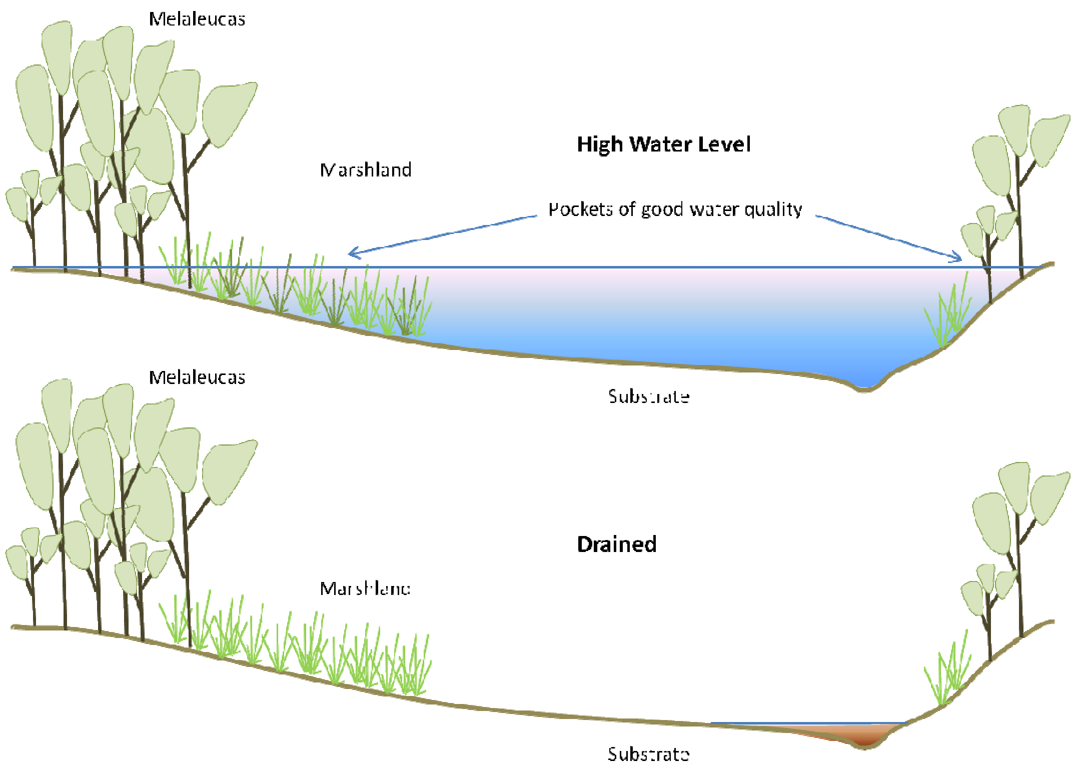

Figure 2. Diagrammatic view of Salty Lagoon during high water and drained conditions.

Although dependent on a number of factors such as tide state, starting water level and beach condition, the initial draining of the system is a rapid event, usually occurring in less than a 12 hours. Table 1 shows the fish kill events also correspond with the the higher peak rates of water level drop. Site inspection immediately after or during fish kill events has shown that fish are stranded by receding water. Based on our observations of fish behaviour during fish kill events, this is thought to occur more due to fish avoidance of poor water quality rather than inability to follow the water surface downslope. However, comparison of Table 1 and Figure 1 shows that whilst the identified fish kill risk factors as described above were present in September 2008, there was no fish kill. This may be explainable by the lower peak rate of water level draw down during this event (due to a high tide at the time). To date we have not fully explored the stranding risk associated with drawdown events.

At extreme low water level, Salty Creek averages 0.5m depth with some pools approaching 2m depth. Clearly, Salty Creek is a significant refuge for surviving fish. This effect is increased by the fact that falling water levels will draw additional catchment water through the system, hence providing a flushing effect and preventing propagation of poor quality water through the upper reaches of Salty Creek.

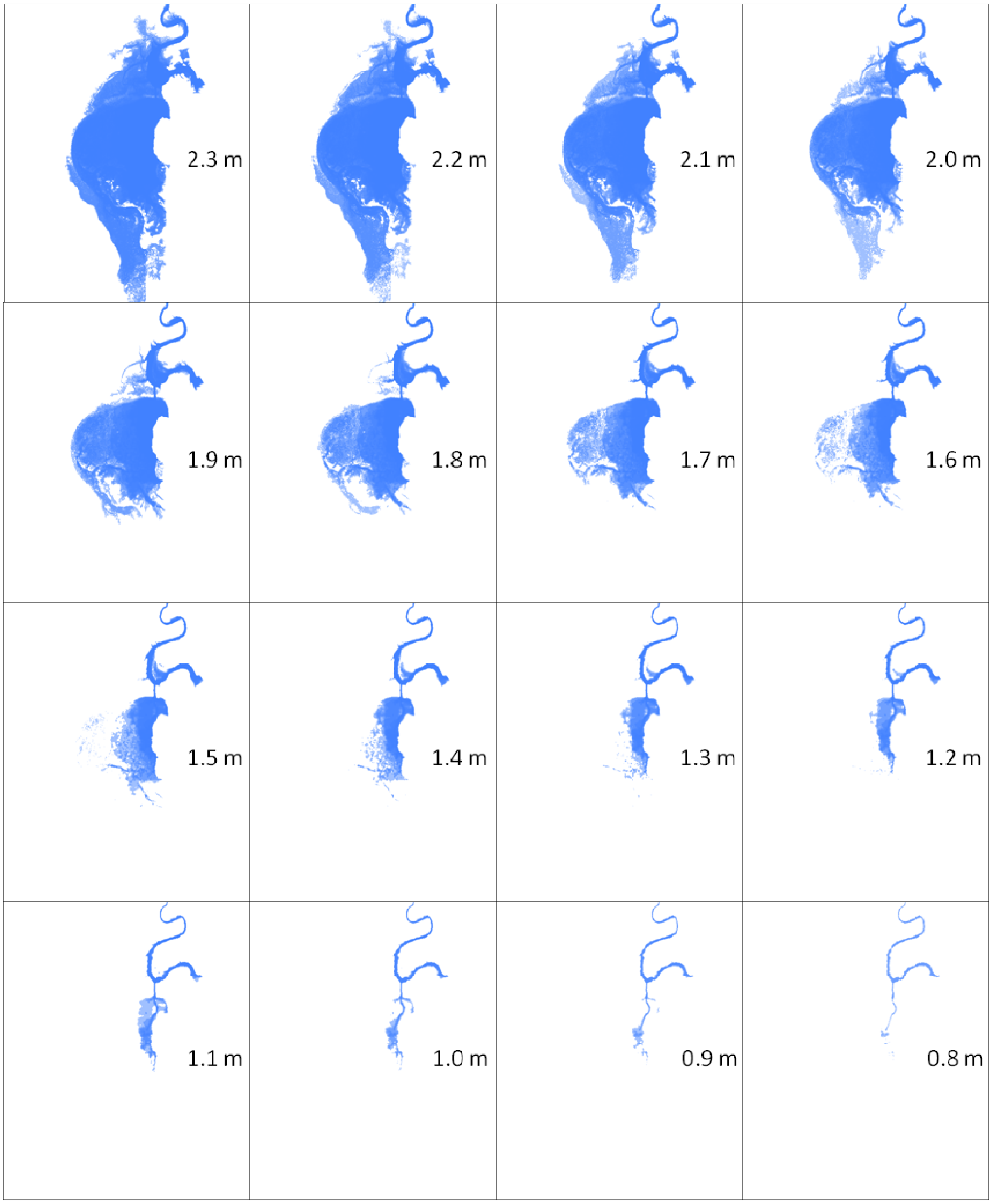

Figure 3. Surface Area of Salty Lagoon (southern end) and Salty Creek (northern end) at various inundation levels (water levels are in m AHD)

Fish behaviour and habitat utilisation also affects the outcomes of a fish kill event. The introduced Mosquitofish (*Gambusia*) is well known for its tolerance of both low dissolved oxygen conditions and salinity. As such it has a significant advantage over the native freshwater species in Salty Lagoon.

Native species such as the benthic goby (*Afurcagobius tamarensis*) is strongly associated with bare substrate habitats and the verges of the marshland within Salty Lagoon. This species is exposed to degrading water quality conditions even prior to a draining event and will either be displaced to other areas (such as Salty Creek) or will succumb to the low D.O. conditions early in an event. It is interesting to note that a build up in poor water quality in one area (or depth range) will tend to displace fish from a habitat and may ultimately lead to these fish moving to areas where they are not as significantly involved the main fish kill event during lagoon draining.

The influence of wind is also evident. Wind has the effect of breaking down stratification and introducing poor quality water into pockets that may otherwise enjoy acceptable water quality (e.g. marshland pools only marginally connected to the stagnating Lagoon). As an example, strong easterly winds may create turbulence and mixing of poor water throughout the western shore of the Lagoon. Fish will vacate these areas where possible in favour of areas of better water quality. The location of fish following a fish kill event, and considerations of the reasons for this pattern of fish distribution can aid significantly in our understanding of water quality dynamics in the system.

The long-term implications of repeated fish kills in the system are a concern for on-going management of Salty Lagoon. Fish abundance is generally low and effects of fish kills are likely to be more selective to the native fish that are not as well adapted to low oxygen conditions compared to the exotic *Gambusia*. Despite this, aggregations of breeding and juvenile gudgeons have been observed within the system and this resilience is one of the indicators that the Salty Lagoon ecosystem can respond favourably during periods of good water quality.

Conclusions

Fish kills are an unfortunate but informative indicator of the health of aquatic ecosystems. In the case of Salty Lagoon, it has been possible to gain a good understanding of the key risk factors leading up to a fish kill as well as the triggers for such events. In turn, fish kill events have provided insights into the water quality and hydrodynamics of the system that would be hard gained by other means.

It is clear from our studies at Salty Lagoon that fish kills are not simple events that can be explained in text book fashion without regard for the complexities of the site. In the case of Salty Lagoon, a fish kill event is a culmination of interacting biogeochemical processes, hydrodynamics, bathymetry, fish behaviour and fish biology. Knowledge of all these factors is required in order to understand the risk of fish kills and to assist in the development of suitable long-term management strategies.